2500/-

STUDIES ON POTENTIAL OF COMPANION CROPS IN MANAGING THE DIAMONDBACK MOTH, *PLUTELLA XYLOSTELLA* (L.) (LEPIDOPTERA : PLUTELLIDAE) IN CABBAGE/KALE CROPPING SYSTEMS IN KENYA.

By:

Makatiani Jacqueline
B.Ed (Science)
Kenyatta University

Thesis Submitted in Partial Fulfillment of the Requirement for the Award of a Master of Science (M.Sc.) Degree in Agricultural Entomology of Kenyatta University.

Zoology Department
Kenyatta University
P.O. Box 43844
Nairobi – Kenya.

July 2003.

DECLARATION

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

11/07/03

Makatiani Jacqueline.

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

Dr. Callistus K. P. O. Ogol
Zoology Department
Kenyatta University
P.O. Box 43844
Nairobi – Kenya

16/7/03

Dr. Sithanantham Srinivasan
International Centre of Insect
Physiology and Ecology
P.O. Box 30772
Nairobi – Kenya.

11/07/03

Prof. Gaya Agong'
Jomo Kenyatta University of
Agriculture and Technology
P.O. Box 62000
Juja – Kenya.

11/07/2003

DEDICATION

To my beloved Dad Maurice Makatiani,

Mum Wilkyster Akumu

and siblings.

Acknowledgement

I wish to extend my sincere gratitude and thanks to my University supervisor, Dr. Callistus K.P.O. Ogol for his total commitment in the academic supervision and moral support during my study. His advise, criticisms and comments are highly appreciated. Special thanks go to my Co-supervisors, Dr. S. Sithanantham (ICIPE) and Prof. Gaya Agong' (JKUAT) for their great assistance of research grant, design of research methodology, provision of the necessary laboratory and field facilities and close supervision of data collection. Special thanks also go to the Director, KARI-Matuga for allowing me to conduct the field trials on the farm. I acknowledge the valuable help I received from Dr. Nicholas Gikonyo in setting up some of the laboratory experiments. The great technical support I received from Mr. Charles Matoka, Mr. Andrew Wanyonyi, Ms Rebecca Raini, Mr. Joseph Ondijo, Mr. Martin Okila, Mr. Joseph Mucheru, Mr. Gideon Jira, Silas Onyango, Gabriel Ochieng, Regina Rono, George Nderitu, Lydia Masambu, Jane Waweru and the entire staff of Egg parasitoids project (ICIPE) in setting up the field trials, data collection, rearing of *P. xylostella* cultures, data analysis and computer handling is greatly acknowledged. Thanks to M. Muli and my student colleagues: Z. Osiemo, L. Migiro, C. Muholo, G. Momanyi, W. Ogutu, M. Ndila and J. Muturi for their constant encouragement.

I appreciate the help by all my friends, most especially C. Geno, for the great moral support he provided right from the start of this work.

My deepest gratitude goes to dad, mum and siblings for their understanding and support all through my study period.

ABSTRACT

The diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) is a major pest and threat to brassica production in many parts of Africa. The adverse ecological and environmental effects as well as the cost of chemical pesticides that are commonly used in its control, besides the increasing resistance to chemicals makes it necessary to explore alternative control methods. Integrated Pest Management (IPM), being the emerging pest control paradigm, offers a number of options out of which biocontrol, companion cropping among others, have great potentials. This study investigated the potential of utilising companion vegetable crops as trap or repellent crops in managing the diamondback moth in cabbage/kale cropping systems.

Crop preferences for oviposition and suitability for survival and development of *P. xylostella* were assessed in the laboratory on seven different test plants: cabbage (*Brassica oleracea* var *capitata* L.), kale (*Brassica oleracea* var. *acephala* L.), rape seed (*Brassica napus* L. subvar. *oleifera*), Ethiopian mustard (*Brassica carinata* B.), *Cleome* (*Cleome gynandra* L.), tomato (*Lycopersicon esculentum* L.) and coriander (*Coriandrum sativum* L.). In addition, the effect of the test plants on *P. xylostella* adult olfactory responses, longevity and fecundity were investigated. In the field, each of the latter five test plants was intercropped with cabbage at Jomo Kenyatta University of Agriculture and Technology (JKUAT) farm and kale at Kenya Agricultural Research Institute (KARI-Matuga) and the *P. xylostella* infestation levels and damage assessed. Another field trial with different planting patterns of both cabbage and coriander was conducted at JKUAT to evaluate the most appropriate planting pattern for reducing *P. xylostella* infestation. The effect of the companion crops on non-target insects and important plant diseases was also evaluated on cabbage.

Laboratory choice and no-choice tests indicated that Ethiopian mustard was found to be a preferred host for oviposition by *P. xylostella* while tomato was the least preferred for oviposition, as compared to other test plants. Choice tests also revealed that the number of eggs laid by the moths were significantly fewer

(P<0.05) on treatments of cabbage or kale combined with tomato, coriander or *Cleome*, when compared to those laid on sole-cabbage or kale. Larval percent survival was significantly lower (P<0.05) on mustard and *Cleome,* thus recording a prolonged developmental period while coriander and tomato did not support larval development beyond first instar. Moths fed on different test plant flowers showed no significant differences in the adult male and female longevity and fecundity, except that adult longevity of JKUAT culture males was significantly prolonged (P<0.05) on mustard than on other test plants flowers, while fecundity was significantly higher (P<0.05) on coriander and *Cleome.* A significantly higher percentage of moths showed upwind orientation to mustard than all other test plants.

Field trials, however, revealed that the unsprayed plots of cabbage and kale grown alone supported significantly higher infestation levels of *P. xylostella* as compared to the intercropped plots and thus resulted in higher *P. xylostella* damage scores and reduced marketable produce. The Dipel® sprayed plots of sole-cabbage and sole-kale had the lowest *P. xylostella* infestation, although not significantly different from infestation on cabbage or kale interplanted with tomato. The results also indicated that a planting pattern of 2 rows of cabbage to a row of coriander (where coriander was scattered throughout the hills within a plot) was found to be promising for successful management of *P. xylostella.* The test plants also significantly affected infestation levels of other insects and plant diseases on cabbage. These results indicate that Ethiopian mustard can be successfully utilised as a trap crop and tomato as a repellent crop for the management of *P. xylostella* in Kenya.

TABLE OF CONTENTS

CHAPTER 3

CHAPTER 4

LIST OF TABLES

CHAPTER 1

1.0. INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION

1.1.1. Brassica production in Kenya

Members of the plant family Brassicaceae (formerly Cruciferae) occur in temperate and tropical climates and they represent a diverse, widespread and important group of vegetables that includes cabbage, kale, Brussels's sprouts, cauliflower, broccoli, collards, mustard and rape seed. In Kenya, these vegetable crops are largely grown for local consumption, export and processing (dehydration and oil extraction). They produce various edible plant parts, such as roots of radishes and turnips, stems of kohlrabi, leaves of cabbage and other leafy brassicas and seeds of mustard and rape seed, all of which are consumed as fresh, cooked or processed vegetables. While most of its production in East Africa is by smallholder farmers, commercial production is on the increase, especially for cabbage and kale (Oduor *et al.*, 1998). During 1997, HCDA (1998) reported that Kenya produced a volume of 30.9 tonnes of vegetables (brassicas included), valued at 52.2 million US dollars.

Brassicas are grown in a variety of cropping systems from backyard gardens to large-scale fully mechanised farms. A wide range of soils and agro-ecological zones (wherever water is available) favour their growth. Their production is done on either rain-fed or irrigated farms. Brassicas in Kenya are grown on over 40,000 hectares and 604,000 metric tonnes grown form an important part of the diet of many Kenyans, especially in the low-income groups (Ministry of Agriculture, Livestock, Development and Marketing, 1988).

1.1.2. Constraints of brassica production

In Kenya, cabbage and kale are among the most important crops grown by smallholder farmers and their production faces several major constraints, among which insect pests (i.e. *Plutella xylostella* L., *Brevicoryne brassicae* and *Lipaphis erysimi*) and diseases (i.e. *Xanthomonas campestris (black rot), Mycosphaerella brassicola* (ring spot) and *Phorma lingam* are major factors (Anyango *et al*, 1994). The diamondback moth (DBM), *Plutella xylostella* L. is an important pest on brassica vegetables in Africa (Ikin *et al*., 1993) and is becoming the target of an ever more frenzied spray regime (Mwaniki *et al*., 1998). It has become the most destructive and numerous caterpillar pest of brassicaceous plants throughout the world, and the annual cost for managing it is estimated to be US $ 1 billion (Syed, 1992; Talekar, 1992).

Verkerk and Wright (1996) have reported that *P. xylostella* can cause more than 90% crop loss. It has attained a cosmopolitan distribution due to the widespread occurrence of its host plants and its tremendous ability to migrate (Oduor *et al*., 1998). Besides these, absence of effective natural enemies, especially parasitoids, is believed to be a major cause of its pest status in most parts of the world (Lim, 1986). Their larva attacks both cultivated and wild plants of the family Brassicaceae as well as a number of brassicaceous ornamentals, all of which contain mustard glucosides (feeding stimulant). Talekar *et al*., (1986) observed that when the pest is subjected to suitable host plants in a favorable tropical climate, it could complete up to 20 generations per year with considerable overlapping of generations in the field.

1.1.3. Chemical control of *P. xylostella* and its shortcomings

The increasing demand for quantity and quality in the produce grown for local sale or export has encouraged farmers to resort to extensive use of chemical pesticides hence exceeding the optimum dose. They use as many as 16 sprays of insecticides in a single crop season. In their anxiety to do away with the pest, they sometimes spray a mixture of two or three different insecticides thus, reducing their efficacy. Such over-reliance on broad-spectrum chemical pesticides has resulted in several problems such as depletion of natural enemies, increased cost of production, pest resurgence, unacceptable levels of toxic chemical residues on products thus endangering human health, environmental degradation and increased crop losses (Jussoh *et al*., 1992). It has also led to a selection of insect strains resistant to the commercially available pesticides. Talekar and Shelton (1993) have reported that *P. xylostella* has become resistant to every synthetic insecticide used against it in the field.

Trials by Kenya Agricultural Research Institute (KARI) have shown that poor insect pest control due to resistance to chemical pesticides reduces yields by up to 50% and the trials confirmed that many chemicals including the most popular, the synthetic pyrethroids, are loosing efficacy against *P. xylostella*. Recent work under the R6614 Pest Management Project has also confirmed that these chemical insecticides are now largely ineffective against *P. xylostella*. The only current alternatives to chemical products are imported insecticides based on the *kurstaki* and *aizawai* strains of the bacterium *Bacillus thuringiensis*. These bacterium insecticides are however very expensive for the poor Kenyan farmers.

In addition, *P. xylostella* have the distinction of being the first insects to develop resistance in the field to the bacterial insecticide *Bacillus thuringiensis* var. *Kurstaki* (Hama, 1992; Tabashnik, 1994). Ikin *et al*., (1993) also reported resistance to pesticides among populations in *Helicoverpa amigera* and *P. xylostella* in East Africa. It is also well documented that resistance to *B. thuringiensis* has developed rapidly in *P. xylostella* when *B. thuringiensis* has been introduced for control of the pest in South East Asia, Hawaii and America. It is possible that it will also develop resistance to botanicals and Insect Growth Regulators (IGRs). Insecticide resistance and control failures are now common in tropical climates and in some areas, economical production of brassicas has become impossible (Talekar and Shelton, 1993).

There is therefore need to develop new alternatives for *P. xylostella* control to increase the productivity of brassica production in Kenya and to ensure a secure supply of food for the rapidly expanding population. Emphasis should be placed on biological control, plant resistance, cultural control and other effective and non-polluting methods (Charleston and Kfir, 2000). According to Potdar and Kakkar (2001), most cultural practices are usually non-chemical strategies and ecologically based and therefore they can offer best alternative options for designing and managing new agroecosystems. Attempts to use cultural pest control measures have been demonstrated in several regions. For instance, in India, studies by Chelliah and Srinivasan (1986) revealed that in an intercrop planting pattern of one row of cabbage and one row of tomato (the tomato planted 30 days earlier than cabbage) afforded greater reduction of *P. xylostella* larvae on cabbage. In another study from India, when one row of mustard was alternated with 15-20 rows of cabbage, *P. xylostella* was found to colonize the mustard and spared the main crop (Srinivasan and Krishna Moorthy, 1992). In Florida, Mitchell *et al*., (1997) planted two rows of collard green (*Brassica oleracea* var. *acephala*) between two cabbage fields and this resulted into high *P. xylostella* larval infestation on collard than on cabbage on adjacent fields. The study also showed that collard can play an important role in the maintenance of *P. xylostella*'s natural enemy, *Diadegma insulare* (Cress) (Hymenoptera: Ichneumonidae).

Therefore, the use of companion and trap crops in a cabbage/kale cropping system is a cultural control method that would possibly serve as a safer alternative that can be used in combination with other noble pest control methods. For instance, it can be integrated with the chemical and biological pest control strategies for developing a sustainable crop protection measure in the promising cropping systems.

1.2. LITERATURE REVIEW

1.2.1. Diamondback moth (Morphology)

The adult is greyish brown moth with a 9 mm long body and a wingspan of about 12-15 mm (Reid and Cuthbert, 1971). The upper (coastal) two-thirds of forewing in males is light fuscous sometimes mixed with whitish scales and flecked with scanty small blackish dots, while in females it is light or light grey. Lower one-third of the male forewing is ochreous-white, the upper edge being nearly white, margined broadly with dark or black-brown and in females the contrast not so pronounced between upper and lower portions in coloration, but the markings are like those of males. When wings are folded, three or four diamond-shaped areas formed by forewings are visible on the dorsal side. Larvae are smooth, green and tapered at both ends. Head capsule is pale to pale-greenish or pale-brown, mottled with brownish and black brown spots. When prodded at the head end, it wiggles its whole body vigorously and often drops from the plant. It is 10-12 mm long when fully grown (New South Wales Department of Agriculture, 1983). The pupa is 5-6 mm, about four times as long as the width and is covered with a white silken cocoon. Initially pupa is pinkish-white to pinkish-yellow with subdorsal and subspiracular lines.

1.2.2. Host range and host specificity

The range of host plants that *P. xylostella* attacks is restricted to members of the Brassicaceae family, which contain glucosinolates that degrade into volatile mustard oils (Salinas, 1986). Members of this family occur in temperate and tropical climates and represent a diverse, widespread and important plant group.

Many glucosinolates stimulate feeding in *P. xylostella*, but two of these (3-butenyl and 2-phenylethyl) are toxic to them at high concentrations (Nayar and Thorsteinson, 1963). Sinigrin, sinalbin and glucocheirolin act as specific feeding stimulants for *P. xylostella* hence plant species containing one or more of these chemicals serve as hosts. Non-host plants may contain these stimulants but also contain feeding inhibitors (Gupta and Thorsteinson, 1960). Sulfur-containing glucosinolate or its metabolites, allyl isothiocyanates, act as oviposition stimulants in brassicas (Reed *et al.*, 1989).

Its primary hosts include head crops (namely; *Brassica oleracea* var. *capitata* L. {cabbages}, *Brassica oleracea* var. *botrytis* L. subvar. *cymosa* {broccoli}, *Brassica oleracea* var. *botrytis* L. {Cauliflower} and *Brassica oleracea* var. *gemmifera* {Brussels sprouts}), leafy crops (namely; *Brassica oleracea* L. var. *acephala* {collards}, *Brassica oleracea* L. var. *alboglabra* {kale}, mustard greens and turnip greens) and root crops (namely; *Brassica rapa* var. *pekinesis* {turnip}, *Raphanus sativus* {radish} and *Brassica oleracea* L. var. *gongyloides* {kohlrabi}.

Studies on food plant preference of *P. xylostella* have revealed that among several brassicas, *P. xylostella* exhibits a marked preference for cauliflower and cabbage. This is probably due to the fact that both plants possess fleshy and succulent leaves compared to the rest of the brassicas tested and this probably provides olfactory and gustatory stimuli for successful host selection and development (Singh and Singh, 1982). In addition, *P. xylostella* feeds on numerous brassicaceous plants that are considered to be weeds. They maintain themselves on these weeds only in the absence of more favoured cultivated hosts (Talekar and Shelton, 1993).

A non-cruciferous crop like *Amaranthus virdis* L. has also been reported to be the host of this species. Alternate weed hosts are especially important in maintaining *P. xylostella* populations in temperate countries in spring before brassicaceous crops are planted. Reports from Kenyan vegetable export growers also suggests that *P. xylostella* may have developed a taste for other new host crops, completely outside the original host range. In Kenya, it has been reported from sugar snap and snow (mangetout) peas (both *Pisum sativum*) grown for export (Lohr, 2001). Data has shown that there is really a new strain with biological differences; while the cabbage strain of *P. xylostella* cannot normally survive on peas, the new strain fares equally well on both hosts. However, this adaptation to peas seems to have come at some cost in that the development of pea strain is slower and the average pupal weights tend to be lower than for the normal strain while the sex ratio seems to be slightly affected in favour of males.

1.2.3. Biology and ecology

The biology of *P. xylostella* has been studied in the laboratory and under natural conditions in relation to ecological factors (Jayarathnam, 1977). The eggs are small (0.44 x 0.26 mm) and yellowish (Harcourt, 1961). Incubation period is temperature dependent and ranges from three to four days under both laboratory and field conditions (Jayarathnam, 1977). There are four larval instars. The freshly hatched larvae are whitish yellow to pale green with a pale brown head (Bhalla and Dubey, 1986). On hatching, the first instar larvae mines into the leaf and feeds on the spongy mesophyll tissue (Harcourt, 1957). After the first instar, the larvae are surface-feeders and attack leaves and other plant parts, causing significant damage. On stems, it nibbles the chlorophyll-rich green areas. Larval period ranges from 7.8-19.5 days at the temperature range of 17.5-32.5°C (Yamada and Kawasaki, 1983). Pupae are encased in loosely woven cocoons often fastened to the plant parts and frequently hidden in crevices near the bud. Spinning of the cocoon by the fully-grown larvae is followed by one or two days of quiescence that marks the prepupal stage. The time from cocoon spinning to pupation is temperature dependent, maximum development being at 27.5°C (Yamada and Kawasaki, 1983).

Jayarathnam (1977) also observed that mating begins at dusk on the day of emergence, while oviposition begins in the evening and reaches its peak about 2 hours later and that after midnight the moths are not active. Eggs are laid in depressions on the leaf along the midrib and larger veins or on concave surfaces near smaller veins. Plant volatiles, secondary chemicals, temperature, trichomes and waxes on leaf surfaces all influence oviposition (Tabashnik, 1985). Average longevity of female and male is 16 and 12 days, respectively. Most females (90%) lay eggs from the day of emergence up to 10 days and fecundity ranges from 159 (Harcourt, 1957) to 288 (Ooi and Kelderman, 1979) eggs per female. Jayarathnam (1977) postulated that if the eggs were to be laid by the adults of each generation on the same day as emergence, up to 16 generations per year could be completed.

P. xylostella has a wide ecological tolerance, which enables them to reproduce under extremely varied climatic conditions. Since its life history is influenced by temperature, the generation time varies accordingly (Chua and Lim, 1977). It breeds all year round in the tropics. However, Yamada and Kawasaki (1983) reported that its rate of development (e.g. hatching, pupation and adult emergence) was not affected by humidity. Rainfall, along with other limiting factors (e.g. food scarcity and natural enemies), influences its population density.

