DECLARATION

I ………………………………………….. do hereby declare that this work is my original work undertaken at Africa University, Mutare, Zimbabwe in partial fulfillment of the requirements for the degree of Master of Science in Crop Production and has not been submitted nor is being currently submitted to any university for the award of any other degree.

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Student's signature

Date ……../……./……….

Approved for submission

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Name of Supervisor

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Signature

Date ……/……./………

ABSTRACT

The diamondback moth (*Plutella xylostella* L.) (DBM), (Lepidoptera: Plutellidae), is a major pest of brassicas worldwide and is estimated to cost US$ 1 billion in direct losses and control costs. Field studies were conducted at Africa University to evaluate the impact of intercropping and insecticides on DBM population density in cabbage (*Brassica oleracea* var*. capitata*) cultivar Drumhead. Two trials were conducted and each had five treatments in a Randomized Complete Block Design (RCBD). Cabbage seedlings were raised in a greenhouse and transplanted into field plots on 29 September 2010. Compound S (7-21-8 and 7.5 % S) was applied as a basal fertilizer at a rate of 300 kg/ha. At 40 days after transplanting, a top dressing of Ammonium Nitrate (AN) was applied at a rate of 100 kg/ha. Cultural practices such as weed control and sprinkler irrigation were carried out as when necessary. For the intercropping trial cabbage was intercropped with *Brassica juncea*, Tomato (*Lycopersicon esculentum* Mill*.)* and *Cleome gynandra,* and *B. juncea* was sown as a sole crop. Sole cabbage was used as the control. For the insecticide trial, the insecticides used were Match 5 EC (lufenuron), Malathion 50 EC (malathion), Decis 2.5 EC (deltamethrin) and Malathion 25 WP (malathion). Unsprayed cabbage was used as the control.

Results of the study demonstrated the impact of intercropping cabbage with tomatoes in managing DBM population below the economic injury level of 1.0 larva per plant. The mean of DBM population density varied from 0.03 to 2.42 small larvae per plant and 0.09 to 2.06 large larvae per plant. The lowest DBM density was on *B. juncea* as a sole crop with an average of small and large larvae of 0.06 larvae per plant. The average DBM population density on cabbage intercropped with tomato was 0.94 small larvae per plant and 0.97 large larvae per plant. The density of larvae parasitized by *Cotesia plutellae* was significantly higher (P<0.05) in cabbage intercropped with tomato with a mean of 0.60 parasitized larvae followed by cabbage intercropped with *B. juncea* with a mean of 0.47 parasitized larvae. Cabbage head damage was significantly low (P<0.05) on cabbage intercropped with tomato with a mean of 2.33 damaged heads followed by a mean of 3.0 damaged heads in the intercrop with *Brassica juncea.* The results showed that intercropping can improve both parasitoid population densities and the yield and quality of cabbage heads.

In the insecticide trial the mean DBM population on the untreated cabbage (control) was 2.6 small larvae per plant and 2.0 large larvae per plant. The lowest DBM larval density (P<0.05) was on cabbage sprayed with Match 5 EC with 0.92 small larvae per plant and 0.98 large larvae per plant. In terms of parasitism, unsprayed cabbage had a significantly high density (P<0.05) of larvae parasitized by with a mean of 0.47 parasitized DBM larvae. The lowest density of parasitized DBM larvae was 0.13 on cabbage treated with Malathion 50 EC. The insecticides used reduced the activity of *C. plutellae* as noted in the trials. The high infestation level of cabbage by DBM in the insecticide treated trial might have resulted from partial removal of the parasitoid by insecticides such as Malathion 50 EC and Malathion 25 WP. It seems that Match 5 EC and Decis 2.5 EC are less toxic to *Cotesia plutellae* and it would be advisable for farmers to use such insecticides in DBM management.

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DEDICATION

This work is dedicated to the fond memory of my father Timoteo Adelino, my mother Monica Garcia Kiala, my children Flavio Kosy Kiala and Isbelkia Kosy Kiala and my fiancée Elga Cardoso “Suzy”, my sister Cecilia “Cila” and brothers, nephew and niece and all my family.

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CHAPTER ONE

1 INTRODUCTION

The Diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: *Plutellidae*), is the most destructive insect pest of crucifers throughout the world, (Liu *et al.*, 2003; Sarfraz *et al*., 2005). Brassicas are grown in temperate and tropical climates and represent a diverse, plant family that includes cabbage, broccoli, cauliflower, collards, rapeseed, mustard, and Chinese cabbage (De Lannoy, 2001; Doubrava *et al*., 2004).

Diamondback moth may have its origin in Europe in the Mediterranean (Stoll, 2000), but on the basis of the presence of its biocontrol agents with 14 species of parasitoids and 175 host plant species, of which 32 are exotic, it is speculated that it originated in South Africa (Kfir, 1998, Liu *et al.,* 2000). Using similar arguments, Schuler *et al.* (2004) are of the view that *Plutella. xylostella* originated in China. This pest is now present wherever its host plants exist and is considered to be the most widely distributed of all Lepidoptera (Kfir, 1998; Liu *et al*., 2000; Stoll, 2000; Shelton 2004; Sarfraz *et al.*, 2005).

According to Perez *et al.* (2004), the diamondback moth feeds only on members of the family *Brassicae*. This diverse plant group is cultivated for various edible plant parts, such as the roots of radishes and turnips, the stems of kohlrabi, the leaves of cabbage and other leafy brassica, and the seeds of mustard and rape, which are consumed as fresh, cooked, or processed vegetables (Bewick, 1994).

The absence of effective natural enemies, especially parasitoids, is believed to be a major cause of the diamondback moth's pest status in most parts of the world. Lack of parasitoids in a particular area may have occurred because the diamondback moth is better able than its natural enemy complex to become established in newly planted crucifers (Perez *et al.,* 2004). Records of the ability of diamondback moth to migrate long distances are numerous, but there is no record of migration of any of its parasitoids. Another reason for the lack of effective biological control in an area may be the destruction of natural enemies by the use of broad-spectrum insecticides (Stoll, 2000).

Host plant resistance and action of its natural enemies are two key biotic factors that regulate DBM populations in the field (Kfir, 1998). However, in many countries, synthetic insecticides are used to control DBM, which often eliminates natural enemies. This, in turn, can lead to continued intensive use of insecticides, eventual insecticide resistance and control failure (Shelton *et al*., 2007). DBM was the first crop insect pest reported to be resistant to DDT, and now in many crucifer-producing regions it has shown significant resistance to almost every insecticide applied in the field including new chemistry pesticides such as spinosyns, avermectins, neonicotinoids, pyrazoles and oxadiazines (Shelton, 2007; Shelton *et al* 2007). This has prompted increased efforts worldwide to develop integrated pest management (IPM) programmes, principally based on manipulation of natural enemies (Sarfraz *et al.*, 2005). Although over 130 parasitoid species are known to attack various life stages of DBM, most control worldwide is achieved by relatively few hymenopteran species belonging to the ichneumonid genera *Diadegma* and *Diadromus,* the braconid genera *Microplitis* and *Cotesia,* and the eulophid genus *Oomyzus* (Stoll, 2000). However, DBM populations native to different regions have genetic and biological differences, and specific parasitoid strains may be associated with specific diamondback moth strains (Stoll, 2000).

The use of integrated pest management strategies to control diamondback moth will keep the level of damage below that which will hurt farmers economically (Varella *et al.*, 2003). The objective of any pest control strategy is to reduce pest populations to non-economic levels (Francis *et al*., 2005). In Australia and the United States, farmers use a threshold level of 1 DBM larva per plant (Furlong *et al*, 2004; Khan *et al.,* 2004). In Zimbabwe, however, no threshold levels for brassica pests have been established (Shelton *et a*l., 1995; Dobson *et al*., 2002). Thus, most large scale brassica growers end up applying routine sprays to avoid insect pest damage (Manyangarirwa, 2009).The purpose of this study was to determine the effect of biological control and intercropping to reduce diamondback moth damage on cabbage and the effect of insecticides used on the pest's natural enemies.

1.1 Objectives

1.1.1 Main Objective

To determine the effect of biological control and intercropping on diamondback moth population density and damage on cabbage and the effect of insecticides on the pest's natural enemies..

1.1.2 Specific Objectives

1) To determine the effect of biological control on diamondback moth density in cabbage.
2) To determine the effect of intercropping on diamondback moth density in cabbage.

3) To determine the effect of insecticides on parasitoids of diamondback moth in cabbage.

1.2 Hypotheses

1) Biological control reduces the diamondback moth population in cabbage.
2) Intercropping reduces diamondback moth damage in cabbage.
3) Some insecticides kill biological control agents that control diamondback moth.

CHAPTER TWO

2 LITERATURE REVIEW

The diamondback moth (DBM) (*Plutella xylostella* L.) (Lepidoptera; Plutellidae) is one of the most destructive cosmopolitan insect pest of brassicas (Alton and Sparks, 2004). DBM probably originated in Europe but is now found throughout Africa, the Americas, Southeast Asia and Australia (Andrahennadi and Gillott, 1998; Sarfraz *et al.*, 2005).

The adaptability of diamondback moth has been demonstrated in its remarkable ability to thrive in tropical, subtropical and temperate climates (Altieri and Leibman, 1998). In hot conditions, the pest develops rapidly throughout the year with a new generation emerging every two to four weeks. Consequently, pest numbers increase significantly within a very short time. DBM has also developed resistance to most commonly used pesticides and, as a result farmers are increasingly using a cocktail of chemicals and spraying more frequently (Sarfraz *et al.*, 2005).

Intercropping brassicas with repellent plants such as tomato has been reported to be effective in Kenya, and the use of neem has been shown to achieve slow but effective control of DBM. Current focus on IPM programs is on the assessment of parasitoids and introduction, where necessary, of more efficient parasitoids from other countries (ICIPE, 2003; CABI, 2004).

Diamondback moth is now recorded everywhere where cabbage is grown. However, it is highly dispersive, and is often found in areas where it cannot successfully overwinter (Talekar and Shelton, 1993). In the tropics and subtropics, DBM is present all year-round, with the highest infestations being found over the spring and early summer months from September to December. In the autumn months of March to May, additional smaller peaks in infestation are found. In the winter months and late summer, diamondback moth abundance decreases (Facknath, 1997b).

In commercial cabbage fields the main form of control against the diamondback moth is through broad-spectrum insecticides, mainly pyrethroids and organophosphates (Manyangarirwa *et al*., 2009). However, resistance to these chemicals has been established (Facknath, 1997). The long persistence and extensive use of the synthetics resulted in the development of resistance in target pests, elimination of parasitoids and predators resulting in secondary pest outbreaks, toxicity to higher animals and environmental pollution (Walia and Parmar, 1995).

Numerous parasitic wasps attack diamondback moth. The most common are wasps of the genera *Cotesia*, *Diadegma*, *Diadromus* and *Oomyzus*. These wasps are also known from Africa and some are reported to effect excellent control of the diamondback moth elsewhere (Alton and Sparks, 2004). Unfortunately, the locally existing wasps do not provide satisfactory control of the diamondback moth in eastern and southern Africa. For this reason, two species of wasps (*Diadegma semiclausum* (Hellen) and *Cotesia plutellae* (Kurdjumov)), were imported and released by the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya, Uganda and Tanzania. The former has provided almost control of this pest in highland growing conditions while the latter is specific to mid-altitude, semi-arid areas where it also provides good control (Alton and Sparks, 2004).

Oomyzus sokolowskii, is another parasitoid found worldwide, as well as *Diadegma mollipla*, which until recently was believed to be identical to *D semiclausum*. However, the overall level of parasitism of indigenous parasitoids was only recorded as 10-15% - much lower than was found in similar situations in SE Asia and South Africa (Shelton, 2004; Löhr *et al.,* 2007). *Cotesia plutellae* was also recorded in East Africa but only in very low numbers (Löhr *et al.,* 2007). Elsewhere, this parasitoid is known to be very effective and, in recent years, has been used to control DBM in St Helena islands (Kfir, 1998). The South African strain is also known to parasitise at effective levels. It is hoped that this particular species may be introduced into the semi-arid regions of East Africa (ICIPE, 2003).

Agricultural ecosystems interact, and, through a set of feedback loops, maintain balance within functional fluctuating bounds. Therapeutic interventions into these systems are met by countermoves that neutralize their effectiveness (Shelton *et al*., 2008). The foundation for pest management in agricultural systems should be an understanding and shoring up of the full composite of inherent plant defenses, plant mixtures, soil, natural enemies, and other components of the system (Shelton, 2004). These naturally built-in regulators are linked in a web of feedback loops and are renewable and sustainable. The use of pesticides and other treat-the-symptoms approaches are unsustainable and should be the last rather than the first line of defense. A pest management strategy should always start with the question "Why is the pest a pest?" and should seek to address underlying weaknesses in ecosystems and/or agronomic practices that have allowed organisms to reach pest status (Lewis *et al*., 1997; Shelton *et al*., 2007).

2.1 Cultivation of Brassicas in Africa

A variety of brassica crops are grown in Africa, though kales and cabbages are generally the most important in terms of quantity of production (Bewick, 1994). In Kenya, the estimated annual production of brassicas is 550,000 tons, with 95% of the production in the highlands on 35,000 ha (FAOSTAT, 2007). In East Africa, about 90% of the brassicas produced by smallholder growers is on plots of 0.1–0.5 ha and this probably applies to other regions of sub-Saharan Africa, although in South Africa, large scale commercial production is predominant (Kfir, 2004). Brassicas are particularly important in the peri-urban farming sector in East Africa (Oruku and Ndun'gu, 2001) as they are key components of the local diet and nutritionally very important for poor people who cannot afford alternative vegetables. Kales in particular are a major item in the local diet and are an important smallholder subsistence crop in Kenya, Ethiopia, Mozambique and Zimbabwe (Kfir, 2004).

2.2 Description of the Diamondback Moth

2.2.1 Eggs

Eggs are less than 1 mm in diameter, flat and oval in shape, yellowish in colour and are laid singly or in groups of 2 to 3 along the veins on the upper and lower leaf surfaces. The eggs hatch in 3 to 8 days depending on the environmental conditions. Females may deposit 250 to 300 eggs but average total egg production is probably 150 eggs. Development time averages 5.6 days (Talekar and Shelton 1993; Stoll, 2000; Alton and Sparks, 2004).

2.2.2 Larvae

Larvae are pale yellowish-green to green covered with fine, tiny, scattered, erect hairs. Mature larvae are cigar-shaped and about 12 mm long. They have chewing mouthparts.

The larvae go through four instars and complete their development and pupate in 10 to 28 days. If disturbed, larvae wriggle violently, move backward, and spin down from the plant on a strand of silk. The larval body form tapers at both ends, and a pair of prolegs protrudes from the posterior end, forming a distinctive "V". The larvae are colourless in the first instar, but thereafter are green (Alton and Sparks, 2004). Initially, the feeding habit of first instar larvae is leaf mining, although they are so small that the mines are difficult to notice. The larvae emerge from their mines at the conclusion of the first instar, moult beneath the leaf, and thereafter feed on the lower surface of the leaf. Their chewing results in irregular patches of damage, and the upper leaf epidermis is often left intact and a large proportion of young larvae are often killed by rainfall (Stoll, 2000; Alton and Sparks, 2004).

2.2.3 Pupae

Pupae are initially light green and turn brown as the adult moths become visible through the cocoon. They are covered with a loosely spun net-like cocoon that is attached to the leaves, stems or seed pods of the host plant. Pupation may occur in the florets. The moths emerge 3 to 15 days after pupation depending on the environmental conditions (Stoll, 2000; Alton and Sparks, 2004).

2.2.4 Adults

The adult is a small, slender, grayish-brown moth approximately 8 to 9 mm long with a wingspan of 12 to 15 mm with pronounced antennae. It has diamond-shaped markings on the back when the wings are folded, which gives the common name to this insect. Adult males and females live about 12 and 16 days, respectively. Adult females can lay an average of 150 eggs during their lifespan of about 16 days. Moths lay eggs at night. The greatest number of eggs is laid the first nights after emergence and egg laying continues for about 10 days. In the field, moths will fly out of the plant canopy when disturbed, usually flying within 2 m of the ground, and not flying long distances. However, they are readily carried by the wind. The adult is the overwintering stage in temperate areas, but moths do not survive under cold conditions (Stoll, 2000; Alton and Sparks, 2004). Adult survival is thought to be principally a function of the weather that acts to regulate insect population density by interacting with the other physical and biotic aspects of a habitat (Bebach, 1975).

2.2.5 Overall Life Cycle

Total development time from the egg to the adult averages 25 to 30 days, depending on the weather, with a range of about 17 to 51 days. The number of generations varies from four in cold climates to six in tropical climates (Talekar and Shelton 1993; Stoll, 2000; Alton and Sparks, 2004). Many natural enemies prey on the diamondback moth at different stages of its life cycle. Birds and spiders feed on moths; ants, lacewings, wasps, and parasitic wasps among others attack the larvae (Alton and Sparks, 2004).

2.2.6 Damage Caused by DBM

Throughout the world DBM is considered the main insect pest of brassicas particularly cabbage, kales, broccoli and cauliflower (Muniappan and Lali, 2000). The economic impact of diamondback moth is difficult to assess since it occurs in diverse small scale and large-scale production areas, but it has been known to completely destroy cabbage and kale crops. It is considered a major pest in all countries of the eastern and southern African region (Alton and Sparks, 2004). In addition, the diamondback moth feeds on numerous cruciferous plants that are considered to be weeds. However, DBM maintains itself on these weeds only in the absence of more favored cultivated hosts (Talekar and Shelton, 1993).

Plant damage is caused by larval feeding. Although the larvae are very small, they can be quite numerous, resulting in complete removal of foliar tissue except for the leaf veins. This is particularly damaging to seedlings, and may disrupt head formation in cabbage, broccoli, and cauliflower. The presence of larvae in florets can result in complete rejection of produce, even if the level of plant tissue removal is insignificant (Talekar and Shelton, 1993 and Stoll, 2000).

Newly hatched DBM larvae feed as leafminers inside the leaf tissue. Older larvae feed on all plant parts. They feed on the leaf tissue leaving the upper leaf surface intact. This type of damage is called "windowing", since it gives the appearance of translucent windows on the leaf. In cases of severe infestation, entire leaves could be damaged. Older larvae are often found around the growing bud of young plants. DBM larvae also feed on stems and pods. Heavy damage results in the marketable parts contaminated with excrement, which makes the produce unmarketable (Alton and Sparks, 2004).

2.3 General Diamondback Moth Management in Africa

In the search for an alternative to the ‘‘chemical treadmill’’ approach to managing DBM and other brassica pests, several IPM initiatives in Africa have pursued biological control programmes (Nacknath, 1997a; Williamson, 2005). A series of major international workshops on DBM management have been concerned with developing the use of parasitoids, pathogens and natural enemies for DBM IPM (Kirk and Bordat, 2004; Endersby and Ridland, 2004). In Zimbabwe, large scale and smallholder farmers grow brassicas as one of their principal crops and DBM is a major pest of cabbage (*Brassica oleracea* var. *capitata*), covo (*Brassica oleracea* var. *acephala*) and rape (*Brassica* *napus*). A unilateral pest control approach that relies predominantly on the use of pesticides on vegetables has been the practice (Sibanda *et al*., 2000). Several studies (Liu *et al*., 1981; Hill and Foster, 2000; Liu *et al*., 2000) have shown that the use of insecticides is not a sustainable pest management option for farmers as it is fraught with problems such as increased cost of pesticides, reduced control efficacy and contamination of the farming environment.

One alternative to pesticides in developing an integrated management strategy against DBM is conservation biological control using endemic parasitoids (Sarfraz *et al*., 2005). In Africa, extensive studies on the incidence and efficacy of DBM parasitoids have been conducted in South Africa and Kenya (Kfir, 1998; Akol *et al*., 2002; Kfir, 2003; Löhr *et al*., 2007). Parasitoids of DBM in South Africa and Kenya include *C. plutellae*, *Diadegma mollipla* (Holmgren) and the introduced *D. semiclausum* (Kfir, 1998; Kfir, 2003; Akol *et al*., 2002; Löhr *et al*., 2007). Ayalew and Ogol (2006) documented the predominance of *Oomyzus sokolowskii* (Kurdjumov) (Hymenoptera: Eulophidae) in the Rift Valley region of Ethiopia where insecticide use is intensive.

The diamondback moth is a major insect pest of brassicas in Zimbabwe and larval incidence is high in the hot-dry season from August to November, reaching densities as high as 15.58 larvae per plant at some sites (Manyangarirwa, 2009). The major larval endoparasitoid is *Cotesia plutellae* (Hymenoptera: Braconidae) and parasitism reached about 95.51% at a host density of 2.83 larvae per plant in early summer of 2008 (Manyangarirwa *et al*., 2009).

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Compared to other regions, no meaningful work has been conducted in Zimbabwe to quantify the incidence of DBM and its complex of endemic parasitoids (Sibanda *et al*., 2000). Since the pest is resistant to many conventional pesticides and spraying DBM infested cabbage often has little effect on the pest, farmers may be tempted to carry out extensive spraying and eventually give up cabbage production. Furthermore, there is a growing concern about the pollution of the environment and its resultant effects on the health of humans and animals arising from the continued use of these pesticides. An effective and environmentally friendly approach in managing the DBM menace is thus required ((Kwarteng and Towler, 1994; Youdeowei, 2002).

South Africa has a large number of parasitoids, many of them indigenous, that are associated with the diamondback moth and that can provide suitable control in particular circumstances. Kfir (1998) found 14 species of primary parasitoids in the Pretoria region of South Africa and more recently Smith and Villet (2004) found 23 species. These parasitoids are not affected by hyperparasitoids as these are very rare. It is therefore important that the commercial cabbage growers are encouraged to use more selective pesticides and reduce the number of applications in an attempt to build up parasitoid populations within the area (Smith and Villet, 2004).

A detailed study of farmers in Kenya indicated that aphids (97%) and DBM (75%) are the major insect pest threats to kale, a pattern similar to that reported for cabbages, where 89% of farmers reported aphids as a problem and 69% cited DBM (Oruku and Ndun'gu, 2001). However, other authors have stressed the pre-eminence of DBM, with aphids as a secondary, early-season pest in Kenya (Kibata, 1997) and East Africa in general

(Nyambo and Löhr, 2005). In addition other species, including the cabbage looper (*Trichoplusia ni*) and cutworms (*Agrotis* spp.), are reported as pests by up to 60% of farmers in Kenya. *Hellula undalis* is reported as a major larval pest in Mozambique, Zambia and Zimbabwe (Sithole, 2005). *Crocidolomia pavonana* is locally important in Tanzania (Nyambo and Löhr, 2005). In Malawi and Zimbabwe, the Bagrada bug (*Bagrada hilaris*) is also frequently reported as a problem (Seif and Löhr, 1998). The aphid species *Brevicoryne brevis, Myzus persicae and Lipaphis erysimi* are serious pests of brassicas not only because they cause direct damage but also because they are vectors of important viral diseases such as Turnip Mosaic Virus and Cauliflower Mosaic Virus (Cooper, 2002; Spence *et al*., 2007). Outside Eastern and Southern Africa, data on pest importance is sparse but in Ghana and Benin, DBM was again reported as the dominant pest of crucifers (Goudegnon *et al*., 2004). *Hellula undalis* and *B. brassicae* are additional major insect pests limiting cabbage production in Benin (James *et al*., 2007).