1.2.4. Economic impact

P. xylostella attacks the seedling, vegetative, flowering and fruiting stages of all brassica vegetables throughout tropical and subtropical areas of the world. Although it is believed to have originated in South-Eastern Europe, it now occurs wherever brassicas are grown and is believed to be the most universally distributed of all the Lepidoptera in the world (Jussoh *et al.*, 1992). The larva is a surface feeder and with its chewing mouthparts, it feeds voraciously on the leaves, leaving a papery epidermis intact. This type of damage gives the appearance of translucent windows in the leaf blades (Verkerk and Wright, 1996). The larvae and in same cases the pupae are found on the damaged leaves. In cases of severe infestation, entire leaves could be lost. On stems and pods, this pest nibbles the chlorophyll-rich green areas. Heavily damaged plants appear stunted and in most cases die. Thus, total crop failure may occur whenever proper control measures are not adopted.

1.2.5. Natural enemies

Numerous natural enemies (parasitoids and predators) and pathogens attack different stages of *P. xylostella*. Over 90 parasitoid species are known to attack the pest (Goodwin, 1979) and only about 60 of them appear to be important. Among these, 6 species attack eggs, 38 attack larvae and 13 attack pupae (Lim, 1986). Egg parasitoids belonging to the genera *Trichogramma* and *Trichogrammatoidea* contribute little to the natural control and require mass/frequent production and releases. Larval parasitoids belonging to the genera *Diadegma* and *Cotesia* (=*Apanteles*) are the most predominant and effective. A few *Diadromus* species, most of which are pupal parasitoids also exert significant control. *Beauveria bassiana* (Balsamo), *Zoophthora radicans* (Brefeld) and granulosis virus (G.V.) are pathogens known to attack *P. xylostella*.

1.2.6. Control

Currently, the mainstay of control in tropical to subtropical developing countries (where small farms dominate vegetable production) is the frequent use of insecticides (Srinivasan and Krishna Moorthy, 1992). In most of these countries, imported insecticides from developed countries are readily available at reasonable cost. In some countries, pesticides are subsidized. These factors have led to over-use and complete dependence on insecticides to control *P. xylostella*.

1.2.6.1. Rational use of pesticides

Insecticides are usually effective in controlling *P. xylostella*, although populations of the pest in some areas have developed resistance to some chemical insecticides. The biological insecticide *Bacillus thuringiensis* (Dipel, Vegetable Insect Attack) is very effective against *P. xylostella* in both backyard gardens and commercial plantings (Hama, 1992). Because it kills caterpillars but does not kill other insects, it allows natural enemies to survive and contribute to pest suppression. Indiscriminate use of other pesticides frequently results in widespread destruction of the natural enemies' complex (Ikin *et al*., 1993). Therefore, to promote the abundance and performance of these natural enemies, enhanced use of pesticides and botanicals in Integrated Pest Management (IPM) systems should be promoted.

1.2.6.2. Sex pheromone

A sex pheromone consisting of three components: (Z)-11-hexadecenal (Z-11-16: Ald), (Z)-11-hexadecenyl acetate (Z-11-16: OAC) and (Z)-11-hexadecenyl alcohol (Z-11-16: OH) is now available commercially (Chow *et al*., 1977). This pheromone attracts male adults and suitable traps are used to kill the moths attracted to the pheromone. This pheromone has been used in monitoring *P. xylostella* populations in the field (Baker *et al*., 1982). Japanese scientists have succeeded in achieving mating disruption in cabbage fields using high concentrations of the pheromone (Ohno *et al*., 1992).

1.2.6.3. Biological control

Introduction of exotic parasites to control pest insects has been practised for decades and has considerable promise for the control of *P. xylostella*. *Diadegma semiclausum* (Hellen) and *Diadromus collaris* Grav (both

Hymenoptera: Ichneumonidae) were introduced in New Zealand from England (Hardy, 1938) and they continue to suppress *P. xylostella* populations until now and the challenge today is to incorporate this biocontrol into a commercial Integrated Pest Management system. The introductions also resulted in heavy parasitism of *Cotesia plutellae* Kurdj (Hymenoptera: Braconidae) (72-90%) and marked reduction in damage to crucifers (Goodwin, 1979; Hamilton, 1979). Widespread and indiscriminate use of insecticides, for example in Indonesia's crucifer-growing areas in the highlands of Java, has frustrated and delayed the establishment of *D. semiclausum* in *P. xylostella* control in the field (Sastrosiswojo and Sastrodihardjo, 1986). The parasite proliferated in the early 1980s with substitution of chemical pesticides by *B. thuringiensis. Diadegma semiclausum* was introduced in Taiwan from Indonesia and it got established in the highlands where it provides substantial savings in *P. xylostella* control (AVRDC, 1988).

1.2.6.4. Cultural control

Cultural control is the deliberate manipulation of the agroecosystem (either the cropping system or specific crop production practices) to make it less favorable for pests by disrupting their reproductive cycles, eliminating their food or making it more favorable for their natural enemies. Many diverse cultural practices are employed to plant, maintain and harvest crops in all agroecosystems. These measures influence the ecology of the crop production system. Even slight modifications in crop production practices can substantially affect the dynamics of arthropod pest and natural enemy populations, as alteration of such cultural activities alter the microenvironment of the crop (Arkin and Taylor, 1981; Hartfield and Thormson, 1982). Consequently, some measures may lead directly or indirectly to increase or decrease in crop stress from pests. Both cultural practices to reduce the crop and the cultural methods designed to manage pest populations are essentially habitat management.

Cultural control may not by itself reduce the pest population to below economic threshold level, but it is one of the oldest and most effective method (s) in reducing losses due to insect pests (Glass, 1975). Classical control measures that have been tested and recorded some success are irrigation, mulching, manuring and fertilization, intercropping (Helenius, 1989), trap cropping (Hokkanen, 1991), rotation and clean cultivation among others.

a) Irrigation, mulching, manuring and fertilization

These practices, in general, promote rapid growth and shorten the susceptible stage of the crop giving it a better tolerance and opportunity to compensate for insect damage. At the same time, they can also change the physiology of the plant as food for phytophagous species by making it thick and strong and thereby enhancing pest survival. The physical effect of irrigation can be both beneficial and detrimental to pest numbers. Water droplets can cause dislodging, drowning and suffocation or may drive off pests and kill soil-inhabiting species. Natural enemies may be similarly affected. Bytinski-Salz (1965) found that increased irrigation favored the establishment of crawler stage of coccids, but was detrimental to their hymenopterous parasitoids and so caused outbreaks of the scale insects. The type of irrigation used can also have different effects (Westigard *et al*., 1979).

Mulching, on the other hand, may encourage natural enemies by providing shelter and a favorable microenvironment. Plant nutrition can influence feeding, longevity and fecundity of phytophagous insects, but this effect is not always beneficial to them as nitrogen, phosphorus and potassium may have direct or indirect benefits on pest suppression. Hence the benefits of increased plant yield from improved nutrition and water availability must be balanced against increases in the size of the insect populations (Van Emden, 1965).

b) Rotations and clean cultivation

Rotations determine the frequency of annual crops and in general, the more frequent the rotation the more damaging endemic pests are likely to become. Practice of crop rotation involving host and non-host crops of insect pests is particularly effective against species having a limited host-plant range and dispersiveness. It is unsuitable for aphids, blossom beetles and strong flying Diptera and Lepidoptera or species with a range of wild hosts, e.g. cereal aphids or frit fly (Panda and Khush, 1995). Crop rotation is, however, a well-established control method against pests that cannot survive for more than one or two seasons without a suitable host crop. Rotation effects can be lost unless they are also practiced on neighboring fields to avoid dispersion between crops. Clean cultivation can be achieved by planting seedling beds away from production fields.

c) Intercropping

Intercropping is the cultivation of two or more species of a crop in such a way that they interact agronomically (Vandermeer, 1989). In tropical countries the use of monocultures is practised only on larger farms or estates, while the more traditional approaches to farming utilise intercropping systems. These systems include mixed intercropping (no distinct row arrangement), row intercropping (one or more crops planted in rows), strip intercropping (crops grown in different strips, wide enough to permit independent cultivation), relay intercropping (two or more crops grown simultaneously for part of the life cycle of each, a second crop being planted before the harvest of the first) (Andrews and Kassam, 1976) and alley intercropping (annual crops are grown in strips between trees). The earliest successes of using intercropping as a pest control measure occurred in Russia where intercropping cabbage with tomato reduced damage to cabbage by several pests (including *P. xylostella*) (Vostrikov, 1915). This practice had only limited success in India (Srinivasan, 1984; Chelliah and Srinivasan, 1986), Philippines (Magallona, 1986) and Taiwan (AVRDC, 1985). In Taiwan, 54 crops were tested for their usefulness in intercropping and none had any significant impact on the population of *P. xylostella* on cabbage.

Attempts to reduce pest attacks by increasing intracrop diversity have also been made by undersowing plots of Brussels sprouts with either clover (*Trifolium repens*) (O'Donnell and Coaker, 1975) or corn spurrey (*Spergula arvensis*) (Theunissen and den Ouden, 1980). Although the overall effects have been encouraging, it has not always been easy to predict the outcome of any particular intercropping system. Hence, O'Donnell and Coaker (1975) reduced cabbage aphid infestations by 40-90% when 25-100% of the soil was covered by clover, whereas Theunissen and den Ouden (1980) recorded a decrease in aphid numbers only when 100% of the soil was covered with corn spurrey. O'Donnell and Coaker (1975) also showed that the numbers of predatory arthropods were enhanced by additional shelter provided by the clover and suggested that the predators were responsible for the lower survival rate of cabbage caterpillars (30%) and cabbage root fly (60%). Although this is one explanation, the differences recorded could also result from interference by the intercropped plant during the attraction and oviposition phase of the pest and also from the general influence of the intercrop on the microclimate of the plots (Theunissen and den Ouden, 1980). Turkar *et al.* (2000) intercropped chickpea with coriander and this recorded significantly higher parasitic activity, lower pest activity, minimum pod damage and higher grain yield of chickpea as compared to the chickpea sole crop.

Irrespective of the mechanism involved, however, a mixed or intercropping regime will provide a greater total land productivity as well as insurance against the failure or unstable market value of any single crop. In addition crops in intercropping systems may improve soil fertility and the availability of alternative sources of nutritious products (Risch *et al.*, 1983) as well as reducing the incidence of insect pest attack (Tingey and Lamont, 1988) and thereby maintaining lower pest control costs. Its main drawback is that competition from the intercrop often, though not always, reduces crop yield. However, the intercrop may also serve as an essential food source or shelter for some stage in the life cycle of the pest or for the part of the season, enabling the pest to increase and so attack the crop more severely. This negative effect has been demonstrated by interplanting cabbage with garlic or tomato, which gave no substantial reduction of *P. xylostella* infestation (Andrews *et al.,* 1992).

d) Companion (multiple) cropping

Companion cropping or polycultures (i.e. growing more than one crop simultaneously or sequentially in various row arrangements within a field) is one way of increasing vegetation diversity, which plays a key role in Integrated Pest Management. Vegetation diversity can affect arthropod damage and densities by influencing the rate at which arthropods immigrate into a cropped area, their population dynamics once they have entered and the rate at which they emigrate from the area (Smith and McSorley, 2000). The extent of immigration depends on the host-finding mechanisms and mobility of the arthropods.

Companion cropping has been practised for centuries by small-scale farmers in Africa to reduce the risk of crop failure, to attain higher yields and to improve soil fertility (Litsinger and Moody, 1976). Andow (1991) postulates that this diversification in the agroecosystem may lead to a reduction of the herbivore pest populations. Use of modern high yielding cultivars creates monocultures with a narrow genetic base, which are subject to increasing losses to pests. This is because monoculture reduces the diversity of pest species, which tend to explode in numbers because they have a greater potential for greater fecundity under conditions of reduced competition (Southwood, 1975). According to Van Emden (1965), polycultures are ecologically complex because interspecific and intraspecific plant competition occurs simultaneously with herbivores, insect predators and insect parasites. Elimination of alternate habitats may lead to decreased predator and parasite populations.

e) Trap cropping

Trap "attractant" crops are plant stands grown to attract, concentrate and enhance populations of the target insect pests or other organisms so that the target crop escapes pest attack (Stern, 1969). The trap crop can be a different plant species, variety or just a different growth stage of the same species, as long as it is more attractive to the pests when they are present. Trap cropping is most worthwhile for pests that are abundant and destructive in most years. It works best for insects of intermediate mobility rather than those, like aphids, passively dispersed by air currents or those strong fliers that descend on a crop from high elevations. Protection is achieved either by preventing the pests from reaching the crop or by concentrating them in a certain part (i.e. the trap crop) of the field where they can easily be destroyed (Hokkanen, 1991).

Thus, crop stands are often manipulated temporally and spatially to synchronize the attractive host plant growth stages offered at a critical time of the pest's phenology (Panda and Khush, 1995). The principle of trap cropping is similar to "associational resistance" hypothesis, in which the insect pests show distinct preference for certain plant species, cultivars or a crop stage. Before the advent of modern chemical insecticides, a common practice was to plant strips of an economically less important plant highly preferred by *P. xylostella* within a commercial crucifer field (Kanervo, 1932). The preferred crops, primarily white mustard (*B. hirta*) or rape (*B. juncea*) attracted *P. xylostella* adults, which spared the commercial crop such as cabbage and Brussels sprouts from its attack (Ghesquiere, 1939). Due to insecticide resistance problems, trap cropping is becoming a more realistic alternative especially in developing countries. In Florida, when two rows of collard green (*Brassica oleracea* var. *acephala*) were planted between two cabbage fields, high *P. xylostella* larval infestation was observed on collard than on cabbage on the adjacent fields (Mitchell *et al.,* 1997). The study also showed that collard can play an important role in maintenance of the natural enemy, *Diadegma insulare* (Cress) (Hymenoptera: Ichneumonidae). Major benefits of trap cropping are that they yield commercially valuable commodities and the main crop seldom needs to be treated with insecticides; thus, natural control of pests may remain fully operational in most of the field.

For the system to succeed the pest must have a narrow host range and the trap crop species selected need not be different from the main crop. The minimum area for the trap crop can be in the order of 5-15% of the site, selected on the knowledge of the pest's host-plant preferences and dispersal behavior. Once these decisions are made, successful control is possible with little effort and reduced chemical input at the expense of a small reduction in yield. Trap crops must obviously be attractive to the target pest and tolerant of heavy attack. They can either be destroyed or sprayed, necessarily before the pest reproduces and the main crop is available to them.

1.2.7. Theories of pest suppression in diverse ecosystems

During the last few decades, a strong and persistent interest among agricultural ecologists and entomologists has been directed towards the mechanisms involved in the suppression of herbivores. Several gradually accepted working hypotheses have been proposed to explain differences in herbivore populations in simple and diverse habitats.

1.2.7.1. "Enemies" hypothesis

Root's "enemies hypothesis" (Root, 1973) postulates that generalist and specialist natural enemies are expected to be more abundant in polyculture and therefore suppress herbivore population densities more in polycultures than in monocultures. Polycultures provide; (a) greater temporal and spatial distribution of nectar and pollen resources which attract natural enemies for adult feeding, (b) increased ground cover, particularly important to diurnal predators and (c) increased prey, offering alternative food sources when pest species are scarce or at an appropriate time in the predators life cycle. These factors can in theory combine to provide more favourable conditions for the natural enemies and thereby enhance their numbers and effectiveness as control agents. A number of studies have shown that many parasitoids require nectar for normal fecundity and longevity and thus spectacular parasitism increases have been observed in annual crops and orchards with rich floral undergrowth (Leius, 1967; Powell, 1986).

Extrafloral nectar is produced by various plants such as faba bean (*Vicia faba* L.) and cotton (*Gossypium hirsutum* L.), and is an important food source for adult parasitoids. Pollen may be consumed directly (Irvin *et al.,* 1999) or as a contaminant within nectar. The presence of honeydew-producing insects has been suggested as desirable for some parasitoids (England and Evans, 1997). Studies conducted by Tukahirwa and Coaker (1982) revealed that intercropping brassicas with various taxonomically unrelated crops (for instance, alternate rows of brassicas and *Phaseolus* sp.), increased the number of epigeal predators and correspondingly reduced the infestation of lepidopteran pests compared with their numbers on brassicas grown as a sole crop. Therefore outbreaks of phytophagous prey arthropods are less likely to occur because higher proportions of enemies have been maintained in the diverse ecosystem. Andow (1991) has reviewed this hypothesis.

1.2.7.2. Resource concentration hypothesis

Root (1973) also proposed the "Resource concentration" hypothesis (alternatively called the "Disruptive crop" hypothesis {Vandermeer, 1989}) to explain how vegetation diversity can directly affect herbivore populations. This hypothesis stipulates that a second plant species disrupts the ability of an insect to efficiently attack its proper host. This works in the following ways: (1) the insect is less likely to find its host plant because of some kind of confusion (chemical or physical), (2) after having found a host plant, the insect is more likely to leave the patch because of frequent encounters with nonhost plant individuals. Thus diverse habitats lower pest densities by reducing immigration into the crop or increasing emigration from the field. Andow (1991) developed these ideas further. He analysed published research and showed that the outcome of using a multicropping system depends on whether a specialist or generalist herbivore is being studied. The disruptive crop approach is more likely to work for specialist insects than for generalist insects.

The disruptive factors of host-plant finding and colonization by diverse habitats include the olfactory cues that certain insects rely on for host finding (Stanton, 1983). For example, Buranday and Raros (1973) observed significantly more *P. xylostella* adults and eggs in a plot of cabbage as the sole crop than in a plot of cabbage-tomato intercrop. This is presumably because of the repellent effects of tomatoes. A study by Talekar *et al.* (1986) in Taiwan has also indicated the useful effect of garlic intercropping in reducing *P. xylostella* infestation on cabbage. Other factors are physical barriers to movement (Perrin and Phillips, 1978) and other adverse environmental effects such as shading (Risch, 1981) where the pest tends to remain in the intercrop for a shorter period of time simply because the probability of landing on a non-host plant is increased. Inhibition of visual orientation can be achieved by intracrop diversity as with high-density cropping.

Insect survivorship and/or fecundity may also be lower in diverse habitats (Ballidawa, 1985). The extend to which these factors operate will depend on the number of host plant species present and the relative preference of the pest for each, the absolute density and spatial arrangement of each host species and the interference effects obtained from the non-host plants (Risch, 1981). If the density of a host species is low and it is well distributed among non-host plants, then an insect approaching the habitat will have greater difficulty in locating its host than if the host density is high relative to non-hosts and if its distribution is clumped. Also, the concentration of the host resource may influence the probability of the insect staying in a habitat once it has arrived. For instance, an insect pest may tend to fly earlier, further or straighter after landing on a non-host plant resulting in a more rapid movement from habitats having a low resource concentration (Tukahirwa and Coaker, 1982). This hypothesis also involves the concept of "apparency" (Feeny, 1976). It is agreed that host plants that are more apparent to herbivores are more likely to be attacked and hence are more likely to support populations of herbivores. Apparency can be chemically or visually mediated.