The use of synthetic insecticides for DBM control in Africa is characterised by practices such as pesticide mixing, calendar spraying and the use of unregistered and fraudulent products of poor quality (Williamson, 2003). Surveys in a number of countries including Kenya and Zimbabwe (Oruku and Ndun'gu, 2001; Sithole, 2005) have shown that there is an overwhelming reliance on broad-spectrum insecticides (pyrethroids, organophosphates, and carbamates), often applied weekly or biweekly. In addition, the quality of applications is often poor or ineffective (Cooper, 2002; Williamson, 2005). In Kenya, studies suggest that some 30% of production costs are for insecticides and their application, but this can range widely from 25 to 65% (Oruku and Ndun'gu, 2001). Currently, most farmers use the same broad spectrum insecticides for the control of both aphids and DBM, which may occur and be treated simultaneously, so costs are hard to partition between the two (Williamson, 2005). A major issue in addressing DBM control relates to the body of scientific opinion (Kfir, 2003) and some data (Cooper, 2002) indicates that serious outbreaks in Africa occur following applications of broad-spectrum insecticides for aphid or cutworm control, although other researchers reported that applications of insecticides did not result in increased attack by DBM (Oduor *et al*., 1997; Williamson,2003). While this resurgence pattern may not be consistent in all areas, it is probable that in any effective DBM management programme using DBM-resistant plants, the issue of controlling these other pests without exacerbating the DBM problem will be important for ensuring farmer satisfaction (Shelton, 2007).

1.1 The Control of Diamondback Moth Using IPM Techniques

The therapeutic approach of killing pest organisms with toxic chemicals has been the prevailing pest control strategy for over 50 years (Dent, 1999). Safety problems and ecological disruptions continue to ensue, and there are renewed appeals for effective, safe and economically acceptable alternatives (Goudegnon *et al*., 2000). Considerable effort has been directed toward such alternatives, and new technology has been implemented and is still emerging (Williamson, 2005). However, the major trend has been toward the use of modern chemistry and molecular biology to replace traditional pesticides with less hazardous chemicals or nontoxic biologically-based products (Lewis *et al.*, 1997; Shelton *et al*., 2008).

Integrated Pest Management (IPM) is an approach that keeps pest populations below a level causing economic loss through the judicious and compatible use of two or more control measures: biological, cultural, biology-based, genetic, physical/mechanical and chemical (Facknath, 1997a). Selection of the control measures adopted as part of an IPM package is based on available resources such as money, manpower, technical know-how, skills, the agroecosystem, geographical location and socio-economic factors among others (Williamson,2005). However, the general trend appears to incorporate three main components: chemical control using botanical pesticides or selected synthetic pesticides; biological control using parasitoids and cultural control using resistant varieties of crops and non host plants and trap crops (Facknath, 2000; Williamson, 2003; Shelton, 2004).

Mechanisms that influence floral diversification to maintain minimal population of diamondback moth specifically on cruciferous crops, have not been thoroughly tested (Cerruti *et al.*, 2003). Mechanisms accounting for herbivore responses to plant mixtures include reduced colonization, reduced adult tenure time in the marketable crop, and oviposition interference (Cerruti *et al.*, 2003). According to Badenes-Perez *et al.* (2005), cultural practices can have complex and significant impact on insect population dynamics. Understanding how cultural practices affect pest population dynamics is important for developing sustainable and environmental friendly approaches to pest management, especially in cases where insecticides are avoided.

An integrated pest management approach tries to manage conditions on the farm to benefit from the contribution of natural pest controls, such as weather, natural enemies, and the use of intercropping and trap cropping, crop rotation and other cultural management techniques (Dent, 1999). Multiple cropping has been practiced throughout the world for many centuries, and the efficiency of this cropping method to control diamondback month in brassica and in particular cabbage is used more by smallholder farmers and in organic agriculture. Intercropping offers farmers the opportunity to engage nature's principle of diversity on their farms (Srinivasan and Moorthy, 1992). The development of resistant crop varieties would provide an additional component in an integrated management strategy for this pest (Talekar and Shelton, 1993; Shelton *et al*., 2008).

Insecticide resistance and environmental and health concerns have triggered a growing interest in alternative management techniques such as trap crops and intercropping. Despite having been used for decades, trap crops proposed for diamondback moth control still remain unreliable preventing growers from being more open to trying this cultural technique (Badenes-Perez *et a*l., 2004). Planting crop mixtures which increase farmscape biodiversity, can make crop ecosystems more stable, and thereby reduce diamondback moth problems and increased biological control and natural enemies (Cerruti *et al.*, 2003).

1.2 Crop Diversity

Sustainable agriculture seeks, at least in principle, to use nature as the model for designing agricultural systems (Richardson, 1997). Crop pest management achieved by moving from simple monoculture to a higher level of diversity begins with viable crop rotations which break weed and pest life cycles and provide complementary fertilization to crops in sequence with each other (Roberts, 2000). Diversity can be increased by providing more habitats for beneficial organisms, habitats such as borders, windbreaks, and special plantings for DBM natural enemies (Gourdine *et al.,* 2003). On-farm diversity can be carried to an even higher level by integrating different species of beneficial insects and microorganisms. With each increase in the level of diversity comes an increase in stability (Bowen and Bernard, 1986).

The manipulation of the above practices for reducing or avoiding pest damage to crops is known as natural control. Since cultural control manipulations are based on habitat management and require a thorough understanding of different components of the agroecosystem or environments in which the pests thrive, this approach has also been called ecological management or environmental control. The purpose of cultural control practices is to make the environment less favourable for the pest or more favourable for its natural enemies (Dhaliwal and Arara, 2001).

1.3 Host Plant Resistance

Virtually all cruciferous crops are attacked by DBM although not all are equally preferred. The level of damage that DBM inflicts on crops is largely dependent on female ovipositional preference choices or host attractiveness as well as larval survival and suitability (Badenes-Perez *et al*., 2005). Plants posses a range of intrinsic resistance mechanisms against insects and these include hardness of plant tissues, leaf waxiness, trichomes, toxins, digestibility reducers and nutritional factors. In Brassicaceae, a promising source of resistance to DBM is the leaf wax characteristic of cauliflower which causes reduced survival of neonate larvae in field grown plants. These leaf wax characteristics make the plants highly preferred for oviposition by diamondback moth. Further, some plants facilitate host location by parasitoids and other natural enemies (Andrahennadi and Gillott, 1998).

1.4 Natural Enemies

Natural enemy populations have the unique ability of being able to interact with their prey or host populations and to regulate them at lower levels than would occur otherwise. Some are effective at extremely low prey levels, others only at higher levels (Gourdine et al). Natural control is the regulation of population within certain more or less regular upper and lower limits over a period of time by any one or any combination of natural factors be they biotic or abiotic (Khan *et al*., 2004). The most important factors are the parasitoids, predators and pathogens; weather and physical factors; food quantity and quality; interspecific competition; intraspecific competition; and spatial or territorial requirements for population movement (Bebach, 1975; Elwell and Maas, 1995).

Biological control is the regulation by natural enemies of another organism's population density at a lower average than would otherwise occur. Larvae, prepupae, and pupae of DBM are often killed by the parasitoids *Microplitis plutellae* (Muesbeck) (Hymenoptera: Braconidae), *Diadegma insulare* (Cresson) (Hymenoptera: Ichneumonidae), *Diadromus subtilicornis* (Gravenhorst) (Hymenoptera: Ichneumonidae), *Cotesia plutellae* (Hymenoptera; Braconidae) and *Oomyzus* sokolowskii (Hymenoptera; Eulophidae) (Waladde *et al.,* 2001). Natural enemies, be they local or imported can help to keep the pest at acceptable levels if they are conserved and their activity enhanced (Stoll, 2000). Habitat management and avoidance of broad-spectrum insecticides early in the season, when the diamondback moth is present in low numbers may preserve natural enemies that can help keep the pest populations under control later in the season (Waladde *et al.,* 2001).

All stages of the diamondback moth have numerous natural enemies, although larval parasitoids are the most prevalent and effective. Consequently, larval parasitoids have been more widely used to manage diamondback moth populations. *Diadegma insulare* is one of the most important parasitoids of diamondback moth. *D. insulare,* an endoparasitoid, feeds within the diamondback moth larva and emerges from the prepupa shortly after the host forms its cocoon. The synchronization of *D. insulare* with its host's developmental stage and excellent searching capacity makes it suitable for use as a supplemental method for the integrated management of diamondback moth (Khan *et al.*, 2004).

1.5 Chemical Control of Diamondback Moth

Currently, chemical insecticides still constitute the main control tactic for DBM often used indiscriminately and resulting in many undesirable problems (Smith and Villet, 2004). In terms of using chemical insecticides there is an urgent need to refocus their use towards a supplementary function, and integrating them within a more holistic IPM approach (Kennedy, 2008). To enable chemical insecticides to be used more prudently, there is need to identify more selective chemicals, improvement in application technology, applying narrow-spectrum chemicals to achieve ecological selectivity, correct timing and method of application, use of minimal effective dose, and applying appropriate formulations (Grzywacz *et al*., 2010).

Diamondback moth is resistant to many conventional pesticides and spraying DBM infested cabbage often has little effect on the pest; thus farmers may be tempted to carry out extensive spraying and eventually give up cabbage protection (Goudegnon *et al*., 2000; Youdeowei, 2002 and Eziah, *et al*., 2009). Furthermore, there is a growing concern about the pollution of the environment and its resultant effects on the health of humans and animals arising from the continued use of these pesticides. An effective and environmentally friendly approach in managing the DBM menace is thus required (Youdeowei, 2002).

Four major problems encountered with conventional pesticides are toxic residues, pest resistance, secondary pests, and pest resurgence (Srinivasan and Moorthy, 1992). The latter three are fundamental consequences of reliance on interventions that are both dis-ruptive and of diminishing value because of countermoves of the ecological system (Kwarteng and Towler, 1994). A mere switch to nontoxic pesticides, such as microbials or inundative releases of natural enemies, although helpful in reducing environmental contamination and safety problems, still does not truly address the ecologically based weakness of the conventional pest control approach (Lewis *et al*., 1997).

Microbial insecticides based on *Bacillus thuringiensis* (Bt) have been used for decades for the control of pest insects on a wide range of crops (Schuler *et al*., 2004). Extensive information is therefore available on their non-target impact and in the most cases no direct negative effects of microbial Bt formulations on parasitoids have been found (Glare and O'Callaghan, 2000).

Rotation of insecticide classes is recommended, and the use of *B. thuringiensis* is considered especially important because it favours survival of parasitoids. Even *B. thuringiensis* products should be rotated, and current recommendations generally suggest alternating the kurstaki and aizawai strains because resistance to these microbial insecticides occurs in some locations (Glare and O'Callaghan, 2000). Mixtures of chemical insecticides, or chemicals and microbials, are often recommended for diamondback moth control. This is due partly to the widespread occurrence of resistance, but also because pest complexes often plague crucifer crops, and the insects vary in susceptibility to individual insecticides (Talekar and Shelton, 1993).