1.2.7.3. "Associational resistance" hypothesis

Host-plant finding also often involves olfactory mechanisms, and host-plants grown in association with unrelated plants may be an important component in the defence against herbivores, the non-host plant odours leading to disruption of the host-finding behaviour of the insect based on odour cues. This type of protection is known as "associational resistance" (Tahvanainen and Root, 1972). It derives from the masking effect of the non-host plant odours of the host-plant odour causing a reduction in plant apparency, i.e., making the host-plant less easy to find (Feeny, 1976). This effect has been demonstrated in collards interplanted with tomato or tobacco on the flea beetle, *Phyllotreta cruciferae* (Root, 1973) and *P. xylostella* (Buranday and Raros, 1973) and carrot fly on carrots interplanted with onions (Uvah and Coaker, 1984). In the latter example, reduction in infestation occurred only when the onion leaves were expanding and not when the plants had started to bulb, suggesting that the masking odour emanated from young leaves only. Other aromatic herbs have been claimed to be repellent to vegetable insect pests, mostly by organic gardeners.

1.3. RATIONALE AND HYPOTHESES OF THE STUDY

1.3.1. RATIONALE/JUSTIFICATION

In Kenya, cultivation and sale of brassicas in lowland and highland areas has emerged as an important source of income to smallholder farmers due to the attractive prices offered in the market. *P. xylostella* constitutes a major constraint to production in Kenya and different parts of the world (Ikin *et al*., 1993; Farrell *et al*., 1995). This is because farmers incur expenses in attempting to control the pest. Yield losses on cabbage of upto 100% have been reported to be caused by the pest (ICIPE, 1997). The damage caused reduces quantity and quality of the produce and this consequently lowers their market prices. In Kenya, more than 90% of vegetable farmers believe that pesticide use is important in reducing production losses due to pests (Gathui *et al*., 1994) hence they rely heavily on broad-spectrum insecticides in trying to minimise crop damage. This has created an urgent need for a more balanced approach to Integrated Pest Management in cabbage and kale crops with reduced reliance on insecticides.

Although most farmers in the tropics use companion cropping because of labour and land shortages or other agronomic purposes, less emphasis has been placed upon its beneficial and practical effects on pests and diseases (Anonymous, 1981). The practice has obvious pest control effects (Altieri and Letourneau, 1982) as it may decrease damage to the main crop by diverting the pest away from it (Ballidawa, 1985). The practice involves combined use of repellent and trap (attractant) crops, in which insects are repelled from the main crop and are simultaneously attracted to a trap crop (Potdar and Kakkar, 2001). For maximum efficiency, these systems also exploit natural enemies, particularly parasitic wasps, which are important in suppressing pest populations.

Therefore, use of companion crops can make a contribution to Integrated Pest Management systems whose long-term benefits might overweigh some of the short-term economic and environmental costs of present-day chemical control methods and thus provide a beneficial socio-economic option to the Kenyan agriculture. It has been observed that cabbage intercropped with tomatoes had significantly lower *P. xylostella* adults and eggs than in cabbage monocrops (Buranday and Raros, 1973). In Mauritius, cabbage intercropped with garlic, coriander and tomato showed similar results on cabbage (Facknath *et al.*, 1998). Other aromatic herbs have also been claimed to be repellent to insect pests of vegetable crops (Hills, 1992), but little experimental work has been done in Kenya to substantiate these claims. Increased plant diversity through companion cropping has also led to an increase in natural enemies' effectiveness (O'Donnell and Coaker, 1975). Therefore, an understanding of how a host plant is located by insects and how they can be disrupted by non-host plants in their vicinity, which provide the camouflage, diversionary or repellent compounds found in diverse ecosystems is vital before utilising companion crops in pest suppression.

The present study evaluated the potential of companion crops in managing *P. xylostella* in cabbage and kale cropping systems in Kenya. Ultimately the study aimed at describing a sustainable crop protection strategy that is appropriate to the promising low-input cropping systems and one that would create a shift from heavy pesticide use that is popular among farmers by making use of "trap" and "repellent" plants.

1.3.2. HYPOTHESES

1. Companion crops have no effect on *P. xylostella*'s oviposition and larval development.
2. Planting pattern of companion crops has no effect on abundance and damage by *P. xylostella*.
3. Companion crops have no effect on *P. xylostella*'s key parasitoids and non-target arthropods.

1.4. OBJECTIVES

1.4.1. GENERAL OBJECTIVE OF THE STUDY

The general objective of this study was to evaluate the potential of companion crops in managing the diamondback moth in cabbage/kale cropping systems in Kenya.

1.4.2. SPECIFIC OBJECTIVES

1. To investigate the relative attraction or repellence of candidate companion crops to *P. xylostella* population.
2. To evaluate the role of planting pattern on *P. xylostella* infestation.
3. To assess the indirect effects of companion crops on non-target insects and plant diseases in the crop ecosystem.

CHAPTER 2

2.0. GENERAL MATERIALS AND METHODS

2.1. Description of study sites

The study was carried out between August, 2001 and August, 2002, at Jomo Kenyatta University of Agriculture and Technology (JKUAT) and Kenya Agricultural Research Institute (KARI) - Matuga. JKUAT is located in Thika district, Central province, Kenya (latitude 1^{o} 05'S, longitude 37^{o} 00'E at an altitude of 1,525m above sea level) (see map, appendix 1). The temperatures range mostly from 13 ^{0}C to 26 ^{o}C. Rainfall distribution pattern is bimodal with over 55% of the total rain falling in the long rains season (March-July) and the remaining during the short rains season, between October and December. The soils are of red-clay type. Cabbage is commonly grown in the area and finds ready market from the urban population, especially in Nairobi and Thika towns. Matuga is located in Kwale district, Coast province, Kenya (latitude 4^{o} 18.95'S, longitude 39^{o} 33.41'E and 40m above sea level) (see appendix 1). Temperatures vary between 28 ^{o}C and 30 ^{o}C. Rainfall distribution also follows a bimodal pattern. Soils are of sandy type. It is a lowland region which experiences considerable food security problems, which are traceable to substantial yield losses in food crops, due to high insect pest populations (ICIPE, 1995).

2.2. Experimental insects

The test insect, *P. xylostella*, used in the laboratory experiments was obtained from a laboratory culture established at the ICIPE-Duduville insectaries (Nairobi). The foundation collections of larvae were obtained from *Brassica* *oleracea* L. var. *capitata* (cabbage) at JKUAT and from *Brassica oleracea* L. var. *acephala* from ICIPE - Muhaka field station, Kwale. Larvae in these cultures were maintained on fresh potted cabbage and kale plants, while adults were provided with a mixture of 10% honey solution dispensed on cotton wool, as described by Hardy (1938). Insect cages, each measuring 50 × 50 × 70 cm, were used for rearing the *P. xylostella* populations separately. All the potted plants used for rearing and conducting laboratory experiments were raised in the green house at ICIPE-Duduville. Insect rearing and all laboratory experiments were at room temperature (25 ± 2 °C, 70 ± 5% RH, L12: D12).

2.3. Experimental plants

Seven different test plants were grown: Cabbage (*Brassica oleracea* var *capitata* L.), Kale (*Brassica oleracea* L. var. *acephala*), rape seed (*Brassica napus* L. Subvar. *oleifera*), Ethiopian mustard (*Brassica carinata* B.), *Cleome* (*Cleome gynandra* L.), coriander (*Coriandrum sativum* L.) and tomato (*Lycopersicon esculentum*). For laboratory trials, seedlings of cabbage, kale, rape seed and tomato were raised on trays measuring (45×30×8 cm), which were placed in the ICIPE-Duduville greenhouse. Two weeks later, *Cleome* and coriander were directly seeded in pots. Due to the fast growth and development of mustard, it was directly seeded at the time of transplanting cabbage, kale, rape seed and tomato. Planting dates were synchronized such that at the time of conducting the bioassays, all the plants were in their vegetative stage. The plants were established weekly in order to maintain adequate and constant supply.

2.4. Laboratory studies on the relative attraction or repellence of companion crops to *P. xylostella* infestation

2.4.1. Oviposition preference of *P. xylostella* to companion crops

2.4.1.1. Choice tests

Two sets of tests were conducted with the potentially attractive and repellent test plants. In the first test, JKUAT culture moths were tested for oviposition on plant leaves of (1) cabbage, (2) mustard and (3) rape seed. Green and white "paper leaves" were included as checks. The bioassays were conducted in clear plastic cages (30×30×20 cm) placed on a working bench and provided with a large opening covered with a mesh netting on one side and the floor lined with a paper disc. The paper disc was marked off into five equal sized, radial sectors before placing it on the cage floor. Test plant leaves were inserted in vials containing water through holes on the vial lids (one test plant leaf per vial) as described by Charleston and Kfir (2000). Each vial was assigned to one of the sectors within the cage. Twenty-five one-day-old mated female moths were placed in the bioassay cage and provided with 10% honey solution, dispensed on cotton wool. The moths were allowed to oviposit on the test material for one to three days. The leaves and sucrose solution were replaced with fresh ones every 24 hours. Eggs laid on both surfaces of the leaf were counted and pooled as the total number of eggs laid per test plant. Eggs laid on each plant were incubated for four days and the percent of eggs hatched was recorded. This test was replicated six times, with the test plants assigned to the cages in a Completely Randomised Design (CRD). Muhaka culture moths were tested separately on similar test plants except that kale was used in place of cabbage.

In the second choice test, JKUAT culture moths were tested on treatments comprising of (1) cabbage-*Cleome*, (2) cabbage-tomato, (3) cabbage-coriander and (4) cabbage (control). A treatment comprised of four cabbage leaves and four leaves of the potentially repellent plants - *Cleome*, tomato and coriander (cabbage leaves with leaves of one potentially repellent plant at a time). Leaves of each test plant (per treatment) were inserted through the openings of glass flasks containing water, in such a way that cabbage leaves were wrapped around the potentially repellent test plant leaves (four cabbage leaves with four leaves of one potentially repellent test plant at a time). The flask opening was covered with strips of parafilm. One flask, containing test plants for one treatment was then placed in a cage and all the other procedures as for the first test were followed. The test had eight replications, with flasks containing test plants for each treatment assigned to the cages in a CRD. In another test, Muhaka culture moths were tested on similar treatments, except that kale was used in place of cabbage.

2.4.1.2. No-choice tests

For the no-choice test, seven different plants were tested (1) cabbage, (2) kale, (3) rape seed, (4) mustard, (5) *Cleome,* (6) coriander and (7) tomato. Procedures followed were similar to the first choice test, except four leaves of each test plant were placed in a cage at a time. There were six replications, with test plants in vials assigned to different cages placed on a working bench in a

CRD. The moths from JKUAT and Muhaka cultures were tested separately on these test plants.

2.4.2. Effect of companion crops on survival and development of *P. xylostella* larvae

In two sets of no-choice tests, survival and development of DBM larvae was tested on (1) cabbage, (2) kale, (3) rape seed, (4) mustard, (5) *Cleome,* (6) coriander and (7) tomato. In the first test, sixty newly hatched 1st instar larvae were placed on fresh leaf discs of each test plant in petri-dishes lined with moist filter paper. Numbers of the surviving larvae on each test plant were recorded at the end of the second and fourth instars. In the second test, five randomly selected newly hatched first instars were placed on fresh leaf discs of each test plant, in petri-dishes lined with moist filter paper. These were used to measure the developmental time from hatch through pupation. Leaf discs were replaced with fresh ones after every 24 hours. Each test was replicated six times and test plants assigned to petri-dishes placed on a working bench, in a CRD. Both JKUAT and Muhaka DBM cultures were tested separately on these test plants.

2.4.3. Effect of companion crop flowers on adult longevity and fecundity of *P. xylostella*

Bioassays were conducted on flower bouquets of (1) coriander, (2) *Cleome*, (3) mustard and (4) rape seed. For comparison, a 10% mixture of honey water and water alone were included as checks. The flower bouquets were used as nectar source for *P. xylostella.* Stems of flowers of each test plant were inserted in a vial filled with water (one vial per test plant flower). A cabbage leaf (serving as an oviposition substrate) was inserted in another vial containing water. One vial with flowers, a vial with cabbage leaf and one male-female pair of *P. xylostella* (JKUAT culture) (1day-old and not yet fed) were enclosed in a cage 50 × 50 × 70 cm with an opening covered with fine mesh netting at the side. To measure longevity, survival of the female and male adult insects was recorded daily. Fecundity was measured by counting the total number of eggs laid by the female moth on the cabbage leaf during her lifetime. The flower bouquet, cabbage leaf and honey water were replaced with fresh ones every 24 hours. This test had four replications, with the test plant flower bouquets and the checks assigned to cages placed on a working bench in a CRD. A similar test was conducted using moths of Muhaka culture, except that kale was used as an oviposition substrate in place of cabbage.

2.4.4. Effect of olfactory stimuli from companion crops on *P. xylostella* responses

Responses by female *P. xylostella* moths to olfactory stimuli from potted test plants of (1) cabbage, (2) kale, (3) rape seed, (4) mustard, *Cleome*, (6) coriander and (7) tomato were investigated in a no-choice test. A pot of soil was included as a check. Observations were carried out in a wind tunnel (160 cm long × 75 cm high and wide) (Appendix 2). To test whether the moths moved away or towards the stimuli, a potted test plant (one at a time) was placed on a metallic plate fitted on a metallic rack, in the wind tunnel at a distance of 40 cm from the upwind end. An enclosed petri-dish containing a one-day old mated female moth was placed on a metallic rack inside the wind tunnel, at a distance of 40 cm from the downwind end. The petri-dish lid was released and the moth allowed to fly to and land on the test plant. The moths' responses were observed for 5 minutes, during which orientation (zigzagging upwind flight) and landing were recorded. In addition, the latency for the first orientated flight and landing on the test plant material was recorded. This test was replicated six times and 10 insects were tested individually on each test plant in each replication. After each test, the wind tunnel was washed with hot water and rinsed with 70% ethanol. Both moth cultures of JKUAT and Muhaka were tested separately on each test plant.

2.5. Field trials on the relative attraction or repellence of companion crops to *P. xylostella* infestation

For two cropping seasons, two field trials were conducted at JKUAT and Muhaka Field Station (ICIPE-Kwale) and one other trial at KARI-Matuga. The test plants comprised of (1) cabbage/kale sole-crop unsprayed {control}, (2) cabbage/kale sole-crop Dipel sprayed {control}, (3) Ethiopian mustard {attractant}, (4) Rapeseed {attractant}, (5) *Cleome* {repellent}, (6) tomato {repellent} and (7) coriander {repellent}. Cabbage and kale were the respective main crops at JKUAT and Matuga, and were intercropped with the individual test plants (3-7). The planting ratio was 2:1 cabbage/kale (two rows cabbage/kale to one row of test plant "attractant/repellent"). Four-week-old cabbage/kale seedlings from an established nursery bed were transplanted 14 days after planting mustard, rape seed, *Cleome*, coriander and tomato. Tomato was sown in a nursery bed and transplanted when 4 weeks old. *Cleome*, rape seed, mustard and coriander were directly seeded. A total of 77 main crop plants and 33 test crop plants were grown in each plot.

Within the plots, the spacing was 0.6m inter-row and 0.3m intra-row. Each plot consisted of 11 rows with 11 plants in each row. The plots were separated with 1m and 1.5m buffers between plots and replicates, respectively (appendix 3). 12 randomly selected healthy cabbage/kale plants of similar size (3 per row) from the middle 4 rows of main crop and 12 intercrops of similar sizes (4 per row) per plot were tagged two weeks after transplanting the main crops. Dipel spraying of the sole-cabbage/kale plants was done once a week, starting from two weeks after transplanting the main crops. Diammonium Phosphate (DAP) (18.5% NH_2 + 48% P_2O_5) fertiliser, organic manure and a nematicide (carbofuran) were applied prior to planting. Calcium Ammonium Nitrate (CAN-23%N) fertiliser was applied as top-dressing during the third and sixth weeks after transplanting the main crops. Hand weeding was done at the second, fourth and sixth week after transplanting the main crops. Kale was harvested weekly from the fourth week after transplanting to the twelfth week, while cabbage was harvested on the ninth week after transplanting. All other agronomic practices recommended for the two sites were followed. This trial was replicated four times, with test plants assigned to plots in a Randomised Complete Block Design (RCBD) with four replications.

2.5.1. Field data collected

In each plot, the tagged plants were sampled once a week for eight weeks and the numbers of *P. xylostella* larvae (first & second, third & fourth instars) and pupae recorded. These data was to represent the infestation loads of *P. xylostella* in the plots. Foliar damage was also recorded weekly. Foliar damage (leaf damage score) assessment by *P. xylostella* larvae on tagged cabbage/kale plants was done by scoring the mean percent leaf area with lesions caused by *P. xylostella* on all the visible leaves per plant on the scale of 1-9 (Table 1).

Table 1: Classification of foliar damage rating on cabbage/kale by *P. xylostella* larvae.

Percent leaf area with lesions/damage	Score
0-10	1
11-20	2
21-30	3
31-40	4
41-50	5
51-60	6
61-70	7
71-80	8
>81	9

At harvest time, the tagged cabbage plants were cut just above soil level and weighed individually, including all leaves while all kale leaves per individual plant were counted and weighed. The quality of cabbage heads and kale leaves was also graded for *P. xylostella* damage into three categories according to the extent of damage caused by *P. xylostella*; A-slight/no feeding injury, B-moderate/economically insignificant injury (outer cabbage leaves damaged and heads can be marketable after removal of the outer leaves) and C-severe/economic damage (=injury to the marketable heads/leaves).

2.6. Effect of planting pattern on *P. xylostella* infestation

The aim of this experiment was to evaluate the most appropriate planting pattern of both cabbage and coriander in reducing *P. xylostella* infestation. The study was conducted at JKUAT and the test plants grown in the ratios of (1) cabbage : coriander {2:1 row}, (2) cabbage : coriander {8:1 row}, (3) cabbage : coriander {2:1 strip}, (4) cabbage : coriander {8:1 strip}, (5) cabbage : coriander {2:1 hill}, (6) cabbage : coriander {8:1 hill}, (7) sole- cabbage sprayed with Dipel {control} and (8) sole- cabbage unsprayed {control}. Each plot consisted of 19 rows of 18 plants per row, creating a plot of 10.8 × 5.1m. All plots were separated with 1m buffers between plots and replicates (appendix 4). Procedures for planting and collecting data were similar to those conducted in sections 2.5. and 2.5.1. The trial had four replications, with test plants grown in different ratios assigned to the plots in a RCBD.

2.7. Effects of companion crops on non-target insects and plant diseases

2.7.1. Effect on the level of *P. xylostella* parasitism in the field

Larvae used in this study were obtained were obtained from cabbages grown at JKUAT (section 2.5). During the eighth week after transplanting, 50 3rd and 4th instar larvae were collected from the untagged cabbage plants in each plot and taken to the laboratory. The larvae were reared on cabbage foliage in petri-dishes (10 larvae per petri dish) until moth or parasitoid emergence. The fate (numbers of larvae pupating, parasitised, diseased, dying from other mortalities and type, besides the number of parasitoids emerging) of the larvae was recorded.

2.7.2. Effect on other insects and important plant diseases

During each sampling period, populations of other major insects, other than *P. xylostella*, present on foliage of tagged cabbage and kale plants were scored, using the classification in Table 2. Fortnight sampling on the incidence of common foliar diseases of cabbage was assessed using a scale of; 1 = clean (no disease), 2 = moderate (one to two whole leaves attacked by disease) and 3 = severe (more than two whole leaves attacked by disease).

Table 2: Classification of population of other insects found on cabbage.

Insect/plant	Infestation scores					
	1 (clean)	2 (rare)	3 (light)	4 (moderate)	5 (high)	6 (very high)
Aphids/plant	0	1-10	11-50	51-200	201-500	>500
Caterpillars/plant	0	1	2-4	5-10	11-20	>20
Beetles/plant	0	1	2-4	5-10	11-20	>20

2.8. Data management and analysis

Field data was averaged for individual plots during each cropping season and analysed by a two-way analysis of variance (ANOVA) (PROC GLM, SAS Institute, 1995). Numbers of eggs laid, percentage egg hatch, larval survival and developmental times were analysed by a one-way ANOVA. Mean differences were separated using Student- Newman-Keuls test. Paired t-test was used to analyse orientation and landing data.

CHAPTER 3 : RESULTS

3.1. Laboratory studies on the relative attraction or repellence of companion crops to *P. xylostella* infestation

3.1.1. Oviposition preference of *P. xylostella* to companion crops

3.1.1.1. Choice-tests

In both choice tests, the numbers of eggs laid by the moths were significantly different between test plants. In the first test, Muhaka culture moths laid significantly more ($P<0.05$) eggs on mustard and rape seed than on kale (Table 3a). Significantly less ($P<0.05$) eggs were laid on the inert surfaces (green and white "paper leaves") than on kale. Percentage egg hatch on mustard and rape seed showed no significant differences ($P>0.05$) from kale. There was a significantly lower ($P<0.05$) percentage egg hatch on green 'paper leaf' than on kale, and no egg hatch on white 'paper leaf'. The number of eggs laid by the JKUAT culture moths and their percentage egg hatch, displayed similar trends as for Muhaka culture, although cabbage was tested in place of kale (Table 3b).

Table 3a: Oviposition preference of *P. xylostella* to various test plants/surfaces (Muhaka culture).

Test plant/surface	Eggs laid Mean ± SE	Percentage egg hatch Mean ± SE
Kale	8.14 ± 0.85 b	79.71 ± 2.69 a
Rape seed	13.94 ± 1.08 a	79.82 ± 2.98 a
Mustard	16.36 ± 1.01 a	89.06 ± 1.84 a
Green paper	0.58 ± 0.18 c	17.22 ± 6.31 b
White paper	0.09 ± 0.05 d	0.00 ± 0.00 c

Means ± SE in the same column followed by the same alphabetical letter are not significantly different at (P=0.05) by SNK

Table 3b: Oviposition preference of *P. xylostella* to various test plants/surfaces (JKUAT culture).

	Eggs laid	Percentage egg hatch
Test plant/surface	Mean ± SE	Mean ± SE
Cabbage	9.72 ± 0.76 b	81.20 ± 2.80 a
Rape seed	12.56 ± 0.82 a	83.07 ± 1.72 a
Mustard	14.39 ± 1.30 a	87.60 ± 3.11 a
Green paper	0.39 ± 0.12 c	20.67 ± 8.68 b
White paper	0.09 ± 0.05 d	0.00 ± 0.00 c

Means ± SE in the same column followed by the same alphabetical letter are not significantly different at (P=0.05) by SNK

The second test results revealed that the Muhaka culture moths deposited significantly fewer ($P<0.05$) eggs on the leaves of kale + *Cleome*, kale + coriander and kale + tomato, compared to kale (Table 4a). Kale + tomato received significantly fewer ($P<0.05$) eggs among all test plants. Percentage egg hatch on kale + *Cleome* was significantly lower ($P<0.05$) than on kale. No other significant differences were noted. Eggs laid by the JKUAT culture moths on cabbage + coriander and cabbage + tomato were significantly fewer ($P<0.05$) than those on cabbage (Table 4b). Eggs laid on cabbage + *Cleome* did not differ significantly from cabbage. No significant differences were displayed in the percentage egg hatch between cabbage and the rest of the test plants.

Table 4a: Oviposition preference of *P. xylostella* to sole kale and to kale with companion crops (Muhaka culture).

Test plant	Eggs laid Mean ± SE	Percentage egg hatch Mean ± SE
Kale	21.17 ± 2.55 a	93.70 ± 5.42 a
Kale + *Cleome*	17.67 ± 2.04 b	75.45 ± 3.12 b
Kale + coriander	10.04 ± 0.77 c	78.07 ± 3.08 ab
Kale + tomato	3.92 ± 0.47 d	82.00 ± 4.22 ab

Means ± SE in the same column followed by the same alphabetical letter (s) are not significantly different at (P=0.05) by SNK.

Table 4b: Oviposition preference of *P. xylostella* to sole cabbage and to cabbage with companion crops (JKUAT culture).

Test plant	Eggs laid Mean ± SE	Percentage egg hatch Mean ± SE
Cabbage	34.33 ± 3.16 a	85.19 ± 3.51 a
Cabbage + *Cleome*	29.83 ± 1.91 ab	78.86 ± 2.03 a
Cabbage +coriander	28.54 ± 3.16 b	79.11 ± 1.92 a
Cabbbage + tomato	9.79 ± 1.07 c	79.28 ± 3.34 a

Means ± SE in the same column followed by the same alphabetical letter (s) are not significantly different at (P=0.05) by SNK

3.1.1.2. No-choice tests

The no-choice tests revealed that the Muhaka culture moths laid significantly more (P<0.05) eggs on mustard and rape seed than on kale, while eggs laid on cabbage, *Cleome*, coriander and tomato were significantly less (P<0.05) than those on kale (Table 5a). A significantly higher (P<0.05) percentage egg hatch was recorded on mustard than on kale, while tomato showed the lowest percentage egg hatch than all other test plants. There were no other significant differences (P>0.05) noted between the rest of the test plants. On the other hand, the JKUAT culture moths also deposited significantly more (P<0.05) eggs on mustard, rape seed and kale than on cabbage (Table 5b). *Cleome,* coriander and tomato received significantly fewer (P<0.05) eggs than cabbage. Percentage egg hatch on kale was significantly higher (P<0.05) than on cabbage. *Cleome*, coriander and tomato recorded significantly lower (P<0.05) percentage egg hatch than cabbage while no significant differences were noted between cabbage and rape seed or mustard.

Table 5a: Oviposition preference of *P. xylostella* to seven test plants (Muhaka culture).

Test plant	Eggs laid	Percentage egg hatch
	Mean ± SE	Mean ± SE
Cabbage	26.74 ± 2.17 c	88.31 ± 1.85 ab
Kale	31.51 ± 2.55 b	86.05 ± 1.91 bc
Rape seed	32.56 ± 1.95 a	83.37 ± 1.96 bc
Mustard	35.44 ± 2.12 a	92.46 ± 1.02 a
Cleome	13.28 ± 0.67 d	80.09 ± 2.24 cd
Tomato	2.78 ± 0.31 f	67.74 ± 3.36 e
Coriander	11.53 ± 0.50 e	76.27 ± 2.43 d

Means ± SE in the same column followed by the same alphabetical letter (s) are not significantly different at (P=0.05) by SNK.

Table 5b: Oviposition preference of *P. xylostella* to seven test plants (JKUAT culture).

Treatment	Eggs laid	Percentage egg hatch
	Mean ± SE	Mean ± SE
Cabbage	21.44 ± 1.70 c	88.47 ± 1.28 b
Kale	25.32 ± 1.93 b	93.07 ± 0.92 a
Rape seed	24.26 ± 1.34 b	87.81 ± 1.16 b
Mustard	31.87 ± 2.13 a	87.42 ± 1.02 b
Cleome	7.10 ± 0.38 d	58.39 ± 2.65 c
Tomato	1.41 ± 0.14 e	24.65 ± 3.66 d
Coriander	6.82 ± 0.45 d	54.57 ± 2.63 c

Means ± SE in the same column followed by the same alphabetical letter are not significantly different at (P=0.05) by SNK.

3.1.2. Effect of companion crops on survival and development of *P. xylostella* larvae

Muhaka culture moths showed significantly higher survival rate of the early instar (hatch through 2nd) on rape seed, although this was not significantly different (P>0.05) from kale (Table 6a). Cabbage, mustard and *Cleome* had significantly lower (P<0.05) survival rates than kale, while no survival was recorded on coriander or tomato. Similar trends were displayed by the percentage survival of 3rd through 4th instar *P. xylostella*. The developmental time of *P. xylostella* larvae was significantly longer on mustard and *Cleome* than on kale. Developmental time on rape seed and cabbage was not significantly different (P>0.05) from kale, while coriander and tomato did not support full larval development.

Table 6a: Larval survival and developmental time of *P. xylostella* larvae when reared on seven test plants (Muhaka culture).

Test plant	Percent larval survival at different larval stage		Developmental time(days) (hatch – pupation)
	Early instar (hatch – 2 nd)	Late instar (3rd – 4th)	
	Mean ± SE	Mean ± SE	Mean ± SE
Cabbage	77.30 ± 6.81 b	73.33 ± 6.45 b	12.88 ± 0.67 b
Kale	86.11 ± 7.10 a	83.11 ± 7.30 a	11.89 ± 0.56 b
Rape seed	87.67 ± 9.40 a	85.31 ± 6.89 a	12.34 ± 0.41 b
Mustard	59.11 ± 10.56 d	66.50 ± 5.71 c	15.56 ± 1.34 a
Cleome	68.78 ± 7.30 c	71.33 ± 7.10 bc	16.44 ± 0.41 a
Tomato	0.00 ± 0.00 e	0.00 ± 0.00 d	NFD
Coriander	0.00 ± 0.00 e	0.00 ± 0.00 d	NFD

Means ± SE in the same column followed by the same alphabetical letter (s) are not significantly different at (P=0.05) by SNK. NFD = no full development

Similar observations were recorded with the JKUAT culture moths which showed higher survival rates of the early instar (hatch through 2^{nd}) on kale and rape seed, although the two test plants were not significantly different (P>0.05) from cabbage (Table 6b). Mustard and *Cleome* had significantly lower (P<0.05) survival rates than cabbage, and no survival was recorded on coriander or tomato. Similar trends were also displayed in the percentage of survival of 3^{rd} through 4^{th} instar *P. xylostella*. Developmental time of *P. xylostella* larvae was significantly longer (P<0.05) on mustard and *Cleome* than on cabbage. Cabbage showed no significant differences (P>0.05) from kale or rape seed, and just as with the Muhaka culture moths, coriander and tomato did not support full larval development.

Table 6b: Larval survival and developmental time of *P. xylostella* larvae when reared on seven test plants (JKUAT culture).

Test plant	Percent larval survival at different larval stage		Developmental time (days) (hatch – pupation)
	Early instar (hatch – 2nd)	Late instar (3rd – 4th)	
	Mean ± SE	Mean ± SE	Mean ± SE
Cabbage	58.25 ± 7.21 a	79.21 ± 5.31 a	14.88 ± 0.67 b
Kale	63.34 ± 3.28 a	83.21 ± 3.22 a	14.89 ± 0.56 b
Rape seed	70.02 ± 5.21 a	85.31 ± 6.23 a	14.34 ± 0.41 b
Mustard	30.21 ± 2.33 b	39.45 ± 2.56 b	17.00 ± 1.34 a
Cleome	37.34 ± 3.12 b	33.21 ± 3.56 b	17.44 ± 0.41 a
Tomato	0.00 ± 0.00 c	0.00 ± 0.00 c	NFD
Coriander	0.00 ± 0.00 c	0.00 ± 0.00 c	NFD

Means ± SE in the same column followed by the same alphabetical letter are not significantly different at (P=0.05) by SNK. NFD = no full development

3.1.3. Effect of companion crop flowers on adult longevity and fecundity of *P.xylostella*

Male and female longevity of Muhaka culture population moths was significantly prolonged (P<0.05) when moths were fed on a mixture of honey water than on distilled water alone (Table 7a). Among the different test plant flowers tested, adult female and male longevity was higher on rape seed, although this did not show any significant differences (P>0.05) from mustard, *Cleome* or coriander. Fecundity results followed a similar trend as that of the adult longevity. Slight differences were observed when similar test plants were tested on the JKUAT culture moths (Table 7b). Longevity of adult males was significantly prolonged (P<0.05) when fed on mustard than on *Cleome* or rape seed, while fecundity was significantly ($P<0.05$) higher on coriander and *Cleome* than on mustard or rape seed.

Table 7a: Effect of companion crop flowers on the adult longevity and fecundity of *P. xylostella* (Muhaka culture).

Test plant	Adult longevity (Days ± SE)		Eggs laid per female
	Female	Male	
Corinader	9.78 ± 0.35 a	7.88 ± 2.78 a	125.63 ± 10.23 ab
Cleome	9.89 ± 0.64 a	7.45 ± 2.34 a	116.33 ± 8.92 ab
Mustard	9.64 ± 0.88 a	8.21 ± 0.23 a	133.03 ± 9.34 ab
Rape seed	10.41 ± 0.49 a	8.42 ± 2.19 a	140.25 ± 11.24 a
Water	7.50 ± 0.23 b	4.89 ± 0.34 b	75.75 ± 7.89 b
Honey water	11.25 ± 0.56 a	8.92 ± 0.35 a	152.89 ± 20.29 a

Means ± SE in the same column followed by the same alphabetical letter (s) are not significantly different at ($P=0.05$) by SNK.

Table 7b: Effect of companion crop flowers on the adult longevity and fecundity of *P. xylostella* (JKUAT culture).

Test plant	Adult longevity (Days ± SE)		Eggs laid per female
	Female	Male	
Corinader	10.78 ± 0.55 a	8.34 ± 2.25 ab	115.63 ± 9.23 a
Cleome	11.23 ± 0.65 a	7.55 ± 2.54 b	114.33 ± 8.05 a
Mustard	11.89 ± 0.78 a	9.33 ± 0.13 a	71.75 ± 5.34 b
Rape seed	10.59 ± 0.58 ab	7.43 ± 2.16 b	78.75 ± 9.24 b
Water	7.89 ± 0.25 c	5.33 ± 0.55 c	45.575 ± 5.89 c
Honey water	10.33 ± 0.56 b	8.20 ± 0.35 ab	117.33 ± 10.29 a

Means ± SE in the same column followed by the same alphabetical letter (s) are not significantly different at ($P=0.05$) by SNK.

3.1.4. Effect of olfactory stimuli from companion crops on *P. xylostella* adult responses

A significantly higher percentage of Muhaka culture moths showed upwind orientation to mustard, although there were no significant differences (P>0.05) from rape seed and kale (Table 8a). On the other hand, a significantly lower (P<0.05) percentage of the moths orientated to a pot of soil, which showed no significant differences from tomato. Percentage of moths landing on the test plants followed similar trends, except that no moths landed on tomato and the pot of soil. Latency of the first orientated flight to the pot of soil was longer than all other test plants, though not significantly different (P>0.05) from tomato. Latency for the first orientated flight to mustard was shorter than all others, though not significantly different (P>0.05) from rape seed and kale. Latency period for the first landing on coriander was longer, although not significantly different (P>0.05) from *Cleome*, while mustard recorded the shortest latency period for landing than all other test plants.

Slight differences were noted with the JKUAT culture moths in that a significantly higher (P<0.05) percentage showed upwind orientation to mustard than to all other test plants (Table 8b). A significantly lower (P<0.05) percentage orientated to a pot of soil (check), which however was not significantly different from tomato. A similar trend was observed for the percentage of moths landing on the test plants, except that there was no significant difference (P>0.05) between mustard and rape seed, and that no moths landed on the pot of soil. Latency for the first orientated flight towards the pot of soil was significantly prolonged (P<0.05), while that for mustard was significantly shorter (P<0.05) than all the other test plants. Latency for the first orientated landing was longer on tomato, although not significantly different from coriander and *Cleome*, while latency for first landing on mustard took a significantly shorter (P<0.05) period than all others.

Table 8a: Effect of olfactory stimuli from companion crops on orientation and landing of *P. xylostella* females and latency for the first orientated flight and landing (Muhaka culture).

Test plant	Orientation (%) to:	Landing (%) on:	Latency (in seconds) of first: Orientated flight	Latency (in seconds) of first: Landing
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Cabbage	42.34 ± 2.01 b	34.46 ± 6.02 b	31.88 ± 2.88 c	75.48 ± 10.48 b
Kale	53.12 ± 2.56 a	42.35 ± 6.37 ab	20.94 ± 3.86 cd	69.84 ± 8.12 b
Rape seed	56.67 ± 3.23 a	51.34 ± 5.87 a	18.44 ± 4.99 d	60.78 ± 8.37 b
Mustard	60.34 ± 5.56 a	50.84 ± 10.52 a	10.35 ± 2.98 d	50.89 ± 5.10 c
Cleome	16.51 ± 5.12 c	18.36 ± 6.64 c	60.69 ± 10.73 b	84.83 ± 9.27 a
Tomato	3.24 ± 2.31 d	0.00 ± 0.00 d	80.79 ± 11.98 a	NL
Coriander	12.37 ± 3.71 c	12.09 ± 4.01 c	63.90 ± 8.89 b	89.11 ± 8.87 a
Soil	1.01 ± 0.98 d	0.00 ± 0.00 d	87.35 ± 9.98 a	NL

Means ± SE in the same column followed by the same alphabetical letter (s) are not significantly different (P=0.05; t-test assuming equal variances). NL = No landing.

Table 8b: Effect of olfactory stimuli from companion crops on orientation and landing of *P. xylostella* females and latency for the first orientated flight and landing (JKUAT culture).

Test plant	Orientation (%) to:	Landing (%) on:	Latency (in seconds) of first:	
			Orientated flight	Landing
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Cabbage	32.28 ± 5.77 c	33.37 ± 5.52 c	41.22 ± 3.41 c	50.34 ± 4.37 b
Kale	41.33 ± 6.34 b	43.21 ± 7.24 b	32.87 ± 2.32 cd	48.27 ± 4.21 b
Rape seed	43.24 ± 6.25 b	57.17 ± 11.76 a	27.22 ± 2.71 d	48.34 ± 3.88 b
Mustard	57.87 ± 9.35 a	59.37 ± 13.28 a	15.33 ± 2.77 e	38.37 ± 3.27 c
Cleome	8.74 ± 5.38 d	21.27 ± 5.74 d	87.33 ± 4.27 b	57.33 ± 4.77 a
Tomato	1.37 ± 0.89 e	1.01 ± 0.01 e	97.27 ± 5.87 b	63.21 ± 5.21 a
Coriander	7.89 ± 5.27 d	18.78 ± 3.83 d	92.38 ± 4.77 b	59.41 ± 4.32 a
Soil	1.17 ± 0.69 e	0.00 ± 0.00 e	121.07 ± 7.33 a	NL

Means ± SE in the same column followed by the same alphabetical letter (s) are not significantly different (P=0.05; t-test assuming equal variances). NL = No landing.

3.2. Field studies on the relative attraction or repellence of companion crops to *P. xylostella* infestation

3.2.1. *P. xylostella* larval and pupal abundance and damage

Field trails set at the Muhaka Field Station failed due to poor crop establishment and very low *P. xylostella* infestations. This resulted into a shift to KARI-Matuga Field Station. The JKUAT long rains season trial also faced problems of very low infestations. Besides, cabbage in this trial established well while the companion crops in some plots did not establish properly. Therefore, these field results are based on trials conducted during one cropping season (short rains season) at JKUAT and KARI-Matuga Field Station.