Inconsistent control of the diamondback moth with synthetic insecticides, and later with Bt have demonstrated the need to develop a holistic approach for managing the diamondback moth. Thus, a strategy integrating cultural practices, scouting, using natural enemies, or improving the environment to enhance the effectiveness of natural enemies and the judicious use of Bt products and new chemistry insecticides must be developed for managing diamondback moth (Khan *et al*., 2004)

2.4 The Use of Intercropping to Control DBM

Insecticide resistance and environmental and health concerns have triggered a growing interest in alternative management techniques such as intercropping. Despite having been used for decades, trap crops proposed for DBM control still remain unreliable preventing growers from being more open to trying this cultural technique (Buranday and Raros, 1973; Srinivasan and Krishna, 1991; Badenes-Perez *et al*., 2004)

Intercropping is a traditional method of crop production, particularly in the tropics, which in addition can be used as a cultural control method (Andrahennadi and Gillott, 1998). Intercropping has been shown to successfully suppress a range of pests including nematodes, pathogens, insects and weeds (Facknath, 1997b). The method certainly also has some application and potential for use in low input farming of temperate regions. Intercropping is unlikely, however, to find a place in most modern agriculture until the research technology for intercrops is as well developed as it is today for monoculture and sole crops (Dent, 1999).

Deterrence of colonization is probably one of the most promising means of controlling insect pest through intra-field diversity, because only a little additional diversity in the crop field may have a profound effect on colonization by insects, both pest and beneficials. The diversity of a crop system can be increased by intercropping, trap cropping or by crops grown in the adjacent fields (Dhaliwal and Arara, 2001).

When interplanted, crops or weeds in the main crop are also suitable host plants for a particular pest as they may reduce feeding damage to the main crop by diverting the pest. On the other hand, these may also serve as an essential source of food or shelter at some point in the life cycle or during some part of the season, enabling the pest to maintain or build up its numbers in the field and so attack the main crop more severely (Dhaliwal and Arara, 2001; Said and Itulya, 2003).

Tactics used for choosing companion plants, and the future perspective for mixed-crucifer crops usage provide some evidence that habitat manipulation techniques that impact crop growth include intercropping, under sown non-host plants and vegetation borders. So, the indirect role habitat manipulation plays in the population dynamics of diamondback moth pests and natural enemies still remains unclear in many systems (Cerruti *et al.*, 2003).

There is overwhelming evidence that plant mixtures support lower numbers of pests than pure stands as higher natural enemy populations persist in diverse mixtures due to more continuous food sources of nectar, pollen, and prey and favourable habitat (Innis, 1997; Grundy and Short, 2003). Insects that feed on only one type of plant have greater opportunity to feed, move around and breed in pure crop stands because their resources are more concentrated than they would be in a crop mixture. In essence, crops growing together in a mixture complement one another, resulting in lower pest levels (Grossman and William, 1993). Integrated pest management using intercropping techniques aids diamondback moth pest control efforts by reducing the ability of the pest insects to recognize their host plants (Lim, 2000).

The effect of more diversified cropping systems on pest populations are varied and may interfere with the host-seeking behaviour of the pest by camouflaging the many crop plants, changing the texture or colour of the crop background; diverting the pest away from the main crop to a secondary host which is more attractive (Bowen and Bernard 1986, Perez *et al.,* 2004). Spatial arrangements of plants, planting rates, and maturity dates must be considered when planning intercrops (Stoll, 2000). Intercrops can be more productive than growing pure stands, including mixed intercropping, strip cropping, and traditional intercropping arrangements. Pest management in cabbage benefits can also be realized from intercropping due to increased diversity of the natural enemy population of diamondback moth (Asare-Bediako *et al.*, 2010). Understanding why trap crops work requires identifying the basic mechanisms by which insects prefer them to other possible hosts. Insects are particularly attracted to certain plants because of chemical olfactory or gustatory, physical tactile or visual stimuli. In *P. xylostella* and other crucifer specialists, glucosinolates and their volatile hydrolysis products seem to be the main attractants and oviposition stimulants (Badenes-Perez *et al.*, 2004).

For some situations, intercropping has reduced pest populations due to three reasons (i) because the plants act as physical barriers to the movement of pest insects, (i) because natural enemies are more abundant or (iii) the visual communication between pest insects and their host plants is disrupted (Talekar and Shelton, 1993). To have persisted, intercropping had to have merit biologically, environmentally, economically, and sociologically. To gain acceptance, any agricultural practice must provide advantages over other available options in the eyes of the practitioner. Thus many of the impediments to adoption of new strategies or practices of diversification are sociological rather than technological (Talekar and Shelton, 1993). Farmers have generally regarded intercropping as a technique that reduces risks in crop production; if one member of an intercrop fails, the other survives and compensates in yield to some extent, allowing the farmer an acceptable harvest.

CHAPTER THREE

3 MATERIALS AND METHODS

The study was conducted at Africa University and was composed of two trials focusing on intercropping and the use of insecticides in DBM control. Each trial had five treatments replicated three times in a Randomized Complete Block Design (RCBD). Cabbage seedlings of the cultivar Drumhead and tomato seedlings of the cultivar Rodade were raised in a greenhouse on 16 of August 2010 and transplanted into field plots on 29 September 2010. At transplanting, a basal dressing of compound S (7-21-8, 7.5 % S) was applied at a rate of 300 kg/ha. At 40 days after transplanting, a top dressing of ammonium nitrate (34.5 % N) was applied at a rate of 100 kg/ha. Cultural practices such as weed control and overhead irrigation were carried out as when necessary.

1.6 Intercropping Trial

The objective of the trial was to evaluate the effects of intercropping cabbage with various vegetables on the population density and parasitism of DBM. A secondary objective was to evaluate the impact of intercropping on cabbage quality and bacterial black rot disease incidence.

3.1.1 Treatment combinations

The trial consisted of five treatments replicated three times in a Randomized Complete Block Design (RCBD). The treatment combinations used are given in Table 3.1

Table 3.1 Treatment combinations for the intercropping trial.

Treatment	Combinations of Intercrops
1. Cabbage	Sole Cabbage (*Brassica oleracea* var. *Capitata*) as a control
2. Cab- tomato	Cabbage (*Brassica oleracea* var. *capitata*)-Tomato (*Lycopersicon*

	esculentum)
3. Cab-Juncea	Cabbage (*Brassica oleracea* var. *capitata*) - *Brassica juncea*
4. Cab-Cleome	Cabbage (*Brassica oleracea* var. *capitata*) – *Cleome gynandra*
5. Juncea	Sole *Brassica juncea*

1.6.1 Set up of the field trial

The cabbage was planted using an inter row spacing of 0.90 m and an intra-row spacing of 0.30 m. There were 4 rows per plot with 12 plants per row, making a total of 48 plants per plot. For the cabbage-tomato intercrop, the tomato seedlings were transplanted between the cabbage rows resulting in three rows with 12 plants per row yielding a total of 36 tomato plants per plot (Plate 3.1). For the cabbage-*B. juncea* (Plate 3.2) and the cabbage-*C. gynandra* intercrops, the *B. juncea* and *C. gynandra* seeds were sown *in situ* between the cabbage rows and thinned to two plants per station at two weeks after emergence. In each respective treatment there were three rows per plot and the plant stations were 0.30 m apart within the row. For the sole *B. juncea* treatment the seeds were sown *in situ* and there were 48 planting stations per plot with two plants per station.

Plate 3.1: Cabbage intercropped with tomato

Plate 3.2: Cabbage intercropped with *Brassica juncea.*

3.2 Chemical Control Trial

The objective of the trial was to evaluate the effects of different insecticides on the population density and parasitism of DBM. A secondary objective was to evaluate the effect of insecticides on cabbage quality and the incidence of bacterial black rot disease.

3.2.1 Treatments for the insecticides trial

Table 3.2 Treatments for the insecticides trial

Treatment	Active Ingredient	Rate
1. Control	-	-
2. Match 5 EC	Lufenuron	10 ml/15 l of water
3. Malathion 50 EC	Malathion	25 ml/10 l of water
4. Malathion 25 PW	Malathion	30 g/15 l of water
5. Decis 2.5 EC	Deltamethrin	15 ml/10 l of water

3.2.2 Field set up of the insecticides trial

Cabbage seedlings were transplanted into the field plots at an inter-row spacing of 0.90 m and in intra-row spacing of 0.30 m. There were four rows per plot with 12 plants per row giving a total of 48 plants per plot. Four insecticide treatments were used and the rates and active ingredients are shown in Table 3.2. Each treatment was replicated three times in a Randomized Complete Block Design (RCBD). Diamondback moth populations were left to build up for the first four weeks after transplanting and the insecticide treatments were applied on the fifth week. Further insecticide applications were stopped due to increased rainfall activity as from week six after transplanting (see Appendix C for the rainfall pattern).

3.3 Data Collection

For both the intercropping and insecticide trials, sampling for DBM larvae and parasitoids was done weekly for 16 weeks which covered all the phenological stages of the crops. A total of 20 plants per plot were sampled targeting the two central rows as the net plot. In each net plot row sampled, the first and last plants were left out. A total of 300 plants per trial were sampled during each sampling session. A scouting form was used to record counts of small DBM larvae (1^{st} -2^{nd} instars), large DBM larvae (3^{rd}- 4^{th} instars), DBM pupae and parasitized DBM larvae or pupae noted as parasitoid cocoons in the field (see Appendices A and B).

Data were also taken on the mean number of cabbage heads damaged at harvest and mean head weights at harvest. The incidence and severity of bacterial black rot disease was also recorded in both the intercropping and insecticide trials (see Appendices D and E).

3.4 Laboratory Rearing of Larvae and Pupae

To determine parasitism levels in the field, DBM larvae and pupae collected in the field were placed in Perspex plastic cups and taken to the Africa University entomology laboratory, and maintained in a cool room at a temperature of approximately 18-25°C, and 60-70% relative humidity. The individual Perspex plastic diet cups holding individual larvae or pupae were labeled with the collection date, locality, plot, treatment and host plant. Larvae were fed with fresh cabbage leaf discs until pupation. The development of each specimen was registered individually until a DBM adult or parasitoid emerged. Specimens of the parasitoids were kept for further identification.

3.5 Parasitoid Identification

Parasitoid specimens were fixed in 70% ethanol in glass vials. Parasitoid identification was based predominantly on wing morphology, using taxonomic keys in Azidah *et al.* (2000). A stereo-microscope was used to view the specimens and dissect the forewings at a magnification of X4.0. The dissected forewings were mounted on slides and viewed under a compound microscope at a magnification of X40. A Motic Images digital microscopic camera (Moticam 1000®) was used to take images of the wing morphology for identification purposes (see Plate 4). Voucher specimens of pest species and parasitoids were deposited in the Africa University (AU) Entomology Collection.

1.7 Disease Assessment

The incidence and severity of bacterial black rot disease of brassicas (Plate 3.3) caused by the bacterium *Xanthomonas campestris* pv. *campestris* is influenced by crop management practices. In this regard, records of black rot incidence and severity were taken in order to determine the effects of intercropping and insecticide treatments. Disease severity was determinate using a scale of 1 to 5, in which 1= no disease and 5= whole plant dead (see Appendix D). A scoring sheet was used to record the black rot disease incidence, severity and disease index (see Appendix E). The disease index was determinate by multiplying the disease incidence by severity; Disease Index = (Disease incidence x Disease severity).

Plate 3.3: Bacterial black rot disease on cabbage head.

3.6 Data Analysis

Minitab Statistical Package Version 15 (Minitab, 2006) was used to generate means of DBM counts and percentage parasitism for the trial data. For the assessment of treatment effects on DBM populations, ANOVA tests were done at p=0.05, p= 0.01 and p=0.001 to compare means of small DBM larvae, large DBM larvae, DBM pupae, parasitized DBM larvae, eclosed DBM larvae and dead DBM larvae. Data on cabbage head damage, yields, disease incidence and severity, and the disease indices were also subjected to ANOVA. Graphs were prepared using Microsoft Excel.

CHAPTER FOUR

4 RESULTS

4.1 Effect of Intercropping on DBM Larval and Pupal Density

Low DBM population density was found in the cabbage intercropped with tomatoes and *B. juncea.* Figure 4.1 shows the weekly mean larval density, in which cabbage intercropped with tomato and *B. juncea* had lower larval density. However, cabbage planted as sole crop had a higher larval density compared to the other treatments.

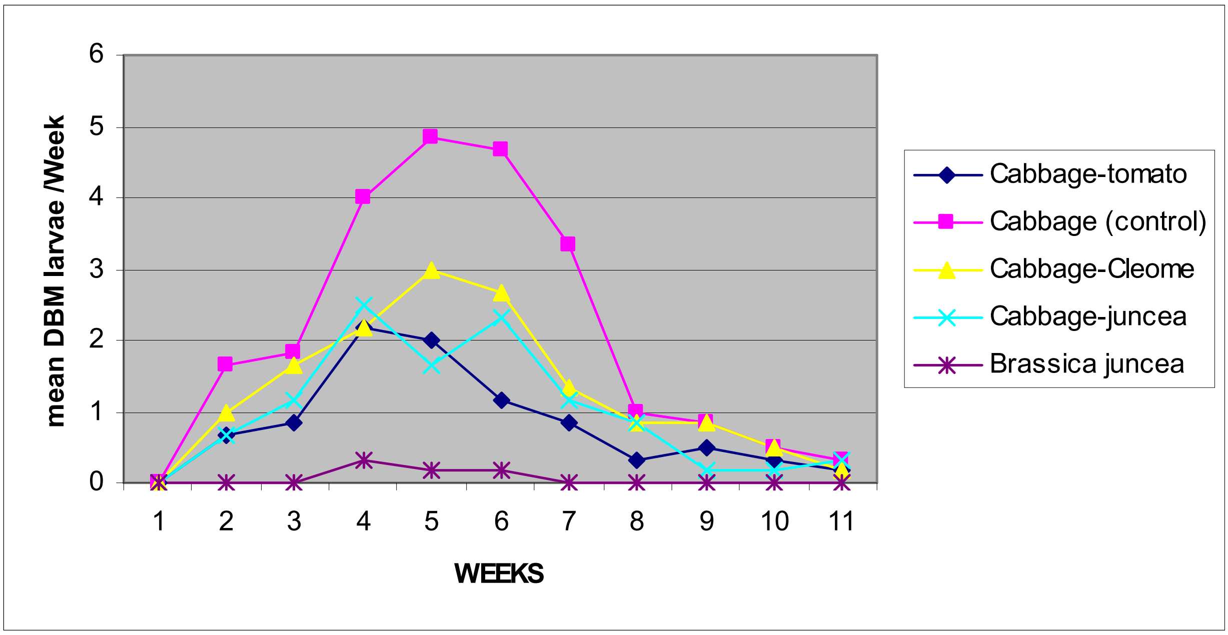


Figure 4.1: Effect of intercropping on mean DBM larval density per week

Comparison of infestation levels in the sole cabbage with cabbage intercropped with different crops such as tomato, *C. gynandra* and *B. juncea* revealed that diamondback moth larval and pupal infestation were significantly higher ($p<0.001$) in sole cabbage for the small larvae (1^{st} and 2^{nd} instars), large larvae (3^{rd} and 4^{th} instars) and pupae compared to the other treatments (Table 4.1). *B. juncea* had a significantly lower ($P<0.001$) larval density compared to the other treatments across all larval instars.

The mean density of small larvae (1st and 2sd instars) on sole cabbage (control) was significantly higher (P<0.001) with 2.42 DBM larvae per plant. *B. juncea* planted as sole crop had the lowest density of 0.03 small DBM larvae per plant (P<0.001). The mean small DBM larvae of 1.09 recorded on cabbage intercropped with *B. juncea* was not significantly different from the mean of 1.33 small larvae per plant recorded on cabbage intercropped with *C. gynandra* (Table 4.1). Large DBM larvae (3rd and 4th instars) had significantly high levels (P<0.001) of infestation on sole cabbage (2.06 larvae per plant) while sole *B. junce*a had the lowest (0.09 larvae per plant) infestation on cabbage intercropped with tomato and cabbage intercropped with *B. junce*a were not significantly different. Cabbage intercropped with *B. juncea* and cabbage intercropped with *C. gynandra* were also not significantly different in terms of infestation by large DBM larvae. Sole cabbage had a significantly higher (P<0.001) number of pupae recorded at 0.55 pupae per plant. There were no significant differences in the pupae recorded in the cabbage-tomato intercrop and in the cabbage-*Brassica juncea* intercrop. No pupae were recorded in the sole *Brassica juncea* (Table 4.1).

Table 4.1: Effect of intercropping on mean DBM larval and pupal density per plant.

Treatments	**Mean small larvae ± SE**	**Mean large larvae ± SE**	**Mean pupae ± SE**
Cabbage –tomato	0.94 ±0.053 b	0.97 ± 0.191 b	0.21 ± 0.052 b
Cabbage (sole)	2.42 ±0.229 e	2.06 ± 0.051 e	0.55 ± 0.091 e
Cabbage - *Cleome gynandra*	1.33 ±0.139 cd	1.33 ± 0.189 cd	0.39 ± 0.052 cd
Cabbage - *Brassica juncea*	1.09 ±0.091 bc	1.12 ± 0.105 bc	0.33 ± 0.052 bc
Brassica juncea (sole)	0.03 ±0.053 a	0.09 ± 0.091 a	0.00 ± 0.000 a
Significance	***	***	***

Means within a column followed by different letters are significantly different from each other (P<0.001).

4.1.1 Effect of intercropping on DBM larval parasitism, eclosion and death by unknown causes in laboratory rearing.

4.1.1.1 Parasitoid identity

DBM parasitoid specimens were obtained from field colleted DBM larvae after rearing in the laboratory for a week. The parasitoid found was the solitary larval endoparasitoid *Cotesia plutellae* which was identified using the venation of the forewing mounted on slides and viewed under a compound microscope at a magnification of X40. The wing venation is shown in Plate 4.1.

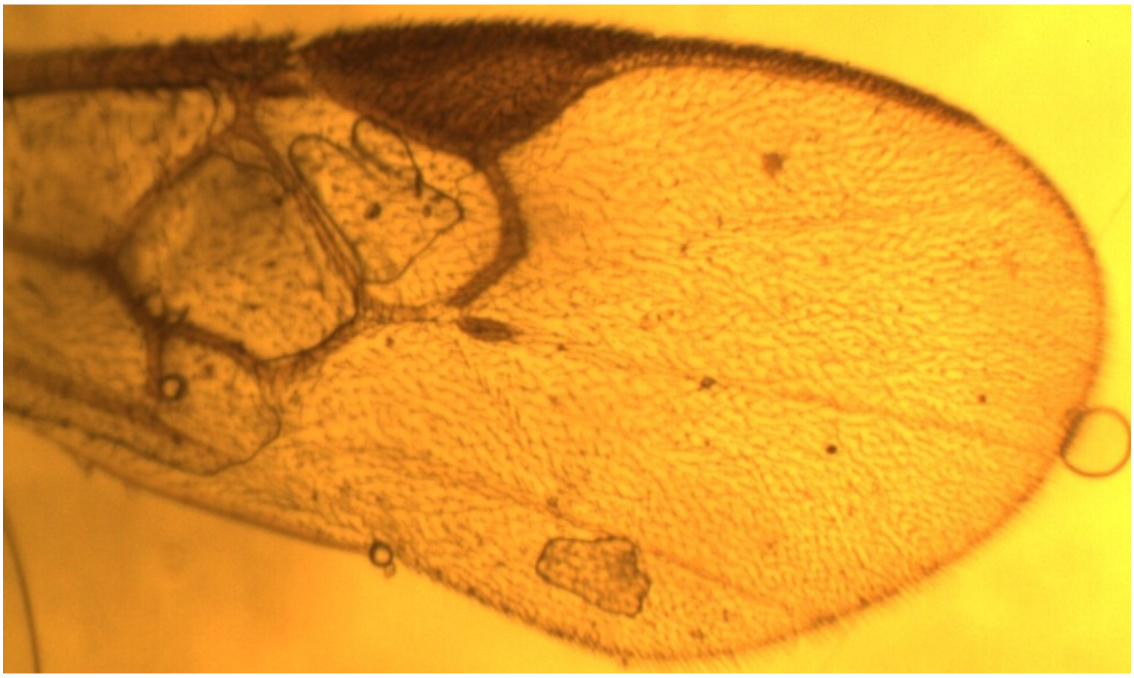


Plate 4.1: Forewing of the endoparasitoid *Cotesia plutellae* (Hymenoptera: Braconidae).

The number of larvae that eclosed into diamondback moth adults varied among the treatments (Table 4.2). The number of larvae that eclosed on sole cabbage was significantly higher ($P<0.001$) than those that eclosed in the cabbage-tomato intercrop and the cabbage-*B. juncea* intercrop. There was no significant difference in the number of larvae that eclosed in the cabbage-C *gynandra* intercrop and cabbage alone as a control. No larvae from the sole *B. juncea* eclosed.

There was a significantly higher (P<0.001) level of larval parasitism in the cabbage-tomato intercrop (Table 4.2). However, there was no significant difference in larval parasitism between cabbage-tomato intercrop and cabbage-*B. juncea* intercrop. There was no parasitism in the larvae collected from the sole *B. juncea*. There were no significant differences in the number of larvae that died of unknown causes across all treatments with the exception of *B. juncea* (Table 4.2).

Table 4.2: Effect of intercropping on DBM larval parasitism, eclosion and death from unknown causes.

Treatments	**Mean eclosed larvae ± SE**	**Mean parasitized larvae ± SE**	**Mean dead larvae ± SE**
Cabbage –tomato	0.77 ± 0.058 b	0.60 ± 0.100 d	0.50 ± 0.100 b
Cabbage (sole)	1.20 ± 0.200 cd	0.23 ± 0.058 b	0.33 ± 0.058 b
Cabbage – *Cleome gynandra*	0.90 ± 0.100 bc	0.37 ± 0.058 bc	0.43 ± 0.115 b
Cabbage - *Brassica juncea*	0.77 ± 0.208 b	0.47 ± 0.058 cd	0.47 ± 0.208 b
Brassica juncea (sole)	0.00 ± 0.000 a	0.00 ± 0.000 a	0.00 ± 0.000 a
Significance	***	***	***

Means within a column followed by different letters are significantly different from each other (P<0.001).