Results from JKUAT revealed that unsprayed sole-cabbage had significantly higher ($P<0.05$) larval infestation than all the other test plants, though the late instar infestation was not significantly different from ($P>0.05$) cabbage-mustard (Table 9a). On the other hand, Dipel sprayed sole-cabbage test plants had the lowest larval infestation, which however was not significantly different ($P>0.05$) from cabbage-tomato test plants. A similar trend was observed for pupae except that infestation on the Dipel sprayed sole-cabbage was significantly lower ($P<0.05$) than all the others. Infestation on the five different companion plants interplanted with cabbage revealed that rape seed had a significantly higher ($P<0.05$) larval and pupal infestation than all the others, while tomato, coriander and *Cleome* recorded no significant differences ($P>0.05$).

Foliar damage rating followed a similar trend as for infestation on the intercropped cabbage, with the unsprayed sole-cabbage recording significantly higher (P<0.05) rating and the Dipel sprayed sole-cabbage recording significantly lower (P<0.05) rating than all the others. Among the cabbages interplanted with the companion crops, the cabbage-tomato had the lowest damage rating, although not significantly different (P>0.05) from the cabbage-rape seed and cabbage – coriander test plants.

Table 9a: Number of *P. xylostella* and foliar damage caused by *P. xylostella* larvae on cabbage interplanted with selected companion crops over a period of eight weeks (JKUAT-short rains season).

Test/companion plant	*P. xylostella* developmental stage on cabbage			Foliar damage rating
	Early instar (1st and 2nd)	Late instar (3rd and 4th)	Pupae	
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Sole cabb-unspr	2.76 ± 0.21 a	1.41 ± 0.14 a	0.48 ± 0.05 a	4.12 ± 0.27 a
Sole cabb Dipel spr	0.57 ± 0.07 e	0.20 ± 0.03 d	0.06 ± 0.01 d	1.11 ± 0.27 d
Cabb - mustard	2.03 ± 0.14 b	1.04 ± 0.07 ab	0.38 ± 0.03 b	3.57 ± 0.28 b
Cabb – rape seed	1.39 ± 0.08 d	0.89 ± 0.07 b	0.39 ± 0.03 b	2.78 ± 0.19 c
Cabb - *Cleome*	1.70 ± 0.22 c	0.91 ± 0.07 b	0.31 ± 0.03 bc	3.01 ± 0.24 b
Cabb - coriander	1.38 ± 0.12 d	0.76 ± 0.06 c	0.32 ± 0.05 bc	2.63 ± 0.14 c
Cabb - tomato	0.71 ± 0.09 e	0.56 ± 0.12 cd	0.27 ± 0.03 c	2.26 ± 0.08 c

Means in the same column followed by the same alphabetical letter (s) are not significantly different at (P = 0.05) by SNK. Cabb = cabbage, unspr = unsprayed, spr = sprayed. Damage rating: 1 = 0-10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, 9 = >81% (of leaf area with damage/lesions).

Table 9b: Number of *P. xylostella* on test/companion plants grown between cabbage over a period of eight weeks (JKUAT-short rains season).

Test/companion plant	*P. xylostella* developmental stage on companion crop		
	Early instar (1st and 2nd)	Late instar (3rd and 4th)	Pupae
	Mean ± SE	Mean ± SE	Mean ± SE
mustard	0.61 ± 0.05 b	0.35 ± 0.03 b	0.12 ± 0.02 b
Rape seed	0.90 ± 0.06 a	0.59 ± 0.04 a	0.23 ± 0.03 a
Cleome	0.00 ± 0.00 c	0.01 ± 0.01 c	0.01 ± 0.01 c
Coriander	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c
Tomato	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 c

Means in the same column followed by the same alphabetical letter are not significantly different at (P = 0.05) by SNK.

Results from KARI-Matuga Field Station were almost similar to those from JKUAT in that the unsprayed sole-kale supported significantly higher (P<0.05) larval and pupal infestations than all other test plants, while the Dipel sprayed sole-kale had the significantly lowest (P<0.05) infestation (Table 10a). Among the intercropped plots, kale-tomato recorded significantly lower (P<0.05) *P. xylostella* infestation than kale interplanted with the other test plants. Early instar, late instar and pupal abundance on companion plants revealed that rape seed had significantly higher (P<0.05) larval and pupal infestations, while tomato supported the lowest infestation levels among the companion plants (Table 10b). Damage ratings followed a similar trend as for the infestation on sole-kale. Kale-tomato had the lowest damage rating, although it was not significantly different (P>0.05) from kale-coriander.

Table 10a: Number of *P.xylostella* and foliar damage caused by DBM larvae on kale interplanted with selected companion crops over a period of ten weeks (Matuga-short rains season).

Test / companion plant	*P. xylostella* developmental stage on kale			Foliar damage rating
	Early instar (1st and 2nd)	Late instar (3rd and 4th)	Pupae	
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Sole kale-unspr	2.86 ± 0.03 a	1.92 ± 0.09 a	1.20 ± 0.06 a	2.11 ± 0.05 a
Sole kale Dipel spr	0.10 ± 0.02 f	0.11 ± 0.02 f	0.03 ± 0.01 f	1.10 ± 0.01 e
Kale - mustard	1.16 ± 0.06 bc	1.06 ± 0.06 b	0.51 ± 0.03 bc	1.47 ± 0.03 b
Kale - rape seed	1.23 ± 0.06 b	1.00 ± 0.06 bc	0.61 ± 0.04 b	1.43 ± 0.01 b
Kale - *Cleome*	0.98 ± 0.06 c	0.85 ± 0.06 c	0.45 ± 0.03 c	1.37 ± 0.03 c
Kale - coriander	0.65 ± 0.05 d	0.49 ± 0.05 d	0.40 ± 0.04 d	1.22 ± 0.02 d
Kale - tomato	0.44 ± 0.05 e	0.24 ± 0.03 e	0.14 ± 0.02 e	1.17 ± 0.02 d

Means in the same column followed by the same alphabetical letter (s) are not significantly different at (P = 0.05) by SNK. Unspr = unsprayed, spr = sprayed. Damage rating: 1 = 0-10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, 9 = >81% (of leaf area with damage/lesions).

Table 10b: Number of *P. xylostella* on test/companion plants grown between kale over a period of ten weeks (Matuga-short rains season).

Test / companion plant	*P. xylostella* developmental stage on companion crop		
	Early instar (Ist and 2nd)	Late instar (3rd and 4th)	Pupae
	Mean ± SE	Mean ± SE	Mean ± SE
mustard	1.16 ± 0.06 b	1.02 ± 0.05 b	0.53 ± 0.04 b
Rape seed	2.60 ± 0.14 a	1.76 ± 0.09 a	1.07 ± 0.06 a
Cleome	0.92 ± 0.06 c	0.84 ± 0.06 c	0.40 ± 0.03 c
Coriander	0.60 ± 0.05 d	0.46 ± 0.05 d	0.36 ± 0.04 c
Tomato	0.36 ± 0.04 e	0.20 ± 0.03 e	0.09 ± 0.01 d

Means in the same column followed by the same alphabetical letter are not significantly different at (P = 0.05) by SNK.

3.2.2. Yield of cabbage and kale

There was inconsistency in the assigning harvested cabbage heads and kale leaves to the various grade categories since what had the greatest weight in grade I had the least weight in grade III and vice verse. The number of cabbage heads and kale leaves in a given category could have affected the total weight. Overall, the total weight of harvested cabbages showed that the Dipel sprayed cabbage heads were significantly heavier ($P<0.05$) than all the others, except heads of cabbage interplanted with tomato (Table 11a). The unsprayed sole-cabbage heads were significantly lighter ($P<0.05$) than the rest. Weight of the harvested kale leaves followed a slightly different trend. The Dipel sprayed sole kale leaves had the greatest weight than all the others except kale from the kale-*Cleome*, kale – coriander and kale- tomato test plants (Table 11b).

Table 11a: Influence of companion cropping on the marketable yield of cabbage in relation to infestation by *P. xylostella* (JKUAT-short rains season).

Test/companion plant	Number of cabbage heads harvested per category			Mean weight of harvested cabbage heads per category (in kgs)			Total weight (in kgs/plot))
	Grade I	Grade II	Grade III	Grade I Mean ± SE	Grade II Mean ± SE	Grade III Mean ± SE	
Sole cabb-unspr	4	14	30	0.03 ± 0.06 d	0.20 ± 0.07 c	0.88 ± 0.07 a	**1.11 d**
Sole cabb Dipel spr	43	3	2	1.65 ± 0.07 a	0.69 ± 0.06 a	0.34 ± 0.05 c	**2.68 a**
Cabb - mustard	24	17	7	0.71 ± 0.06 c	0.51 ± 0.07 b	0.09 ± 0.07 d	**1.31 c**
Cabb – rape seed	35	9	4	0.88 ± 0.04 b	0.57 ± 0.07 b	0.47 ± 0.07 b	**1.92 b**
Cabb - *Cleome*	28	14	6	0.84 ± 0.05 b	0.50 ± 0.06 b	0.19 ± 0.07 cd	**1.53 c**
Cabb - tomato	39	5	4	1.50 ± 0.04 a	0.53 ± 0.06 b	0.28 ± 0.07 c	**2.31 ab**
Cabb - coriander	30	14	4	0.88 ± 0.07 b	0.73 ± 0.07 a	0.49 ± 0.06 b	**2.10 b**

Means in the same column followed by the same alphabetical letter (s) are not significantly different at (P = 0.05) by SNK. Cabb = cabbage, unspr = unsprayed, spr = sprayed. Grade I = slight/no feeding injury, Grade II = moderate injury, Grade III = severe damage.

Table 11b: Influence of companion cropping on the marketable yield of kale in relation to infestation by *P. xylostella* (Matuga-short rains season).

Test/companion plant	Number of kale leaves harvested per category			Mean weight of harvested kale leaves per category (in kgs)			Total weight (in kgs/plot))
	Grade I	Grade II	Grade III	Grade I	Grade II	Grade III	
				Mean ± SE	Mean ± SE	Mean ± SE	
Sole kale-unspr	21	37	37	0.15 ± 0.15 d	0.27 ± 0.11 b	0.46 ± 0.16 a	**0.95 b**
Sole kale Dipel spr	102	18	18	0.97 ± 0.01 a	0.19 ± 0.18 c	0.02 ± 0.28 c	**1.18 a**
Kale – mustard	64	36	36	0.50 ± 0.16 b	0.25 ± 0.18 b	0.23 ± 0.25 b	**0.98 b**
Kale – rape seed	52	43	43	0.37 ± 0.13 c	0.36 ± 0.20 a	0.22 ± 0.09 b	**0.88 c**
Kale - *Cleome*	73	39	39	0.60 ± 0.01 b	0.39 ± 0.16 a	0.19 ± 0.16 b	**1.08 ab**
Kale - tomato	97	28	28	0.86 ± 0.25 a	0.19 ± 0.01 c	0.09 ± 0.18 c	**1.16 a**
Kale - coriander	84	32	32	0.70 ± 0.21 b	0.25 ± 0.03 b	0.17 ± 0.11 b	**1.12 a**

Means in the same column followed by the same alphabetical letter (s) are not significantly different at (P = 0.05) by SNK. Unspr = unsprayed, spr = sprayed. Grade I = slight/no feeding injury, Grade II = moderate injury, Grade III = severe damage.

3.3. Effect of planting pattern on *P. xylostella* infestation

3.3.1. *P. xylostella* larval and pupal abundance and damage

The unsprayed sole-cabbage had significantly higher ($P<0.05$) infestation of early instar than all the other test plants grown in different patterns, while Dipel sprayed sole-cabbage had the lowest larval infestation, although not significantly different from cabbage in the 8:1 hill and 2:1 hill planting patterns (Table 12). A similar trend was observed in the case of infestation by late instar and pupae, except that the Dipel sprayed sole-cabbage had the lowest infestation that was not significantly different from cabbage in the 2:1 hill-planting pattern. Damage ratings followed a similar trend as for the pupae and late instar infestation.

3.3.2. Yield of cabbage

Just as in section 3.2.2, the grading scale used for grading the harvested cabbages showed inconsistencies since the pattern varied between the grades and the numbers of cabbage heads in a given grade category affected the total weight. Overall, the Dipel sprayed sole-cabbages had the greatest weight than all the others, except cabbages from the 8:1 hill and 2:1 hill planting patterns (Table 13). Heads from the unsprayed sole-cabbage were significantly lighter ($P<0.05$) than the rest.

Table 12: Number of *P. xylostella* and foliar damage on cabbage when grown with coriander in different planting patterns over a period of nine weeks (JKUAT- short rains season).

Planting pattern (cabbage : coriander)	*P. xylostella* developmental stage on cabbage			Foliar damage rating
	Early instar (Ist and 2nd)	Late instar (3rd and 4th)	Pupae	
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
2:1 row	1.23 ± 0.15 c	1.02 ± 0.11 d	0.35 ± 0.05 c	3.96 ± 0.26 bc
2:1 strip	1.66 ± 0.16 b	1.27 ± 0.10 cd	0.70 ± 0.04 b	4.26 ± 0.25 b
2:1 hill	0.22 ± 0.15 d	0.21 ± 0.11 ef	0.16 ± 0.03 cd	1.69 ± 0.15 d
8:1 row	1.52 ± 0.19 b	1.37 ± 0.11 c	0.64 ± 0.04 b	4.12 ± 0.16 b
8:1 strip	1.28 ± 0.16 c	0.53 ± 0.10 e	0.31 ± 0.03 c	2.97 ± 0.15 c
8:1 hill	0.18 ± 0.16 d	1.73 ± 0.12 b	0.84 ± 0.03 b	3.02 ± 0.25 c
Sole cabb unspr	2.63 ± 0.14 a	2.09 ± 0.10 a	1.24 ± 0.07 a	5.14 ± 0.26 a
Sole cabb Dipel spr	0.11 ± 0.07 d	0.12 ± 0.11 f	0.12 ± 0.12 d	1.54 ± 0.03 d

Means in the same column followed by the same alphabetical letter (s) are not significantly different at (P = 0.05) by SNK. Cabb = cabbage, Unspr = unsprayed, spr = sprayed. Damage rating: 1 = 0-10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, 9 = >81% (of leaf area with damage/lesions).

Table 13: Influence of different planting patterns on the marketable yield of cabbage in relation to infestation by *P. xylostella* (JKUAT-short rains season).

Test/companion plant	Number of cabbage heads harvested per category			Mean weight of harvested cabbage heads per category (in kgs)			Total weight (in kgs/plot))
	Grade I	Grade II	Grade III	Grade I	Grade II	Grade III	
				Mean ± SE	Mean ± SE	Mean ± SE	
2:1 row	32	12	4	1.15 ± 0.15 b	0.08 ± 0.01 a	0.02 ± 0.02 c	**1.25 b**
2:1 strip	30	15	3	0.72 ± 0.16 c	0.11 ± 0.01 a	0.01 ± 0.01 c	**0.84 c**
2:1 hill	38	5	5	1.27 ± 0.01 ab	0.02 ± 0.02 b	0.08 ± 0.03 c	**1.37 ab**
8:1 row	26	15	7	0.35 ± 0.01 c	0.10 ± 0.01 a	0.15 ± 0.03 b	**0.60 c**
8:1 strip	28	14	6	0.63 ± 0.13 c	0.08 ± 0.01 a	0.05 ± 0.01 c	**0.76 c**
8:1 hill	35	10	3	1.22 ± 0.25 b	0.08 ± 0.01 a	0.06 ± 0.01 c	**1.36 ab**
Sole cabb unspr	5	10	33	0.01 ± 0.01 d	0.02 ± 0.02 b	0.43 ± 0.02 a	**0.46 d**
Sole cabb Dipel spr	40	7	1	1.42 ± 0.21 a	0.02 ± 0.02 b	0.03 ± 0.01 c	**1.47 a**

Means in the same column followed by the same alphabetical letter (s) are not significantly different at (P = 0.05) by SNK. Unspr = unsprayed, spr = sprayed. Grade I = slight/no feeding injury, Grade II = moderate injury, Grade III = severe damage.

3.4. Effects of companion crops on non-target insects and plant diseases

3.4.1. Effect on the level of *P. xylostella* parasitism in the field

Observations made from larvae collected on cabbages at JKUAT showed that larvae collected from cabbage-rape seed had a significantly higher ($P<0.05$) parasitism rate than the others, except larvae from cabbage-coriander (Table 14). Larvae collected from the cabbage-*Cleome* plot had significantly the lowest ($P<0.05$) parasitism rate, though not significantly different from larvae collected from the cabbage-tomato, cabbage-mustard and the Dipel-sprayed sole cabbage. Percent mortality due to diseases was highest in larvae from cabbage-mustard, although not significantly different ($P<0.05$) from the level in cabbage-tomato and cabbage-rape seed. The unsprayed sole-cabbage had significantly the lowest ($P<0.05$) percent mortality level due to diseases. Mortality due to other factors was highest in larvae collected from the cabbage-mustard than all the others, except larvae collected from unsprayed sole-cabbage and cabbage-*Cleome*. Overall percent mortality due to parasitism, diseases and other factors was significantly higher ($P<0.05$) in larvae from cabbage-rape seed, while larvae from Dipel sprayed sole-cabbage had the lowest level of total mortality, though not significantly different ($P>0.05$) from larvae collected from cabbage-*Cleome* and cabbage-tomato.

Table 14: Effect of companion crops on *P. xylostella* larval mortality (JKUAT-short rains season).

Test/companion plant	Percent mortality level due to: Parasitism	Diseases	Other factors	Total mortality
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
S- cabb-unspr	22.63 ± 5.36 b	4.47 ± 1.94 c	3.64 ± 1.52 a	30.73 ± 5.52 b
S- cabb Dipel spr	10.50 ± 2.35 bc	9.50 ± 2.46 b	1.00 ± 0.69 c	21.00 ± 2.89 c
Cabb - mustard	15.88 ± 3.83 bc	14.46 ± 3.61 a	4.00 ± 1.52 a	34.34 ± 5.19 b
Cabb - rape seed	35.26 ± 7.51 a	10.53 ± 2.81 ab	2.11 ± 1.23 b	47.89 ± 9.35 a
Cabb - *Cleome*	8.16 ± 3.09 c	9.47 ± 5.27 b	3.42 ± 1.71 a	21.05 ± 6.25 c
Cabb - tomato	13.63 ± 3.26 bc	13.75 ± 5.99 a	1.50 ± 0.82 c	28.88 ± 6.34 bc
Cabb - coriander	26.99 ± 5.74 ab	9.41 ± 5.64 b	1.05 ± 0.72 c	37.45 ± 9.02 b

Means in the same column followed by the same alphabetical letter (s) are not significantly different at (P = 0.05) by SNK. S-cabb-unspr = sole-cabbage unsprayed, S-cabb Dipel spr = sole-cabbage Dipel sprayed, Cabb = cabbage.

3.4.2. Effect on other insects found on cabbage

Besides *P. xylostella* attacking the cabbages at JKUAT, other insects were also observed on the plants. Cabbage interplanted with *Cleome* recorded a significantly higher (P<0.05) rating for aphids than all the others (Table 15). On the other hand, cabbage interplanted with coriander had the lowest rating, although not significantly different (P>0.05) from cabbage-tomato and Dipel sprayed sole cabbage. A significantly higher (P<0.05) rating for caterpillars was recorded on cabbage ineterplanted with mustard than all the others, while cabbage interplanted with coriander had the lowest rating though not significantly different (P>0.05) from cabbage-tomato, cabbage-rape seed and Dipel sprayed sole-cabbage. Beetles recorded no significant differences (P>0.05) between all the test plants.

Table 15: Effect of companion crops on infestation by other insects present on cabbage (JKUAT-Short Rains Season).

Test / companion plant	Scores of other insects		
	aphids	Caterpillar except *P. xylostella*	beetles
	Mean ± SE	Mean ± SE	Mean ± SE
Sole cabbage-unsprayed	1.77 ± 0.06 b	1.39 ± 0.05 b	1.09 ± 0.02 a
Sole cabbage Dipel sprayed	1.13 ± 0.02 d	1.01 ± 0.01 c	1.06 ± 0.02 a
Cabbage – mustard	1.46 ± 0.04 c	1.65 ± 0.07 a	1.00 ± 0.00 a
Cabbage – rape seed	1.45 ± 0.05 c	1.03 ± 0.01 c	1.00 ± 0.00 a
Cabbage – *Cleome*	2.03 ± 0.08 a	1.43 ± 0.05 b	1.00 ± 0.00 a
Cabbage – tomato	1.08 ± 0.02 d	1.01 ± 0.00 c	1.00 ± 0.00 a
Cabbage – coriander	1.00 ± 0.00 d	1.00 ± 0.00 c	1.00 ± 0.00 a

Means in the same column followed by the same alphabetical letter are not significantly different at (P = 0.05) by SNK. (see rating scale on page 38).

3.4.3. Effect on important plant diseases of cabbage

The common plant diseases observed on cabbage at JKUAT were black rot, soft rot and powder mildew (Table 16). The unsprayed sole-cabbage recorded significantly higher ($P<0.05$) disease rating for black rot than the others while cabbage-tomato had the lowest rating, though not significantly different ($P>0.05$) from cabbage-coriander, cabbage-*Cleome*, cabbage-rape seed and Dipel sprayed sole-cabbage. The unsprayed sole cabbage recorded a significantly higher ($P<0.05$) rating for soft rot disease while Dipel sprayed sole cabbage had significantly the lowest ($P<0.05$) rating than the others. Cabbage-mustard recorded a significantly higher ($P<0.05$) rating for powdery mildew than all the others, which were not significantly different ($P>0.05$) from each other.

Table 16- Effect of companion crops on plant diseases of (JKUAT-Short Rains Season).

Test / companion plant	Scores of plant diseases		
	Black rot	Soft rot	Powdery mildew
	Mean ± SE	Mean ± SE	Mean ± SE
Sole cabbage unspr	2.11 ± 0.05 a	2.10 ± 0.05 a	1.18 ± 0.02 b
Sole cabbage Dipel spr	1.27 ± 0.02 c	1.09 ± 0.01 d	1.00 ± 0.00 b
Cabbage- mustard	1.86 ± 0.05 b	1.99 ± 0.04 b	1.49 ± 0.03 a
Cabbage - rape seed	1.30 ± 0.03 c	1.23 ± 0.02 c	1.00 ±0.00 b
Cabbage - *Cleome*	1.39 ± 0.03 c	1.18 ± 0.03 c	1.00 ± 0.00 b
Cabbage - tomato	1.06 ± 0.01 c	1.26 ± 0.03 c	1.03 ± 0.01 b
Cabbage - coriander	1.15 ± 0.02 c	1.26 ± 0.02 c	1.00 ± 0.00 b

Means in the same column followed by the same alphabetical letter are not significantly different at (P = 0.05) by SNK. Unspr = unsprayed, Spr = sprayed. Disease rating: 1 = clean (no disease), 2 = moderate (one to two whole leaves attacked by disease) and 3 = severe (more than two whole leaves attacked by disease).

CHAPTER : 4

4.0. DISCUSSION

4.1. Effect of companion crops on *P. xylostella* infestation

Both laboratory choice and no-choice tests indicated that mustard and rape seed seemed to be the preferred oviposition hosts for *P. xylostella*, compared to the rest of the test plants, except for the JKUAT culture moths which significantly preferred mustard to rape seed in the no-choice test. These preference results are consistent with previous laboratory and field demonstrations on the high susceptibility of mustard for oviposition by *P. xylostella* (Raini, 2002; Charleston and Kfir, 2000; Andrahennadi and Gillot, 1998; Srinivasan and Krishna Moorthy, 1992). In this study, field results showed that Ethiopian mustard and rape seed attracted *P. xylostella* and other crucifer pests, thereby drawing them away from cabbage and kale. *P. xylostella* has been reported as showing a distinct preference for mustard for oviposition. This attractance and oviposition stimulant property of mustard has been attributed to the effect of volatile compounds such as isothiocyanates released by the mustard plants (Srinivasan and Krishna Moorthy 1991). This could offer a similar explanation as for the case of rape seed, which also contains similar volatile compounds. The continuous presence of mustard and rape seed foliage, which was significantly attractive than cabbage or kale foliage, facilitated oviposition by resident and immigrant moths, thus sparing the main crop (cabbage and kale) from attack.

In another choice test, investigations on oviposition behavior demonstrated that the number of eggs laid on test plants in treatments comprising of cabbage or kale combined with either tomato, *Cleome* or coriander were significantly reduced when compared with eggs laid on sole-cabbage or sole-kale. This agrees with field results from this study, whereby it was observed that intercropped cabbage and kale had significantly lower numbers of *P. xylostella* larvae and pupae as compared to the control (pure stand) unsprayed cabbage or kale plots. Talekar *et al.,* (1986) also reported a similar trend of fewer *P. xylostella* larvae and pupae when cabbage was intercropped with several other plant species compared with cabbage monocultures. In both choice and no-choice tests, *P. xylostella* showed low preference towards tomato and cabbage or kale combined with tomato than to the other test plants, whereas in the field, tomato exhibited the greatest deleterious effect on pest populations than *Cleome* and coriander, as low *P. xylostella* infestations were observed on cabbage and kale interplanted with tomato. The infestation was not significantly different from the Dipel sprayed sole cabbage and kale. It is possible that tomato, *Cleome* and coriander, which were used as potentially repellent test plants, must have camouflaged the host plants.

However, eggs were still laid on these three test plants in the laboratory and this contrasts with field results that showed that no P. xylostella was recorded on them. One possible explanation for the contradictory laboratory results in this study is that some plants like tomato may affect long-range host finding (Stanton, 1983), which would be an important factor in the field but not in the small cages used in the laboratory experiments. Alternatively, the plants may affect the survival of eggs and small larvae, perhaps by altering predation levels, microclimate or other factors.

Host plant allelochemicals are also thought to influence host location and oviposition by the pest, as well as host location by parasitoids (Idris and Grafius, 1996). Oviposition on excised leaves may differ considerably from oviposition on intact leaves (Andrahennadi and Gillot, 1998). In an experiment with excised leaves, Verkerk and Wright (1996) observed that the differences in the allelochemical environment may significantly alter the oviposition rate on a single host plant cultivar. Nevertheless, oviposition-choice tests using leaf discs permit the rapid screening of large numbers of genotypes for potential sources of resistance to pest attack (Harris and Miller, 1988). In this study, detached test plant leaves were used hence this may explain the differences between the number of *P. xylostella* on test plants in the field and in the laboratory.

The tomato influence in reducing *P. xylostella* infestations and damage to the intercropped cabbage or kale corroborated the reports by Buranday and Raros (1973) and Sivapragasam *et al*., (1982). Similarly, garlic in interrows of cabbage also has been reported to decrease *P. xylostella* numbers (Talekar *et al*., 1986). The confusing olfactory and visual cues received from host and non-host plants, leading to disruption of mating, are believed to be partly responsible for the reduction in larval numbers, while the reduction in oviposition and subsequent development of the pest was essentially due to the emission of volatile compounds which have a repellent action on the adult moths. Studies have also shown that certain compounds in tomato leaf extract adversely affect oviposition of *P. xylostella* on cabbage and Chinese cabbage (Gupta and Thorsteinson, 1960). It is possible that similar compounds in *Cleome* and coriander repel the adult *P.*

xylostella and hence reduce their infestation. Previous studies have also indicated that coriander has also been effectively used as a companion crop in reducing incidence of various pests and as an alternative resource fauna for hoverflies.

Previously published results on *P. xylostella* and intercropping have been rather variable. However, in studies where the companion crop may have hidden the host plants, significant reductions in egg and larval density were found (Horn, 1987; Theunissen and Schelling, 1996; Finch and Kienegger, 1997). In a study where no larval reductions was found with companion plants of several different species (Latheef and Irwin, 1979), companion plants were grown around the perimeter of the plots containing cabbage and thus could not visually hide the crop. The mechanism of visual camouflage, host plants hidden by taller non-host plants (Finch, 1996), seems to explain the reduction in *P. xylostella* oviposition. There is no scientific evidence that odors from highly aromatic plants can actually deter pest insects. This is consistent with studies done which have conclusively shown that though insects colonize monocultures and polycultures to the same extent, there is a higher emigration rate from an intercrop compared with a monoculture (Ramert and Ekbom, 1996; Roda *et al*., 1997).

4.2. Effect of companion crops on survival and development of *P. xylostella*

Optimality theory stipulates that ovipositing females should choose plant species that maximize larval fitness (Thompson and Pellmyr, 1991; Barker and Maczka, 1996). Laboratory no-choice studies showed that *P. xylostella* exhibited a significantly higher survival rate on rape seed, kale and cabbage. Interestingly, there was a low survival rate of *P. xylostella* on mustard and *Cleome*. This is contrary to the oviposition tests, which showed mustard to be a highly preferred oviposition site. No larvae reared on coriander or tomato survived beyond first instar. Infact, it was observed that most first instar *P. xylostella* larvae refused to feed or stayed away from coriander and tomato leaves. This indicates the presence of antifeedants in the leaves of coriander and tomato. Although *Cleome* differed significantly with mustard in the oviposition laboratory tests, it is interesting to note that larvae reared on these two plants successfully developed to adults, although their development time was significantly prolonged. It is possible that in the field conditions, this effect could expose individual larva longer to parasitism by *Diadegma* species, *P. xylostella*'s larval major parasitoid. *P. xylostella* is reported to prefer *Brassica* species as host plants but also utilizes other members of the Brassicaceae family, which contain glucosinolates that degrade into volatile mustard oils. Some members of this diverse plant group are cultivated as crops but others are considered to be weeds (Talekar and Shelton, 1993). In this study, development of *P. xylostella* was noted on *Cleome*, which is a non-brassicaceous plant. It is possible that such a non-brassica plant could be containing one or more of the specific feeding stimulants for *P. xylostella,* but might also contain feeding inhibitors (Gupta and Thorsteinson, 1960) or some of the feeding stimulants could be occurring in high concentrations which makes the plant toxic to *P. xylostella* (Nayar and Thorsteinson, 1963).

The results show clearly that there is a poor correlation between oviposition preference and larval survival and development on Ethiopian mustard, and this may be explained by a variety of factors. Ovipositing females may prefer host plants that are sub-optimal but that are not visited by some of their natural enemies, therefore providing enemy-free space (Fox and Eisenbach, 1992; Gratton and Welter, 1998). Results from another study (Fox and Eisenbach, 1992) indicated that parasitoid searching behavior and *P. xylostella* oviposition preferences were opposite, with *P. xylostella* preferring plants of low nutritional quality on which they escape natural enemies. Therefore, it is possible that female moths in this study were selecting mustard as an enemy-free space.

Some aspects of the relationship between preference and performance may also be a consequence of physiological factors such as leaf wax characteristics, which are believed to influence oviposition (Spencer, 1996). Glossy leaves have a reduced wax load (Andrahennadi and Gillot, 1998; Stoner, 1992; Eigenbrode and Shelton, 1992), which improves the adhesiveness of eggs (Uematsu and Sakanoshita, 1989), but reduces larval survival (Eigenbrode and Shelton, 1992), and increases predation on *P. xylostella* (Eigenbrode *et al*., 1995). The surface of glossy plants is dark green and shiny compared to the bluish-white haze on the surface of plants with normal leaf wax. In this study, low survival of *P. xylostella* larvae on mustard in the laboratory as compared to the high oviposition preference in the laboratory possibly indicates that mustard has a reduced wax load, which may play an important role. Furthermore, studies by Eigenbrode and Pillai (1998) have determined that the presence of deterrent compounds in leaf waxes may deter feeding in *P. xylostella* larvae, hence this could also have been the case with mustard and *Cleome,* which also recorded low survival rates.

4.3. Effect of companion crops on adult longevity and fecundity of *P. xylostella*

Moths fed on nectar from flowers of *Cleome*, coriander, mustard and rape seed and on honey water solution showed no significant differences in the adult longevity, except for the JKUAT culture male moths whose adult longevity was significantly increased when fed on mustard, coriander or honey water than on the other test plant flowers and distilled water. Fecundity was significantly increased in moths fed on honey water diet than on distilled water alone. It is possible that the distilled water definitely lacks the food qualities to bring forth-robust generations. Thus, nectar from companion crop flowers has a positive effect on the adult longevity and fecundity of *P. xylostella*.

4.4. Effect of planting pattern on *P. xylostella* infestation

The trial conducted at JKUAT involving different planting patterns of both cabbage and coriander indicated that *P. xylostella* infestations recorded among cabbages in the 2:1 planting patterns (row, strip and hill) was lower as compared to the 8:1 planting patterns (row, strip and hill), including the unsprayed sole cabbage. Dipel sprayed cabbage had the significantly lowest infestation than all the other planting patterns. The overall reduction in *P. xylostella* larvae can be attributed to combined effects of planting pattern and the volatile substances present in coriander, which could have disrupted settling by the moths and inhibited their oviposition. The planting pattern of 2:1 hill and 8:1 hill had coriander plants scattered all over the plot and it is possible that this might have resulted into the insects frequently encountering with the coriander non-host plants and thus resulting into a higher emigration rate from the intercropped plots as compared to the control (unsprayed sole-cabbage).

These results clearly support the second part of the disruptive crop hypothesis, which stipulates that after having found a host plant, the herbivore is more likely to leave the patch because of the frequent encounters with non-host plant individuals. In many cases, it has been shown that insects colonize monocultures and polycultures to the same extent, but there is a higher emigration rate from an intercrop compared with a monoculture (Ramert and Ekbom, 1996; Roda *et al*, 1997). The spreading foliage of the full-grown coriander plants must have also hidden the cabbage from moths and thus reduced oviposition. Other plants have been intercropped with cabbage in different planting patterns and have given variable results. For instance, Srinivasan (1984) conducted experiments involving different combinations of cabbage-tomato intercropping in Bangalore. He reported that there was no reduction in the incidence of *P. xylostella* larvae when different combinations of cabbage and tomato were planted at the same time. According to his study however, a planting pattern of 1:1 cabbage and tomato (the cabbage planted 30 days later than the tomato), attracted greater reduction of *P. xylostella* larvae on cabbage.

4.5. Effect of companion crops on non-target Fauna

In the field where this study was conducted, there exists natural enemies such as predators, parasites and pathogens, which must have contributed to the overall results obtained on *P. xylostella* infestation. Higher parasitism rates were noted on *P. xylostella* collected from cabbage interplanted with rape seed as compared to larvae collected from the control sole-cabbage plot. These results agree with those from other studies that have compared parasitism rates in monocultures and polycultures (Sheenan, 1986), but contrasts with results of Horn (1987), who reported higher parasitism rates of *P. xylostella* in tilled collard plots than in collard plots with weeds. Among *P. xylostella* collected from different intercropped plots, varying rates of parasitism were recorded and this clearly indicates that different plants could have significant effects on parasitism success (Talekar and Yang, 1991).

This study also revealed that the companion crops tested had an added potential to attract aphids and other caterpillar pests. Significantly higher larval densities of aphids and caterpillars were observed on cabbages interplanted with *Cleome* and cabbage interplanted with mustard, respectively, than the rest of the test plants. It is possible that *Cleome* could have attracted high aphid numbers that might have spilled onto cabbage in the same plot. The rate of infestation on cabbage heads by beetles was low and evenly distributed among the test plants. The beetles were probably attracted to both aphids and pollen on companion test crops because these are important food sources.

The common plant diseases noted on cabbage included the bacterial diseases; black rot (caused by *Xanthomonus campestris*) and soft rot (caused by *Erwinia carotovora*), and a fungus disease powdery mildew (caused by *Erysiphe polygoni*). Cabbages in all plots showed symptoms of these diseases although black rot and soft rot were more pronounced in the control (unsprayed) cabbage plots. It is possible that the disease symptoms on the marketable part of the plant affected the quality of cabbages harvested.

4.6. Effect of companion cropping on yield

Intercropped cabbage and kale had higher yield of good quality as compared to the sole-cabbage and kale unsprayed plots. Thus, in vegetable growing, quality usually is more important for the financial result than quantity. In this study, unsprayed sole-cabbage heads and sole-kale leaves were lighter and less marketable and this leads to a gross financial result that is favorable to intercropping. Highest marketable yields were recorded for the Dipel sprayed sole cabbage and kale. Comparing weights of cabbage heads and kale leaves from the Dipel sprayed plots with those from the intercropped plots, it appears that intercropping means loss of weight in the vegetable crops. From an implementation point of view, this must be compensated by increased quality. The bottom line thus seems to be to trade quantity for quality. In systems where achieving maximal quantity is not the primary goal, this could be an economically viable option. Optimization of intercropping systems must therefore provide data for assessing economic prospects (Theunissen *et al.,* 1995).

Apart from the weight and external quality, it is most likely that intercropping has more effects on the morphology and development of the cabbage plants. Although data were not collected on plant size, the heads from the plots with companion crops looked consistently smaller but more compact, and this could play a role in their sensitivity to pest attack (Theunissen *et al.,* 1995). The cabbage heads may also have differed in nutritional quality from those from the sole-cabbage unsprayed plot. Results of the statistical comparisons, however, showed conclusively that these potential indirect effects did not influence *P. xylostella* infestations.

CHAPTER 5

5.0. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

In conclusion, companion crops strongly affected *P. xylostella* infestation on both the main crops and companion crops and pest damage. Ethiopian mustard and rape seed have great potential as attractant crops for *P. xylostella* while tomato, coriander and *Cleome* have the potential as repellent crops for the pest. This study shows that tomato and rape seed serve as the most promising repellent and attractant companion crops respectively, for *P. xylostella*. It is worth noting that the companion crops used in this study have the potential to attract other insect pests and plant diseases, which in the end may damage the main crop. However, intercropped plots attracted the natural enemies of *P. xylostella* and this played a vital role in reducing pest infestations.

The various cabbage-coriander planting patterns revealed that two rows of cabbage can be successfully interplanted with one row of coriander (given that coriander is scattered throughout the hills within a plot) to manage *P. xylostella* infestations. Overall, interplanting reduced densities of *P. xylostella*, but it did not reduce overall early-season pest damage. Direct effects of companion crops were more important than indirect effects of host size and quality in influencing pest infestations. If direct effects also are more important than indirect effects in other agricultural systems, then it would suggest that benefits from interplanting in terms of reducing pest numbers more likely result from the direct presence of non-host plant species than from indirect effects of non-host plants on host plant size or quality.