4.1.2 Effect of intercropping on cabbage head Damage by DBM and cabbage Head Weight at Harvest (ton/ha)

The number of cabbage heads damaged by diamondback moth larvae varied among the treatments (Table 4.3). Head damage on sole cabbage was significantly higher (P<0.01) than that on cabbage intercropped with tomato, cabbage with *B. juncea* and cabbage with *C. gynandra*. There was no significant difference in cabbage head damage in the cabbage-tomato intercrop, cabbage-*B. juncea* intercrop and cabbage-*C. gynandra* intercrop. There were also no significant differences (p<0.01) in cabbage head damage between the cabbage-*Cleome gynandra* intercrop and sole cabbage as a control. The mean cabbage yield was significantly lower (P<0.01) on sole cabbage with 23.32 ton/ha compared with the cabbage-tomato intercrop that yielded 42.72 ton/ha and the cabbage-*B. juncea* intercrop that yielded 41.42 ton/ha (Table 4.3). Cabbage intercropped with tomato and cabbage intercropped with *B. junce*a did not differ significantly in cabbage yield. The cabbage-*C. gynandra* intercrop had a significantly different yield (P<0.01) from the cabbage-tomato intercrop, cabbage-*Brassica juncea* intercrop and sole cabbage (Table 4.3).

Table 4.3: Effect of intercropping on cabbage head damage by DBM at harvesting.

Treatments	Mean head damage ± SE	Yield Ton/ha ± SE
Cabbage-tomato	2.33 ± 1.155 a	42.71 ± 2.973 c
Cabbage (sole)	7.33 ± 2.082 b	23.32 ± 2.436 a
Cabbage - *Cleome gynandra*	4.33 ± 0.577 ab	33.36 ± 4.347 b
Cabbage - *Brassica juncea*	3.00 ± 1.000 a	41.42 ± 2.462 c
Significance	**	**

Means within a column followed by different letters are significantly different from each other (P<0.01).

4.1.2 Effect of intercropping on bacterial black rot disease incidence and severity

Bacterial black rot disease incidence and disease severity in the cabbage-tomato intercrop and the cabbage-*B. juncea* intercrop were significantly lower (P<0.05) compared with sole cabbage (Table 4.4). There was no significant difference (P>0.05) between the cabbage-tomato intercrop and the cabbage-*Brassica juncea* intercrop. Sole cabbage had a significantly higher (P<0.05) disease index than the other treatments but was not significantly different from the cabbage-*C. gynandra* intercrop and the cabbage-*Brassica juncea* intercrop.

Table 4.4: Effect of intercropping on bacterial black rot disease incidence and severity

Treatments	Incidence ± SE	Severity ± SE	Disease index ± SE
Cabbage-tomato	12.51 ± 1.93 a	1.88 ± 0.385 b	27.46 ± 5.73 a
Cabbage (sole)	72.72 ± 18.61 cd	3.21 ± 0.316 cd	246.87 ± 79.14 bc
Cabbage-*Cleome gynandra*	65.20 ± 28.86 bc	2.61 ± 0.392 bc	177.85 ± 88.82 ab
Cabbage-*Brassica juncea*	47.62 ± 28.02 ab	2.96 ± 0.793 cd	155.18 ± 136.04 ab
Brassica juncea (sole)	0.00 ± 0.00 a	0.000 ± 0.00 a	0.00 ± 0.00 a
Significance	*	*	*

Means within a column followed by different letters are significantly different from each other (P<0.05).

4.2 Effect of Insecticides on DBM Larval and Pupal Density

DBM larval and pupal densities were determined before and after spraying with different insecticides. The highest DBM population density was found in unsprayed cabbage (control treatment), Figure 4.2 shows the weekly mean larval density during the period from the first week of October to the last week of December. The DBM larval density reached a peak mean of about 4.5 larvae per plant during the first week of November. Insecticide spraying was done during the fifth week. The untreated cabbage remained with a high DBM population density up to the eighth week. Thereafter the DBM population declined probably due to increasing rainfall activity (Figure 4.2 and Appendix C). At week

6 all the treatments except the control had a mean DBM population density bellow the economic threshold level of 1 larva per plant. As from week 9 the untreated control also reached a DBM larval density bellow 1 larva per plant.

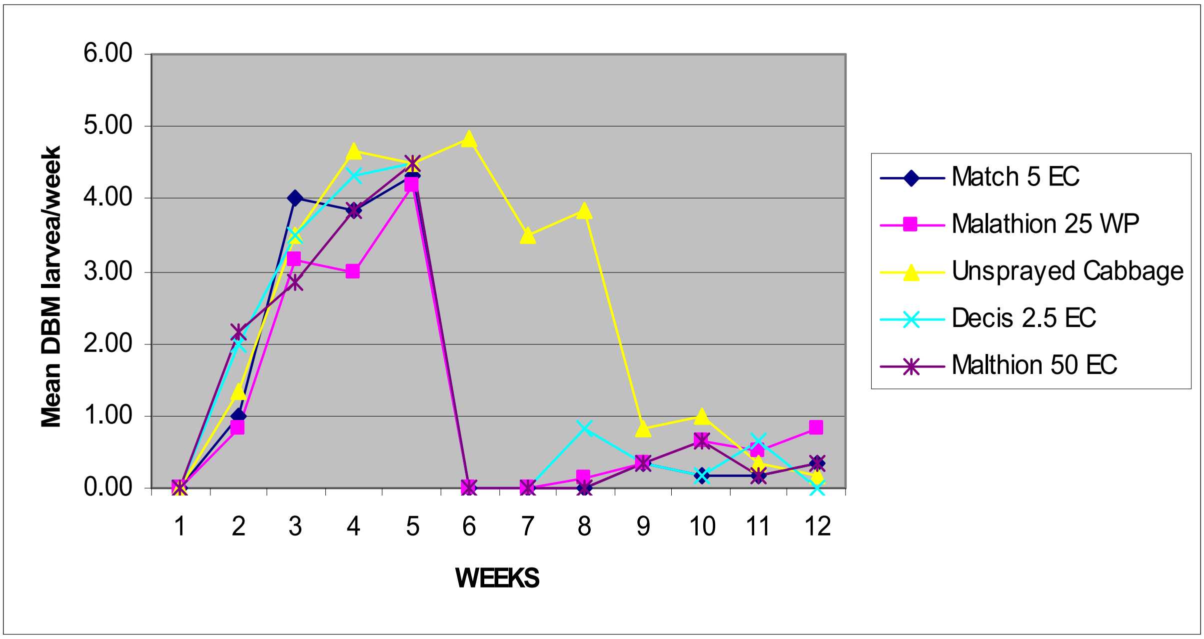


Figure 4.2: Effect of insecticide on mean DBM larvae density per week

Mean DBM larval density was highest (P<0.001) on the untreated cabbage (2.6 small larvae per plant and 2.0 large larvae per plant) (Table 4.5). The lowest DBM larval density (P<0.001) was on cabbage sprayed with Match 5 EC which had a mean of 0.92 small larvae per plant and 0.98 large larvae per plant. Comparison of infestation levels between the untreated cabbage and cabbage treated with Match 5 EC, Malathion 25 WP, Malathion 50 EC and Decis 2.5 EC revealed that diamondback moth larval and pupal infestation levels were significantly higher (P<0.001) on untreated cabbage for the small larvae, large larvae and pupae compared to the other treatments. Cabbage treated with Match 5 EC had a significantly lower (P<0.001) density of small larvae compared to the other treatments. The mean small DBM larval density of 1.28 small larvae per plant recorded on cabbage treated with Decis 2.5 EC was not significantly different (p>0.001) from the mean of 1.47 small larvae per plant recorded on cabbage treated with Malathion 50 EC

Untreated cabbage had the highest infestation by large DBM larvae (2.00 larvae/plant) while cabbage treated with Match 5 EC had the lowest (0.98 larvae/plant) (P=0.001). Infestation by large DBM larvae on cabbage treated with Match 5 EC and cabbage treated with Malathion 25 WP were not significantly different (p>0.001). Cabbage treated with Decis 2.5 EC and with Malathion 50 EC were also not significantly different in terms of infestation by large DBM larvae. Untreated cabbage had the highest (P<0.001) number of DBM pupae (0.64 pupae per plant). On the other hand there were no significant differences in the number of DBM pupae recorded in the cabbage treated with Match 5 EC, Malathion 25 WP, Malathion 50 EC and Decis 2.5 EC.

Table 4.5: Effect of insecticides on DBM larval and pupal density.

Treatments	Mean small larvae ± SE	Mean large larvae ± SE	Mean pupae ± SE
Match 5 EC	0.92 ± 0.083 a	0.98 ± 0.106 a	0.25 ± 0.083 a
Malathion 25 WP	1.18 ± 0.076 b	0.97 ± 0.153 a	0.28 ± 0.048 ab
Control	2.60 ± 0.127 e	2.00 ± 0.091 c	0.64 ± 0.091 c
Malathion 50 EC	1.47 ± 0.058 cd	1.30 ± 0.100 b	0.43 ± 0.058 ab
Decis 2.5 EC	1.28 ± 0.110 bc	1.24 ± 0.139 b	0.30 ± 0.052 ab
Significance	***	***	***

Means within a column followed by different letters are significantly different from each other (p<0.001).

4.1.3 Effect of insecticides on DBM larval parasitism, eclosion and death by unknown causes in laboratory rearing

In the insecticides trial, the number of larvae that eclosed into diamondback moth adults varied among the treatments (Table 4.6). The number of larvae that eclosed on untreated cabbage was significantly higher (P<0.01) than those that eclosed in the cabbage that was sprayed with Match 5 EC, Malathion 25 WP, Malathion 50 EC and Decis 2.5 EC. The number of DBM larvae that eclosed from the cabbage treated with Match 5 EC, Malathion 25 PW, Malathion 50 EC and Decis 2.5 EC were not significantly different (p>001). There was a significantly higher (P<0.01) level of DBM larval parasitism in the untreated cabbage than in the four insecticide treatments which were not significantly different from each other. There were no significant differences (P>0.01) in the number of larvae that died of unknown causes across all treatments.

Table 4.6: Effect of insecticide on DBM larval parasitism, eclosion and death.

Treatments	Mean of larvae eclosed ± SE	Mean larvee parasitized ± SE	Mean larvae dead ± SE
Match 5 EC	0.77 ± 0.152 a	0.27 ± 0.058 a	0.40 ± 0.000
Malathion 25 WP	0.77 ± 0.116 a	0.20 ± 0.100 a	0.43 ± 0.115
Control	1.23 ± 1.233 bc	0.47 ± 0.058 b	0.37 ± 0.058
Malathion 50 EC	1.00 ± 0.100 ab	0.13 ± 0.058 a	0.50 ± 0.000
Decis 2.5 EC	0.93 ± 0.239 ab	0.17 ± 0.058 a	0.33 ± 0.058
Significance	**	**	NS

Means within a column followed by different letters are significantly different from each other (p<0.01). NS= No significant difference.

4.2.1 Effect of insecticides on cabbage head Damage by DBM and yield

The number of cabbage heads damaged on untreated cabbage was significantly higher ($P<0.001$) than those on cabbages treated with Match 5 EC, Malathion 25 WP and Malathion 50 EC (Table 4.7). There was no significant difference ($P>0.001$) in cabbage head damage between the untreated cabbage and cabbage treated with Decis 2.5 EC. There was no significant difference ($P<0.01$) in cabbage head damage between Match 5 EC, Malathion 25 WP and Malathion 50 EC. There was also no significant difference ($P>0.001$) in mean cabbage head damage between cabbage treated with Malathion 25 WP, Malathion 50 EC and Decis 2.5 EC. There was no significant difference ($P>0.001$) in cabbage yield across all treatments (Table 4.7).

Table 4.7: Effect of insecticides on cabbage head damage by DBM and yields (ton/ha).