If companion crops are to be used as attractant or repellent plants for the purposes of reducing insect pest infestations, then they must satisfy a number of important conditions:

1. They must cause the required 'intercropping effects' in terms of pest population suppression.
2. Competition with the main crop should be minimal.
3. They must not create a weed problem in the next cropping season.
4. They must be predictable and manageable within the normal cropping pattern.
5. The seeds must be commercially available in sufficient quantities.
6. They must not generate or stimulate other pests or diseases.
7. Leaching of important soil elements (nutrients) must be prevented or reduced.

It is important to note that the above-described studies were conducted to evaluate the effect of companion crops in managing *P. xylostella*. However, it must be remembered that these trials were carried out both in the laboratory and on farm. In the open field, natural enemies such as predators, parasites and pathogens of *P. xylostella* exist. The role of these natural enemies was quantified in the above-mentioned studies, and they definitely must have contributed to the overall results obtained, in the control of *P. xylostella* in the experimental plots. Furthermore, in the trials at JKUAT, overhead sprinkler irrigation was used, as is the normal practice on the University farm. In the case of *P. xylostella*, this type of irrigation has been shown to have a significantly negative effect on *P. xylostella* populations by causing the eggs and larvae to be dislodged and washed off the plant and to drown. Overhead sprinkler irrigation also disrupts adult flight, mating and oviposition (Talekar *et al.*, 1986). Thus, in the experiments designed to study the effects of companion crops on *P. xylostella*, in actual fact, the Integrated Pest Management strategy comprised of the application of biological control and cultural practices (companion cropping and overhead sprinkler irrigation). The satisfactory results obtained with this combination suggest that this Integrated Pest Management strategy could be used as a base on which to develop an improved and more comprehensive Integrated Pest Management package through the incorporation of some selected measures.

5.2. RECOMMENDATIONS

The following suggestions and recommendations can be made from this study;

- Ethiopian mustard and rape seed can be successfully used as attractant crops for *P. xylostella*, while *Cleome*, coriander and tomato can be used as repellent crops.
- Before Ethiopian mustard, rape seed, *Cleome*, coriander and tomato can be recommended as diamondback moth attractant or repellent crops in Kenya, further investigations on their potential of attracting *P. xylostella* parasitoids in the field situations are required.
- Studies on the effect of these companion crops on competition with the main crops for soil nutrients and other environmental factors should be conducted.
- For the purposes of large-scale farming, further studies on the effect of companion crops on crop pests should take into consideration the role of the irrigation method used and biological control agents in the field, in reducing pest population.
- Tomato and rape seed could be intercropped with cabbage or kale in different row ratios and planting patterns to determine the effect of this on pest numbers.
- Studies on olfactory and other host location cues used by the key parasitoids of *P. xylostella* should be conducted to determine whether certain host plants or cultivars are more attractive to particular key parasitoids.

6.0. REFERENCES

Altieri, M.A. and Letourneau D.K. (1982) Vegetational management and biological control in agroecosystems. *Crop Prot.*, **1** : 405-430.

Andow, D. (1991) Vegetational diversity and arthropod population response. *Annu. Rev. Entomol.*, **36** : 561-86.

Andrahennadi, R. and Gillot, C (1998) Resistance of *Brassica*, especially *B. juncea* (L.) Czern., genotypes to the diamondback moth, *Plutella xylostella* (L.). *Crop Prot.*, **17** : 85-94.

Andrews, D.J. and Kassam, A.H. (1976) The importance of multicropping in increasing world food supplies, pp. 1-10. In: R.I. Papendick, P.A. Sanchez and G.B. Triplett (eds.), Multiple Cropping. Special publication 27. American Society of Agronomy, Madison, WI.

Andrews, K.L., Sanchez R.J. and Cave R.D. (1992) Management of Diamondback moth in Central America. Pp 487-497. In: N.S. Talekar (ed). Management of Diamondback moth and other crucifer pests. Proc. 2nd Internat. Workshop, Shanhua, Taiwan; AVRDC.

Anonymous (1981) Proceedings of the International Workshop on Intercropping, 10-13 January 1979, Hyderabad, India, Pantacheru, AP, India: ICRISAT.

Anyango, J.J., Cooper, J., Smith, D. and Wangendo, L. (1994) Report on the scope for improving pest management and pesticide use in horticultural crops grown by smallholder farms in Kenya. NRI. UK.

Arkin, G.F. and Taylor, H.M. (Eds.). (1981) Modifying the root environment to reduce crop stress. Amer. Soc. Agr. Engr., St. Joseph, M.I. 407 pp.

AVRDC (1985) 1984 Progress Report. Asian Vegetable Research and Development Center, Shanhua, Taiwan, ROC.

AVRDC (1988) 1986 Progress Report. Shanhua, Taiwan: Asian Vegetable Research and Development Center.

Baker, P.B., Shelton, A.M. and Andalaro, J.T. (1982) Monitoring of diamondback moth (Lepidoptera:Yponomeutidae) in cabbage with pheromones. *J. Econ. Entomol.*, **75** : 1025-1028.

Ballidawa, C.W. (1985) Plant species diversity and crop pest control. *Ins. Sci. Applic.*, **6** : 479-487.

Barker, A.M. and Maczka, C.J.M. (1996) The relationship between host selection and subsequent larval performance in three free-living graminivorous sawflies. *Ecol. Entomol.*, **21**: 317-327.

Bhalla, O.P. and Dubey, J.K. (1986) Bionomics of the diamondback moth in the Northwestern Himalaya. Proc. 1st Internat. Workshop, Tainan, Taiwan, 11-15 March, 1985 Shanhua, Taiwan; AVRDC, 55-61.

Buranday, R.P. and Raros R.S. (1973) Effects of cabbage-tomato intercropping on the incidence and oviposition of the diamond back moth, *Plutella xylostella* (L.). *Philipp. Entomol.*, **2** : 369-374.

Bytinski-Salz, H. (1965) Effects of modern agrotechnical methods on the agricultural insect populations in Israel. Proc. XII Int. Congr. Ent (London 1964). 583pp.

Charleston D.S. and Kfir R. (2000) The possibility of using Indian mustard, *Brassica juncea*, as a trap crop for the diamondback moth, *Plutella xylostella*, in South Africa. *Crop Prot.*, **19** : 455-460.

Chelliah, S. and Srinivasan, K. (1986) Bioecology and management of diamondback moth in India. Diamondback Moth Management. Proc. 1st Internat. Workshop, Tainan, Taiwan, 11-15 March, 1985., 63-76; [3 fig.]; 50 ref.

Chow, Y.S., Lin, M.Y. and Hsu, C.L. (1977) Sex pheromone of diamondback moth (Lepidoptera:Plutellidae). *Bull. Inst. Zool. Acad. Sin.* **16** : 99-105.

Chua, T.H. and Lim, B.H. (1977) Effect of interplant distance on the distribution pattern of diamondback moth, *Plutella xylostella* (L.) among host plants. *Malay. Appl. Bio.*, **6** (1): 19-23.

Eigenbrode S.D. and Shelton A.M. (1992) Resistance of diamondback moth in Brassica: Mechanism and potential for resistant cultivars. In: Diamondback moth and other Crucifer Pests: Proc. 2nd Internat. Workshop, December, 1990, Tainan, Taiwan, Shahua, Asian vegetable Research and Development, pp.65-74.

Eigenbrode S.D., Moodie, S. and Castagnola, T. (1995) Predators mediate host-plant resistance to a phytophagous pest in cabbage with glossy leaf wax. *Entomol. Exp. Appl.*, **77** : 335-342.

Eigenbrode, S.D. and Pillai, S.K. (1998) Neonate *Plutella xylostella* responses to surface wax components of a resistant cabbage (*Brassica oleracea*). *J. Chem. Ecol.*, **24** (10): 1611-1628.

England, S. and Evans, E.W. (1997) Effects of pea aphid (Homoptera: Aphididae) honeydew on longevity and fecundity of the alfaalfa weevil (Coleoptera:

Cuculionidae) parasitoid *Bathplectes curculionis* (Hymenoptera: Ichneumonidae). *Environ. Entomol.*, **26** : 1437-41.

Facknath, S., Lalouette, T.A. (ed), Bachraz, Y. (ed), Sukurdeep, N. (ed) and Seebaluck, B. (1998) Integrated pest management of *Plutella xylostella* an important pest in crucifers in Mauritius. In: Proc. 2nd annual meeting of agricultural scientists, Reduit, Mauritius,11-13 August 1997. 1998, 103-108; 17ref.

Farrell, G., Kibata, G.N. and Sutherland, J.A. (1995) A Review of Crop Protection Research in Kenya. KARI-ODA Crop Protection Project KARI, Kenya, 165pp.

Feeny, P. (1976) Plant apparency and chemical defense. Recent advances in Phytochemistry. **10** : 1-49.

Finch, S. (1996) "Appropriate/inappropriate landing", a mechanism for describing how undersowing with clover affects host-plant selection by pest insects of brassica crops, IOBC/WPRS Bull., **19** (11): 102-106.

Finch, S. and Kienegger, M. (1997) A behavioural study to help clarify how undersowing with clover affects host-plant selection b pest insects of brassica crops. *Entomol. Exp. Appl.*, **84** : 165-172.

Fox, L.R. and Eisenbach, J. (1992) Contrary choices: Possible exploitation of enemy-free space by herbivorous insects in cultivated vs. wild crucifers. *Oecologia* **89** : 574-579.

Gathui, C., Ouko, J., Sikinyi, E.O. and Thaku, Z.W. (1994) Report on crop protection measures of Kenyan vegetable farmers and their use of pesticides: a knowledge, attitude and practice survey. KARI/GTZ-IPM Horticulture Project, Nairobi-Kenya. 45pp.

Ghesquiere, J.(1939) The diamondback moth at crucifers in Belgium Congo. *Bull. Cercle Zoo. Congo,* **16** : 61-66 (in French).

Glass, E.H. (1975) Integrated pest management rationale, potential, needs, and implementation. Entomological Society of America, college Park MD.

Goodwin, S. (1979) Changes in the numbers in the parasitoid complex associated with the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera) in Victoria. *Australian J. Zoo.*, **21** : 981-989.

Gratton, C. and Welter, S.C. (1998) Oviposition preference and larval performance of *Liriomyza helianthi* (Diptera: Agromyzidae) on normal and novel host plants. *Environ. Entoml.*, **27** : 926-935.

Gupta, P.D. and Thorsteinson, A.J. (1960) Food plant relationship of diamondback moth (*Plutella maculipennis* (Curt)). 1. Gustation and olfaction in relation to botanical specificity of larva. *Entomol. Exp. Appli.*, **53** : 277-86.

Hama, H. (1992). Insecticide resistance characteristics of the Diamondback moth. In: Talekar, N.S., ed. Management of Diamondback moth and other crucifer pests: Proc. 1st Internat. Workshop. Shanhua, Taiwan: Asian Vegetable Research Development Center, 455-463.

Hamilton, J.T. (1979) Seasonal abundance of *Pieris rapae* (L.), *Plutella xylostella* (L.) and their diseases and parasites. *Gen. Appl. Entomol.*, **11** : 59-66.

Harcourt, D.G. (1957) Biology of the diamondback moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae), in Eastern Ontario, II. Life history, behavior, and host relationships. *Can. Entomol.*, **89** : 554-564.

Harcourt, D.G. (1961) Design of a sampling plan for studies on the population dynamics of the diamondback moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae). *Can. Entomol.*, **93** : 820-831.

Hardy, J.E. (1938) *Plutella maculipennis* (Curt.), its natural and biological control in England. *Bull. Entomol. Res.*, **29** : 343-372.

Harris, M.O. and Miller, J.R. (1988) Host acceptance behavior in an herbivorous fly *Delia antiqua. J. Ins. phy.*, **34** : 179-190.

Hartfield, J.L. and Thormson, I.J. (Eds.). (1982) Biometeorology in integrated pest management. Academic press, N.Y. 491 pp.

HCDA. (1998) Export market statistics figures for fresh fruits, vegetables and cut flowers from Kenya by sea and air in 1997. Horticultural Crops Development Authority (HCDA) Nairobi, Kenya.

Helenius, J. (1989) Intercropping, insect populations and pest damage: Case study and conceptual model. Ph.D. thesis. Univ. Helsinki, Dept. Agricultural and Forest Zoology Report, **14** : 1-49.

Hills, L.D. (1992) Pest control without poisons. Henry Double-day Res. Assn. Bocking, England.

Hokkanen, H.M.T. (1991) Trap cropping in pest management. *Annu. Rev. Entomol.*, **36** : 119-138.

Horn, D.J. (1987) Vegetation background and parasitism of larval diamondback moth on collards. *Entomol. Exp. Appl.*, **43 :** 300-303.

ICIPE Annual Scientific Report, 1994 (1995) Kwale/Kilifi Adaptive Research Project on sustainable management of insect pests and tsetse in Coastal Kenya. Pp. 61-63.

ICIPE. (1997) The International Center of Insect Physiology and Ecology. 1996/97 Annual Report, Nairobi, Kenya, 56pp.

Idris, A.B. and Grafius, E. (1996) Effects of wild and cultivated host plants on oviposition, survival and development of diamondback moth (Lepidoptera: Plutellidae) and its parasitoid *Diadegma insulare* (Hymenoptera: Ichneumonidae). *Environ. Entomol.*, **25** : 825-833.

Ikin, R., Schulten, G.G.M. and De Borhegyi I. (1993) Report of regional seminar on the development and application of Integrated Pest Management on vegetables in Africa, 23-30 November 1992, Dakar, Senegal. FAO Plant Protection Bulletin. **41** : 155-160.

Irvin, N., Wratten, S.D. and Frampton, C.M. (1999) Understory management for the enhancement of the leafroller parasitoid *Dolichogenidea tasmanica* Cameron in Canterbury, New Zealand orchards. In: The Hymenoptera: Evolution, biodiversity and Biological control. Melbourne, Aust.: CSIRO.

Jayarathnam, K. (1977) Studies on the population dynamics of the diamondback moth, *Plutella xylostella* (Linnaeus) (Lepidoptera: Yponomeutidae) and crop loss due to the pest in cabbage. Ph.D thesis, Univer. Of Agricultural Sciences, Bangalore, 215p.

Jussoh, M.M., Loke, W.H., Syed, A.R. and Tyre, M. (eds) (1992) Training manual on integrated pest management of diamondback Moth on cabbage in Malaysia. 68pp. Kuala, Lumpur, Malaysian Agricultural Research and Development Institute.

Kanervo, V. (1932) The Diamondback Moth, a serious vegetable pest. *Puutarha*, **35** : 71-74 (In Finish).

Latheef, M. and Irwin, R.D. (1979) The effect of companionate planting on lepidopterous pests of cabbage. *Can.*, *Entomol.*, **111** : 863-864.

Leius, K. (1967) Influence of wild flowers on parasitism of tent caterpillar and codling moth. *Can. Entomol.*, **99** : 444-446.

Lim, G.S. (1986) Biological control of diamondback moth. Diamondback Moth Management. Proc. 1st Internat. Workshop, Tainan, Taiwan, 11-15 March, 1985 Shanhua, Taiwan; Asian Vegetable Research and Development Center, 159-171.

Litsinger, J.A. and Moody, K. (1976) Integrated Pest Management in multiple cropping systems, pp. 293-316. In: R.I. Papendick, P.A. Sanchez and G.B. Triplett (eds.), Multiple Cropping. Special publication 27. American Society of Agronomy, Madison, WI.

Lohr, B. (2001) Diamondback moth: Biocontrol and a preference for peas. New Agriculturist on-line. http://www.new-agri.co.uk/03-1/develop/dev02.html

Magallona, E.D. (1986) Development in diamondback moth management in the Philippines. Diamondback Moth Management. Proc. 1st Internat. Workshop, Tainan, Taiwan, 11-15 March, 1985 Shanhua, Taiwan; AVRDC, 423-435.

Ministry of Agriculture, Livestock Development and Marketing (1988) Crop Protection Statistics. Kenya Ministry of Agriculture, Livestock Development and Marketing.

Mitchell, E.R., Hu, G.Y. and Okine, J.S. (1997) Diamondback Moth (Lepidoptera: Plutellidae) infestation and parasitism by *Diadegma insulare* (Hymenoptera: Ichneumonidae) in collard and adjacent cabbage fields. *Flo. Entomol.*, **80** (1): 54-62.

Mwaniki, S., Kibata, G.N., Pete, S., Kamau, J., Dobson, H. and Cooper, J. (1998) Pest management in peri-urban vegetable systems in Kenya: Spray application rates and distribution in the crop. In: Crop Protection Research in Kenya. Proc. 2nd Biennial Crop Protection Conference. Pp 1-11.

Nayar, J.K. and Thorsteinson, A.J. (1963) Further investigations into the chemical basis of insect-host plant relationship in an oligophagous insect *Plutella maculipennis* (Curtis) (Lepidoptera: Plutellidae). *Can. J. Zool.* **41** : 923-29.

New South Wales Department of Agriculture (1983) Cabbage moth. Agfacts AE 18. Department of Agriculture. New South Wales, Australia, 2.

O'Donnell M.S. and Coaker T.H. (1975) Potential of intra-crop diversity for the control of brassica pests. Proc. 8th Brit. Insect Fung. Conf. **1,** 101-107.

Oduor, G., Parnell, M., Ong'aro, J. and Kibata, G.N. (1998) Surveys for pathogens of the Diamondback moth (*Plutella xylostella*) on Brassica farms in Kenya. In: G. Farrell and G.N. Kibata (eds). Proc. 2nd Bienniel Crop Protection Confer., NARL-KARI, Nairobi, 16-17th Sept., 1998. Pp 12-17.

Ohno, T., Asayama, T. and Ichikawa, K. (1992) Evaluation of communication disruption method for suppressing diamondback moth infestations at two different areas using synthetic sex pheromones. Management of diamondback moth and other crucifer pests: Proc. 2nd Internat. Workshop, Shanhua, Taiwan: AVRDC, pp.109-14.

Ooi, P.A.C., and Kelderman, W. (1979) The biology of three common pests of cabbages in Cameron Highlands, Malaysia. *J. Malay. Agric.*, **52** : 85-101.

Panda, N. and Khush, G.S. (1995) Host plant resistance to insects. CABI, UK. Pp 284-286.

Perrin, R.M. and Phillips, M.L. (1978) Some effects of mixed cropping on the population dynamics of insect pests. *Entomol. Exp. Appl.*, **24** : 385-393.

Potdar, M.V. and Kakkar, K. (2001) Role of cultural practices in improving the abundance and efficiency of natural enemies. In: S.P. Singh, B.S. Bhumannavar, J. Poorani and D. Singh. (eds.). Biological control. Biocontrol Based Pest Management for Quality Crop Protection in the Current Millennium, July 18-19, 2001.163-172pp.

Powell, W. (1986) Enhancing parasite activity within crops. In: Insect Parasitoids, ed. J.K. Waage, D. Greathead. Pp 314-340. London: Academic. 389pp.

Raini, R.K. (2002) Effect of intercropping on diamondback moth infestation on cabbage. M.Sc thesis, Kenyatta University, Kenya, 130p.