Treatments	Mean head damage ± SE	Yield ton/ha± SE
Match 5 EC	1.33 ± 0.577 a	39.36 ± 1.381
Malathion 25 WP	3.00 ± 1.000 ab	39.73 ± 1.710
Control	7.67 ± 1.155 d	25.46 ± 2.808
Malathion 50 EC	3.33 ± 0.577 ab	37.32 ± 3.125
Decis 2.5 EC	4.00 ± 1.000 bc	40.29 ± 5.287
Significance	***	NS

Means within a column followed by different letters are significantly different from each other ($p<0.001$). NS= No significant difference.

CHAPTER FIVE

5 DISCUSSION

Early summer (October to November) DBM larval density reached the threshold value of 1 larva per plant and was too high to be adequately controlled by the endoparasitoid *C. plutellae* alone. Similar results were recorded by Dobson *et al.* (2002) in a study in peri-urban smallholder vegetable growing farms around Harare in Zimbabwe. It is advisable for farmers to take appropriate control measures against DBM during this critical period in order to avoid crop loss. One way of managing DBM populations in Brassica crops is through Integrated Pest Management (IPM) which is the practical application of ecological principles such as diversity, crop interaction and other natural regulation mechanisms (Wolfe, 2000; Boucher and Durgy, 2003). Intercropping is defined as the growing of two or more crops in proximity in the same field during a growing season to promote interaction between them (Sullivan, 2003). *Brassica juncea* is an attractive crop for DBM oviposition and intercropping with cabbage helps to lure the DBM away from the cabbage (Said and Itulya, 2003; Stoll, 2003; Meyer, 2007). In general, trap crops are used to protect the main cash crop from diamondback moth damage and can be a different plant species, variety, or just a different growth stage of the same species as the main crop, as long as it is more attractive to the diamondback moth adults when they are present (Boller and Hani, 2004).

Results from the study show that tomato intercropped with cabbage reduced the mean population of DBM to 0.94 small larvae and 0.97 large larvae per plant, and also reduced bacterial black rot disease incidence on cabbage and improved cabbage head quality. Badenes-Perez *et al*. (2005) confirm that using tomato could disrupt host finding and subsequent oviposition by DBM adults on cabbage. Intercropping cabbage with tomato promotes crop diversity and stability and can result in enterprise diversification that leads to risk reduction through stability of income and obtaining more crop yield in a given area, which is an important reason why farmers diversify their crops (Meyer, 2007). Increasing diversity on-farm also reduces costs of diamondback moth pest control, because these costs can be spread out over several crops as well as aiding biological control and co-operation between species (Facknath, 2000).

Trap crops such as *B. juncea* were a poor host for the DBM larvae as these serve as a sink rather than a source for subsequent generations (Bedenes-Perez *et al*., 2004). Larvae of DBM on B*. junce*a do not develop well because, the species is only suitable for oviposition and not as a source of nourishment for immature DBM stages (Bedenes-Perez *et al.,* 2004).

The effectiveness of biological control agents may be enhanced in mixed *Brassica* habitats. However, many agro-ecosystems are unfavorable environments for natural enemies due to high levels of disturbance and the incorrect use of agronomic techniques and tactics to enhance biological control (Landis *et al.,* 2000). The significantly higher DBM numbers recorded on the sole cabbage compared with the cabbage-tomato intercrop, cabbage-*Brassica juncea* and cabbage-*C. gynandra* is an indication of the effectiveness of intercropping in protecting cabbage from DBM damage. This observation corresponds with work by Steiner (1982) who noted that mixed-brassica-cropping systems sustain lower pest damage compared with sole cabbage and this was also noted by Hooks and Johnson (2003).

The significantly higher head damage recorded on the sole cabbage attests to the fact that monocultures with a narrow genetic base could lead to explosion of DBM numbers on cabbage resulting in poor head quality. This is consistent with observations by Hill and Waller (1982).

Cultural methods of controlling pests are very useful and effective but have not received the needed attention and support. Low diamondback moth populations have been reported in intercropped fields and the cabbage-tomato intercrop was reported to reduce DBM infestation in cabbage (Altieri and Leibman, 1994; Trevor, 1990; Ofuya, 1991; Theunissen *et al*., 1994; Makumbi, 1996; Facknath, 2000; Said and Itulya, 2003; Stoll, 2003; Bijlmaker, 2005; Meyer, 2007). It is believed that the odour from the tomatoes has repellent and deterring effects on DBM and also has some effects on oviposition as reported by Endersby and Morgan (1991), Stoll (2003), Minja *et al*. (2003) and Silva-Aguayo (2007).

Trap crops my also attract natural enemies thus enhancing natural control. However, it needs to be emphasized that the trap crop just acts to maintain their host or prey. Natural enemies are likely to be destroyed by insecticide sprays. A thorough understanding of the agroecosystem is therefore, essential for recommending trap cropping as a means for minimizing pest damage (Dhaliwal and Arara, 2001).

Badenes-Perez *et al.* (2005) confirm that using tomatoes as a repellent or nonhost crop could disrupt host finding and subsequent oviposition by DBM adults. In intercropping, the available growth resources, such as light, water and nutrients are more completely absorbed and converted to crop biomass by the intercrop as a result of differences in competitive ability for growth factors between intercrop or trap crop components (Facknath, 2000). The more efficient utilization of growth resources leads to yield advantages and increased stability to control diamondback moth and other pests in intercrops compared to sole cabbage (Sullivan, 2003).

Planting intercrops that feature staggered maturity dates or development periods takes advantage of variations in peak resource demands for nutrients, water, and sunlight. Having one crop mature before its companion crop lessens the competition between the two crops (Charleston and Kfir, 2000). Selecting crops or varieties with different maturity dates can also assist staggered harvesting and separation of commodities. An important quality for a trap crop to be effective is that it must be more attractive to the pest as either a food source or oviposition site than the main crop (Altieri and Leibman, 1994; Bedenes-Perez *et al*., 2004.

The solitary larval endoparasitoid *Cotesia plutellae* was the major parasitoid of DBM at AU farm and parasitism was highest from the cabbage-tomato intercrop and followed by cabbage-*Brassica juncea* then cabbage-*C. gynandra.* Cabbage planted as a sole crop recorded the lowest parasitism. Charleston and Kfir (2000) in South Africa noted that DBM larval parasitism by *C. plutellae* was high on cabbage intercropped with tomato compared to other treatments.

The natural enemies' hypothesis emphasizes the role of diverse habitats in attracting and maintaining higher populations of natural enemies that subsequently exert a level of control over the diamondback moth pest species present. An intercrop is considered to provide more favourable conditions than a monocrop by providing a greater temporal and spatial distribution of nectar and pollen source and alternative prey when the pest species are scarce. There have been a number of studies that indicate the natural enemy abundance is increased in more diverse intercrop situations. However, in most studies undertaken there has been little evidence to suggest that they significantly contribute to reduced pest levels (Dent, 1999; Asman, 2002).

Parasitoids are particularly susceptible to chemical insecticides and understanding their role in the ecosystem is important for implementing integrated pest management tactics Shepard *et al*, (1999). The use of synthetic insecticides still constitutes the main control practice against DBM in a wide range of situations. While the use of synthetic insecticides does reduce DBM larval populations to levels that do not cause economic damage as noted in the study, insecticides also reduce the population of parasitoids (Facknath, 2000). Similar results were noted in the North-West Province of South Africa by Kfir, (1998) and in the Eastern Cape Province by Waladde *et al*. (2001). Synthetic insecticides applied on cabbage also have detrimental effects on *C. plutellae* as reported by Endersby and Morgan (1991) and Stoll (2003). The overall use of pesticides is clearly less beneficial than in traditional farming systems which are environmentally attractive (Facknath, 2000).

There are situations where the use of insecticides has not had any negative effects on natural enemies. Results recorded by Lim (2000) in Malaysia noted that when Carbaryl plus Malathion were sprayed on cabbage they did not completely eliminate the *C. plutellae* population. Similar results were noted in South Africa where parasitism by *C. plutellae* was observed in cabbage plots treated regularly with synthetic insecticides such as methamidophos and cypermethrin (Waladde *et al,* 2001). This might indicate some level of tolerance or resistance by the local populations of *C. plutellae*.

CHAPTER SIX

6 CONCLUSION AND RECOMENDATIONS

The study demonstrated the impact of intercropping cabbage with tomatoes in managing DBM populations below the economic injury level of 1 larva per plant. Intercropping cabbage with tomato can significantly reduce DBM infestation probably due to the volatile compounds emitted by tomato plants causing repellent effects against DBM adults.

Insect pests attracted to crops grown as monocultures can sometimes be sidetracked by planting alternate-crop plants nearby such as *B. juncea*. These alternate crop plantings may also favor natural enemies such as *C. plutellae* and other natural enemies that attack DBM larvae. This can improve parasitoid population density with a subsequent improvement in the yield and quality of cabbage heads produced. The canopy effect of tomato plants in a cabbage-tomato intercrop reduces rain splash from the soil and thus considerably reduce the incidence and severity of bacterial black rot disease as noted in the study.

The study demonstrated that the endoparasitoid *C. plutellae* contributes significantly to the control of DBM larvae, and was the predominant larval endoparasitoid at Africa University farm. It is important that these parasitoids are given prime consideration in any Integrated Pest Management program to promote biological control that helps alleviate growing concerns regarding the effects of pesticides on DBM natural enemies.

The insecticides used in the study reduced the activity of the endoparasitoid *C. plutellae*. Furthermore, the higher infestation levels of cabbage by DBM in the insecticides-treated trial might have resulted from partial removal of the parasitoid by insecticides such as Malathion 50 EC and Malathion 25 WP. It seems that Match 5 EC and Decis 2.5 EC are less toxic to *C. plutellae* and it would be advisable for farmers to use such insecticides in DBM management.

It is recommended that the two trials be conducted for the second season to consolidate the results from the trials. There is also need to study further the reason why tomato as an intercrop was more effective than *B. juncea* and *C. gynandra* in reducing DBM levels.

7 REFERENCES

1. Akol, A.M., Sithanatham, S., Njagi, P.G.N., Varela, A. and Mueke, J.M. 2002. Relative safety of sprays of two neem insecticides to *Diadegma mollipla* (Holmgren), a parasitoid of the diamondback moth: effects on adult longevity and foraging behaviour. *Crop. Prot.* **21**: 853-859.

2. Altieri, M.A., and Leibman M. 1998. Insect, weed, and plant disease management in multiple cropping systems. In Francis, C.A. (eds.). Multiple Cropping Systems. Macmillan and Company, New York. pp 383.

3. Alton N. and Sparks, J. 2004. Controlling the Diamondback Moth: A Serious Pest of the Brassica Vegetable Family. The University of Georgia. pp 19.

4. Andrahennadi, R. and Gillott, C. 1998. Resistance of brassica, especially *Brassica juncea* (L.) Czern, genotype to the diamondback moth, *Plutella xylostella* (L.). *Crop Prot.* **17**: 85-95.

5. Asare-Bediako, E., Addo-Quaye A.A, and Mohammed A., 2010. Control of diamondback moth (*Plutella xylostella*) on cabbage (*Brassica oleracea* var. *capitata*) using intercropping with non-host crops. *Am. J. of Food Techn.* **5**: 269-274.

6. Asman, K. 2002. Trap Crop effect on oviposition behavior of the leek moth *Acrolepiopsis assectella* and the diamondback moth *Plutella xylostella*. *Entom Expe. et Appl.* **105**: 153-164

7. Ayalew, G. and Ogol, C.K. 2006. Occurrence of the diamondback moth (*Plutella xylostella* L.) and its parasitoids in Ethiopia: Influence of geographical region and agronomic traits. *J.of Appl. Entom.* **130** (6-7): 343-348.