Ramert, B. and Ekbom, B (1996) Intercropping as management strategy against carrot rust fly (Diptera: Psilidae): a test of enemies and resource concentration hypotheses. *Environ. Entomol.*, **25** : 1092-1100.

Reed, D.W., Pinvick, K.A. and Underhill, E.W. (1989) Identification of chemical stimulants for the diamondback moth, *Plutella xylostella,* present in three species of Brassicaceae. *Entomol. Exp. Appl.*, **53** : 277-286.

Reid, W.J.Jr., and Cuthbert, F.P.Jr. (1971) Control of caterpillars on commercial cabbage and other cole crops in the south. *USDA Farmer's Bull.* No. 2099, **24**.

Risch, S.J. (1981) Insect herbivore abundance in tropical monocultures and polycultures: an experimental test of two hypotheses. *Ecology*. **62** : 1325-40.

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

Roda, A.L., Landis, D.A. and Miller, J.R. (1997) Contact induced emigration of potato leafhopper (Homoptera: Cicadellidae) from alfaalfa-forage grass mixture. *Environ. Entomol.*, **26** : 754-762.

Root, R.B. (1973) Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). *Ecol. Monogr.*, **43** : 94-125.

Salinas, P.J. (1986) Studies on Diamondback moth in Venezuela with reference to other Latinamerican countries. Diamondback moth management. Proc. 1st Internat. Workshop, Tainan, Taiwan, 11-15 March 1985 Shanhua, Taiwan; AVRDC, 17-24.

Sastrosiswojo, S. and Sastrodihardjo, S. (1986) Status of biological control of diamondback moth by introduction of parasitoid *Diadegma eucerophaga* in Indonesia. Diamondback Moth Management. Proc. 1st Internat. Workshop, Tainan, Taiwan, 11-15 March, 1985 Shanhua, Taiwan; AVRDC, 185-194.

Sheenan, W. (1986) Response by specialist and generalist natural enemies to agroecosytem diversification: a selective review. *Environ. Entomol.*, **9** : 1-6.

Singh, S.P; and Singh, D. (1982). Influence of cruciferous host plants on the survival and development of Plutella xylostella L. J. Res. Punjab Agric. Univ. 19: 1, 100-104.

Sivapragasam, A, Tees, S.P. and Ruwaida, M. (1982) Effects of intercropping cabbage with tomato on the incidence of *Plutella xylostella*. MAPPS Newsletter **6** (2): 6 -7.

Smith, H.A. and McSorley, R. (2000) Intercropping and pest management: A review in major concepts. In: J.E. McPherson (ed.), *Amer. Entomol.*, **46** (3) pp 154-161.

Southwood, T.R.E. (1975) The dynamics of insect populations. Pp 151-199. In: Insects, Science, and Society. D.Pimentel (ed). Academic Press, New York.

Spencer, J.I. (1996) Waxes enhance *Plutella xylostella* oviposition in response to sinigrin and cabbage homogenates. *Entomol. Exp. Appl.*, **81** : 163-173.

Srinivasan, K. (1984) Visual damage thresholds for diamondback moth, *Plutella xylostella* (Linnaeus), and leafwebber, *Crocidolomia binotalis* Zeller, on cabbage. PhD thesis. Univ. Agric. Sci., Hebbal, India. 166pp.

Srinivasan, K. and Krishna Moorthy, P.N. (1991). Indian mustard as a trap crop for major lepidopterous pests on cabbage. *Trop. Pest Manag*; **37** (1) : 26 - 32.

Srinivasan, K. and Krishna Moorthy, P.N. (1992) Development and adoption of integrated pest management for major pests of cabbage using Indian mustard as a trap crop. In: Talekar NS, ed. Diamondback Moth and Other Crucifer Pests: Proc. 2nd Internat. Workshop. Shanhua, Taiwan: AVRDC, 511-521.

Stanton, M.L. (1983) Spatial patterns in the plant community and their effects upon insect search, pp 125-157. In: S. Ahmad (ed.), Herbivorous insects: host-seeking behavior and mechanisms. Academic Press, New York.

Statistical Analysis System Institute Inc. (1995). SAS Users Guide: Statistics. Version Sedn. SAS Institute Inc., Cary, North Carolina.

Stern, V.M. (1969) Interplanting alfalfa in cotton to control *Lygus* bugs and other insect pests. Proc. Tall Timbers Conf. On Ecol. Animal Control by Habitat management. **1** : 55-69.

Stoner, K.A. (1992) Resistance and susceptibility to insect pests in glossy genetic lines of Brassica oleracea in Connecticut, USA. In: Diamondback moth and other Crucifer Pests: Proc. 2nd Internat. Workshop, December, 1990, Tainan, Taiwan, Shahua, Asian vegetable Research and Development, pp.57-63.

Syed, A.R. (1992) Management of pests and diseases of vegetable crops in Malaysia in 2000. In: A.A.S.A Kadir and H.S. Barlow (eds). Pest Management and environment in 2000. CABI, UK. Pp213-230.

Tabashnik, B.E. (1985) Deterrence of diamondback moth (Lepidoptera:Plutellidae) oviposition by plant compounds. *Environ. Entomol.*, **14** : 575-78.

Tabashnik, B.E. (1994) Evolution of resistance to *Bacillus thuringiensis. Ann. Rev. Entomol.*, **39** : 47-79.

Tahvanainen, J.O. and Root, R.B. (1972) The influence of vegetation diversity on the population ecology of a specialized herbivore, *Phyllotreta cruciferae*. *Oecologia*, **10** : 321-346.

Talekar, N.S. ed. (1992) Management of Diamondback moth and other crucifer pests: Proc. 1st Internat. Workshop. Shanhua, Taiwan: Asian Vegetable Research Development Center. 603pp.

Talekar, N.S., Lee S.T. and Huang S.W. (1986) Intercropping and modification of irrigation method for the control of diamondback moth. Pp.145-152. In: N.S. Talekar and T.D. Griggs (eds). Proc. 1st Internat. Workshop, Diamondback moth management. Shanhua, Taiwan; AVRDC, 1985.

Talekar, N.S. and Shelton, A.M. (1993) Biology, ecology, and management of the diamondback moth. *Ann. Rev.Entomol.,* **38** : 275-301.

Talekar, N.S. and Yang, J.C. (1991) Characteristics of parasitism of diamondback moth by two larval parasites. *Entomophaga*; **36** : 95-104.

Theunissen, J., Booij, C.J.H. and Lotz, L.A. (1995) Effects of intercropping white cabbages with clovers on pest infestation and yield. *Entomol. Exp. Appl.*, **74** :7-16.

Theunissen, J. and den Ouden, H. (1980) Effects of intercropping with *Spergula arvensis* on pests of Brussels sprouts. *Entomol. Exp. Appl.*, **27** : 260-268.

Theunissen, J. and Schelling, G. (1996) Undersowing crops of white cabbage with strawberry clover and spurrey. IOBC/WPRS Bull. **19** (11): 128-135.

Thompson. J.N. and Pellmyr, O. (1991) Evolution of oviposition behavior and host preference in Lepidoptera. *Ann. Rev. Entomol.*, **36** : 65-89.

Tingey, W.M. and Lamont, W.J. (1988) Insect abundance on field beans altered by intercropping. *Bull. Entomol. Res.*, **78** : 527-535.

Tukahirwa, E.M. and Coaker, T.H. (1982) Effects of mixed cropping on some insect pests of brassicas: reduced *Brevicoryne brassicae* infestations and influences on epigeal predators and the disturbance of ovipositional behavior in *Delia brassicae*. *Entomol. Exp. Applic.*, **32** : 129-140.

Turkar, K.S., Gupta, R., Banerjee, S.K. and Wanjari, R.R. (2000) Influence of intercropping chickpea with coriander on parasitisation of *Heliothis armigera* (Hubner) by *Campoletis chlorideae* Uchida. *J. Entomol. Res.*, **24** : 279-281.

Uematsu, H., Sakanoshita, A. (1989) Possible role of cabbage leaf wax bloom in suppressing diamondback moth, *Plutella xylostella* (Lepidoptera : Yponomeutidae) oviposition. *Appl. Entomol. Zool.*, **24** : 253-257.

Uvah, I.I.I. and Coaker, T.H. (1984) Effects of mixed cropping on some insect pests of carrots and onions. *Entomol. Exp. Appl.*, **36** : 159-167.

Van Emden, H.F. (1965) The role of uncultivated land in the biology of crop pests and beneficial insects. *Scient. Hort.*, **17** : 121-136.

Vandermeer, J. (1989) The ecology of intercropping. Cambridge University Press, 237pp.

Verkek, R.H.J. and Wright, D.J. (1996) Interactions between the diamondback moth, *Plutella xylostella* L. and glasshouse outdoor-grown cabbage cultivars, *Ann. Appl. Biol.*, **125** : 477-488.

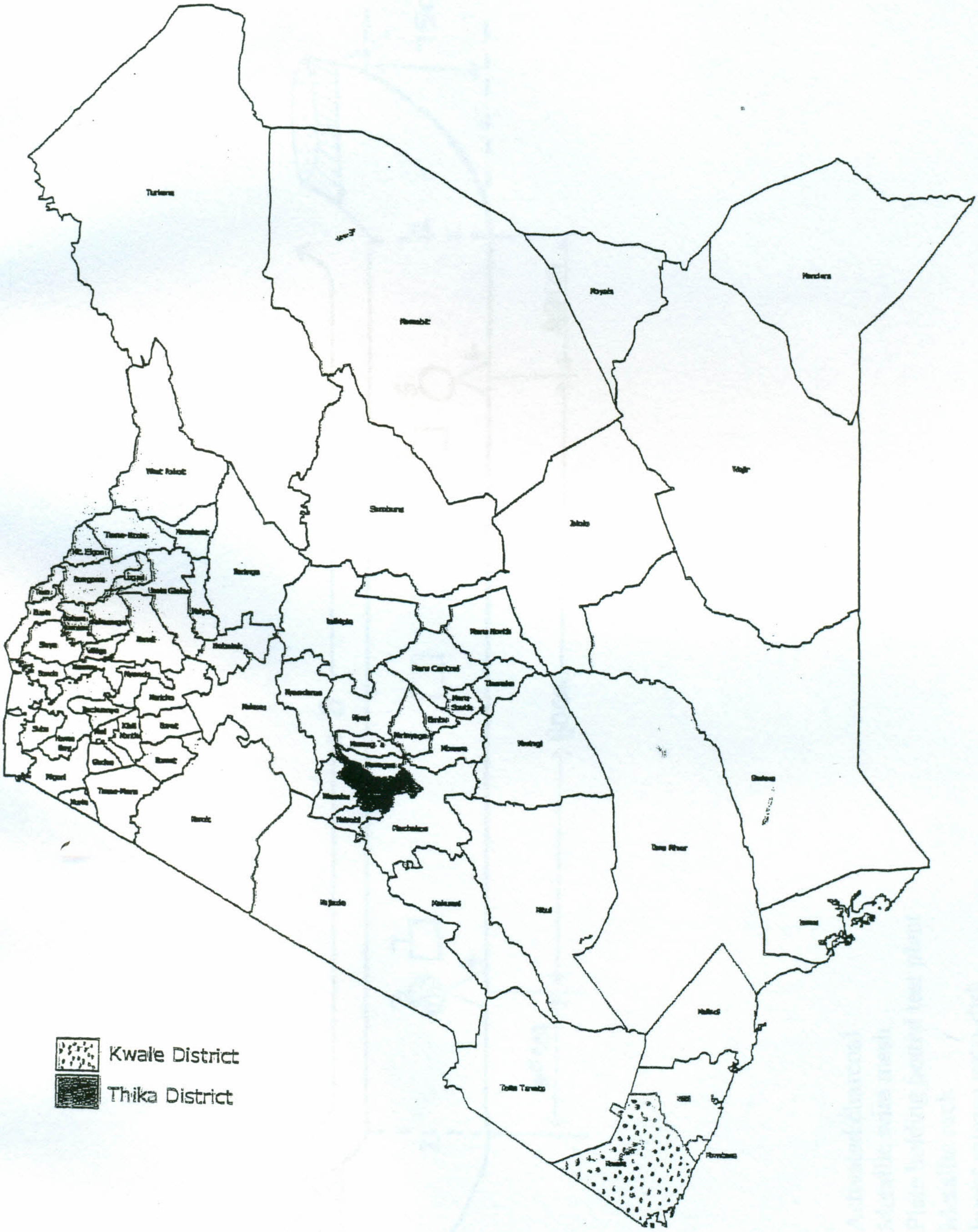
Vostrikov, P. (1915). Tomatoes as insecticides. The importance of Solanaceae in the control of pests of agriculture. *Novotchecherkossk,* **10** : 9-12.

Westgard, P.H., Lambard, P.B. and Allen, R.B. (1979) Effects of overfree irrigation on density and damage of pea pests. *J. Econ. Ent.*, **72** : 839-840.

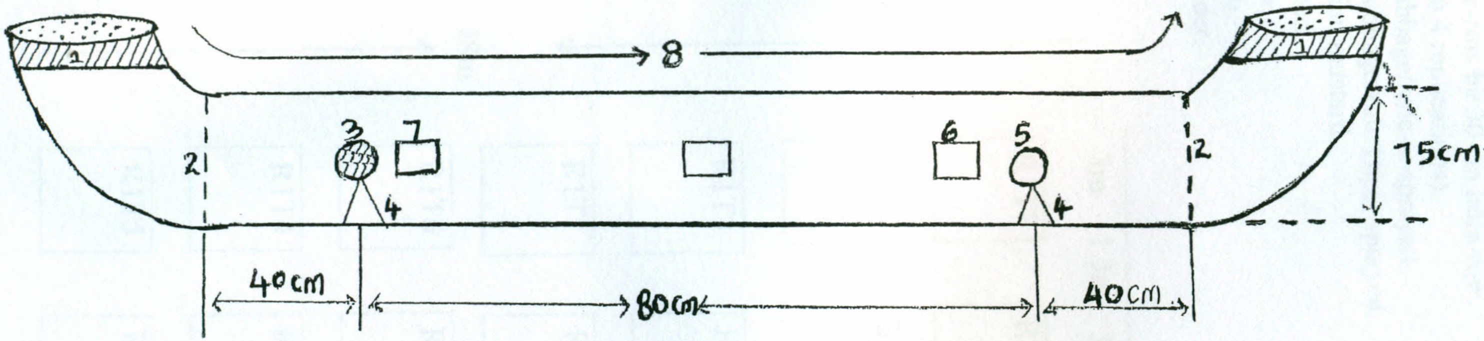
Yamada, H. and Kawasaki, K. (1983) The effect of temperature and humidity on the development, fecundity, and multiplication of the diamondback moth, *Plutella xylostella* (L.). *Jap. J. Appl. Entomol. and Zool.*, **27** (1): 17-21.

7.0. APPENDICES

APPENDIX 1 : MAP OF KENYA SHOWING THE STUDY SITES.



APPENDIX 2 : THE WIND TUNNEL.



1. Activated charcoal
2. Metallic wire mesh
3. Plate holding potted test plant
4. Metallic rack
5. Insect release petri-dish
6. Window for introducing insect release petri-dish
7. Window for introducing potted test plant
8. Air flow

<u>APPENDIX 3:</u> <u>Layout for field trials at JKUAT and Matuga.</u>

Goal: *To evaluate the relative attraction or repellence of companion crops to p. xylostella infestation.*

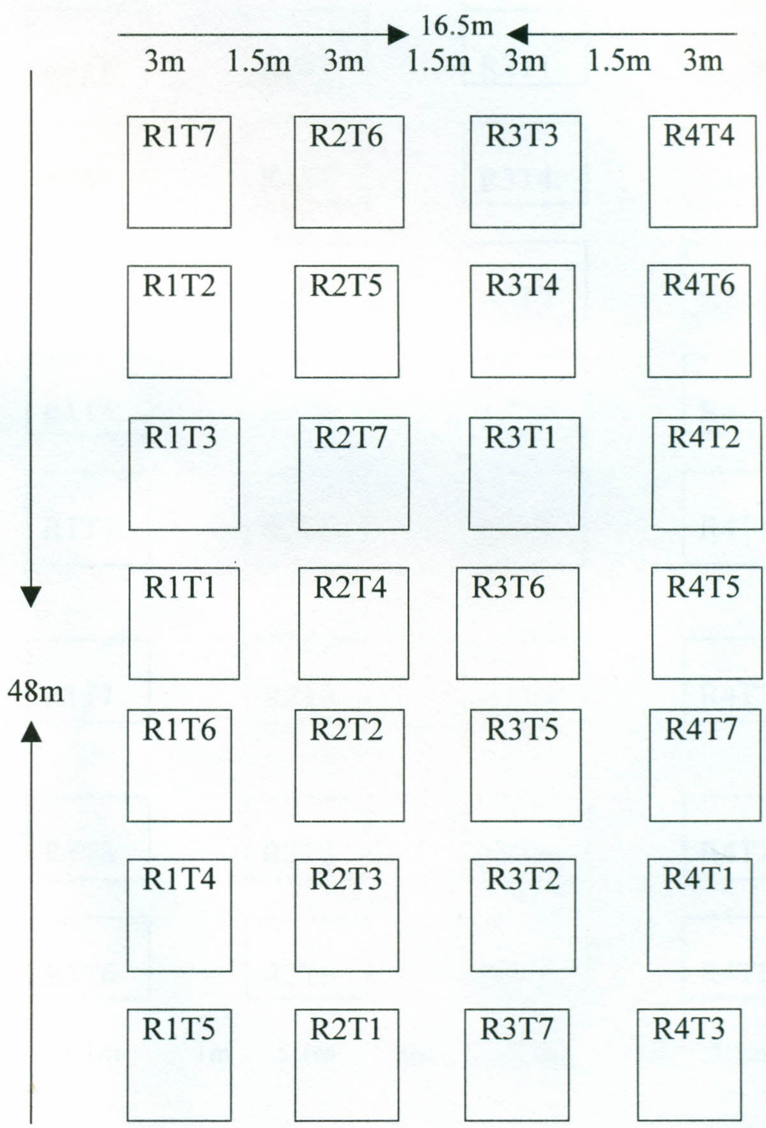
Design: RCBD.

Plot size: 48 × 16.5 m.

Spacing: 60 cm inter-row by 30 cm intra-row.

Treatments = 7 (with 4 replications).

T1=Sole cabbage/kale-unsprayed.
T2= Sole cabbage/kale Dipel sprayed.
T3=Ethiopian mustard.
T4=Rapeseed.
T5=*Cleome.*
T6=Tomato.
T7=Coriander.



<u>APPENDIX 4:</u> <u>Layout for field trial at JKUAT.</u>

Goal: *To evaluate the effect of planting pattern on P. xylostella infestation.*
Design: RCBD.
Plot size: 93.4 × 23.4 m
Spacing: 60 cm inter-row by 30 cm intra-row.
Treatments = 8 (with 4 replications).

T1- cabbage : coriander (2:1 row).
T2- cabbage : coriander (8:1 row).
T3- cabbage : coriander (2:1 strip).
T4- cabbage : coriander (8:1 strip).
T5- cabbage : coriander (2:1 hill).
T6- cabbage : coriander (8:1 hill).
T7- sole-cabbage Dipel sprayed.
T8- sole-cabbage unsprayed.