8. Azidah.A, A., Fitton, M.G. and Quicke, D.L.J. 2000. Identification of *Diadegma* species (Hymenoptera: Ichneumonidae, Compopleginae).Attacking the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *B. Entom. Res.* **90**: 375-389.

9. Badenes-Perez, F. Shelton, A.M. and Nault, B.A 2004. Evaluating trap crops for Diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *J. Economic Entomol.* **97**(4): 1365-1372.

10. Badenes-Perez, F. Shelton, A.M. and Nault, B.A 2005. Manipulating the attractiveness and suitability of hosts for Diamondback Moth (Lepidoptera: Plutellidae). *J. Economic Entomol.* **98**(3): 836-844

11. Bebach, P., 1975. Biological control by natural enemies. Cambridge University Press. pp 323

12. Bewick, T. A. 1994. Cabbage: Uses and production. University of Florida: Florida Cooperative Extension Service Fact Sheet. http://www.geocities.com/habbage/cab.

13. Bijlmaker, H., 2005. Farmers field schools for integrated pest management: Refresh your memory. The IPM DANIDA Project. Thailand.

14. Boller, E. and Hani, F. 2004: *Ecological infrastructures.: Ideabook on functional biodiversity at the farm level.* IOBC, OILB, Mattenbach AG. Winterthur, Switzerland P. (eds).

15. Boucher, T. J. and Durgy R. 2003. Integrated Pest Management, perimeter trap cropping works. USDA NE-IPM and NE-SARE Programs, University of Connecticut.

16. Bowen, J. F., and Bernard A. K. 1986. Successful multiple cropping requires superior management skills. Agribusiness Worldwide. November/December. pp 22-30.

17. Buranday, R.P. and R.S. Raros, 1973. Effect of cabbage-tomato intercropping on the incidence and oviposition of the diamondback moth (*Plutella xylostella* L.). *Philippines Entomology*, **2**: 369-374.

18. CABI. 2004. Crop Protection Compendium, 2004 Edition.CAB International Publishing. Wallingford, UK.

19. Cerruti, R. Hooks, R. and Johnson. M, W. 2003. Impact of agricultural diversification on the insect community of cruciferous crops. *Crop. Prot.*, **22** (2): 223-238.

20. 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.

21. Cooper, J.F.C., 2002. Pest Management in Horticultural Crops: An Integrated Approach to Vegetable Pest Management with the Aim of Reducing Reliance on Pesticides in Kenya. Final Technical Report, Project R7403, 1999–2002. Natural Resources Institute, Chatham, UK. 40 pp.

22. De Lannoy, G. 2001. Leafy Vegetables. In: Crop Production in Tropical Africa. Raemaekers, R.H. (Ed.). Directorate General for International Co-operation (DGIC), Brussels, Belgium. Pp. 403–511.

23. Dent, D. 1999. Integrated Pest Management. Chapman and Hall. pp 356.

24. Dhaliwal, G.S. and Arara. R. 2001.Integrated Pest Management, concepts and approaches. pp. 108 – 124.

25. Dobson, H., Cooper, J., Manyangarirwa, W., Karuma J.and Chiimba, W. 2002. Integrated Vegetable Pest Management; safe and sustainable protection of small scale brassicas and tomatoes. Natural Resources Institute (NRI), Kent, UK. 179 pp.

26. Doubrava, N., Blake J. H., and Williamson. J. 2004. Cabbage, broccoli and other cole crop diseases. Clemson extension, Home and Garden Information Center.

27. Elwell, H. and Mass A. 1995. Natural pest and disease control. The Natural Farming Network, Harare, Zimbabwe.

28. Endersby N. M and Morgan W.C. 1991. Alternative to synthetic chemical insecticide for use in crucifer crop. *Biol. Agric. Hortc*., **8**: 33-52

29. Endersby, N., Ridland, P.M. 2004. (Eds.)The Management of Diamondback Moth and Other Crucifer Pests, Proceedings of the 4th International Workshop on Diamondback Moth, 26-29 November 2001, Melbourne, Australia. pp 415.

30. Eziah, V. Y., Rose, H. A., Wilkes, M. and Clift, A. D. 2009. Biochemical mechanisms of insecticide resistance in the diamondback moth (DBM), *Plutella xylostella* L. (Lepidopterata: Yponomeutidae), in the Sydney region, Australia. *Aust..J. Entomol.*, **48**: 321–327.

31. Facknath, S. 1997a. Integrated Pest Management of *Plutella xylostella*, an important pest of Crucifers in Mauritius. In: Proceedings of the Second Annual Meeting of Agricultural Scientists, MSIRI, Reduit, Mauritius. pp 12-13.

32. Facknath, S. 1997b. Study of botanical pesticides in Mauritius. In Proc. Expert Group Meeting on risk reduction in agrochemical development in the Afro-Arab region. Dec. 1996, Mauritius.

33. Facknath, S. 2000a: Application of neem extract and intercropping for the control of some cabbage pests in Mauritius. Proc. International Neem Conference, Queensland, Australia, Feb. 1996.

34. Facknath, S. 2000b: Integrated pest management of Plutella xylostella. University of Mauritius.

35. FAOSTAT, 2007. Food and Agriculture Organisation, United Nations. Faostat. fao.org

36. Francis, R.L., Smith, J.P. and Shepard, M.B. 2005. Integrated pest management for cabbage and collard; A Grower's Guide. Clemson Extension. Extension Bulletin 156. pp 31

37. Furlong, M.J., Zu-Hua, S., Yin-Quan, L., Shi-Jian, G, Yao- Bin, L., Shu-Sheng, L. and Zalucki, M.P. 2004. Experimental Analysis of the influence of Pest management Practice on the efficacy of an endemic arthropod natural enemy complex of the diamondback moth. *J. Economic. Entomol.,* **97**(6), 1814-1827.

38. Glare, T.R. and O'Callaghan, M. 2000 *Bacillus thuringiensis*: Biology, Ecology and Safety. John Wiley and Sons. Chichester.

39. Goudegnon.A,E., Kirk.A,A., Schiffers. B and Bordat. D. 2000. Comparative effects of deltamethrin and Neem kernel solution treatments on Diamondback moth and

Cotesia plutellae (Hym.,Broconodae) parasitoid populations in the Cotonou peri-urban area in Benin. *J. Appl. Entomol.,* **124**:141-144.

40. Goudegnon, A.E., Kirk, A.A., Arvantitakis, L., Bordat, D. 2004. Status of the diamondback moth and *Cotesia plutellae*, its main parasitoid, in the Cotonou and Porto-Novo peri-urban areas of Benin. In: Bordat, D., Kirk, A.A. (Eds.), Improving Biocontrol of *Plutella xylostella*. Proceedings of the International Symposium in Montpellier, 21–24 Oct 2002. France. pp. 173–178.

41. Gourdine, J. S., McCutcheon, G. S., Simmons A. M and. Leibee G. L. 2003. Kale floral nectar and honey as food sources for enhancing longevity and parasitism of *Diadegma insulare* (Hymenoptera: Ichneumonidae) a parasitoid of the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *J. Agric. Urban Entomol.*, **20**: 1-6.

42. Grundy, P.; Short, S. 2003: Potential alternative to chickpeas for trap cropping. ANP Technology, *Greenmount Press, .***24**:(3)14

43. Grossman, J., and William Q. 1993. Strip intercropping for biological control. IPM Practitioner. pp. 1-11.

44. Grzywacz D., Rossbach, A., Rauf, A., Russell, D.A., Srinivasan, R., and Shelton, A.M. 2010. Current control methods for diamondback moth and other brassica insect pests and the prospects for improved management with lepidopteran resistant Bt vegetable brassicas in Asia and Africa. *Crop Prot.* **29**: 68–79.

45. Hill, T.A**.** and Waller, J. M. 1982. Pests and diseases of tropical crops. In principles and methods of control, Payner W. J. A. (Ed) Longman group Ltd. UK. pp 174.

46. Hill, T.A. and Foster, R.E. 2000. Effect of insecticides on the diamondback moth (Lepidoptera: Plutellidae) and its parasitoid *Diadegma insulare* (Hymenoptera: Ichneumonidae). *J. Economic. Entomol.,* **93**(3): 763-768.

47. Hooks.C. R. R and Johnson. M W. 2003. Impact of agricultural diversification on the insect community of cruciferous crop. *Crop Prot.* **22**: 223-238.

48. ICIPE. 2003: ICIPE Scientific Report. International Center of Insect Physiology and Ecology. 2000 - 2003, Nairobi, Kenya.

49. Innis. D, Q 1997. Intercropping and the Scientific Basis of Traditional Agriculture. Intermediate Technology Publications. pp 179.

50. James, B., Godonou, I., Atcha-Ahowe, C., Glitho, I., Vodouhe, S., Ahanchede, A., Kooyman, C., and Goergen, G. 2007. Extending integrated pest management to indigenous vegetables. *Acta. Hortic.*, **752**: 89–93.

51. Kfir R. 1998. Origin of the diamondback moth (Lepidoptera: Plutellidae). Ann. *Entomol. Soc. Am.,* **91**: 164 – 167.

52. Kfir, R. 2003. Biological Control of the Diamondback Moth *Plutella xylostella* in Africa. In: Neuenschwander, P., Borgemeister, C. and Langewald, J. (eds). Biological Control in IPM Systems in Africa. CABI Publishing, Wallingford, Oxon. pp. 363-375.

53. Kfir, R. 2004. Effect of parasitoid elimination on populations of diamondback moth in cabbage. In: Endersby, N., Ridland, P.M. (Eds.). The Management of Diamondback Moth and Other Crucifer Pests, pp. 197–206. Proceedings of the 4th International Workshop on Diamond Back Moth, 26–29 November 2001, Melbourne, Australia.

54. Khan, M. F. R., Griffin R. P., Garner, G. R, and Gorsuch C. S. 2004. Diamondback Moth (Lepidoptera: Plutellidae) Population Density and Parasitism by *Diadegma insulare* on Collard in South Carolina. *J. Agric. Urban Entomol.,* **21**(3): 164-170.

55. Kennedy, G.G. 2008. Integration of insect-resistant genetically modified crops within IPM programs. In: Romeis, J., Shelton, A.M., Kennedy, G.G. (Eds.), Integration of Insect-Resistant, Genetically Modified Crops within IPM Programs. Springer, Dordrecht, The Netherlands.

56. Kibata GN. 1997. The diamondback moth: a problem pest of brassica crops in Kenya. In: The management of diamondback moth and other crucifer pests (Eds. A Sivapragasam, WH Loke, AK Hussan & GS Lim). Proceedings of the Third International Workshop, 29 October - 1 November 1996, Kuala Lumpur, Malaysia, Malaysian Agricultural Research and Development Institute (MARDI), pp. 47-53.

57. Kirk, A.A. and Bordat, D. (Eds.), 2004. Improving biological control of *Plutella xylostella*. Proceedings of the International Symposium in Montpellier, France, 21–24 Oct 2002. CIRAD, Montpellier, France, pp. 71–84.

58. Kwarteng, J.A. and Towler M.J. 1994. Enhancement of biological control in West African Agriculture. MacMillan Education Ltd., UK.

59. Landis, D.A., Wratten, S.D. and Gurr, G.M. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. *Ann. Rev. Entomol.,* **45:** 175-201.

60. Lewis W. J., van Lenteren J. C., Phatak, S. C., and Tumlinson, H. 1997. Perspective. A total system approach to sustainable pest management. *Proc. Natl. Acad. Sci*., **94**: 12243-12248.

61. Lim, G, S. 2000. Integrated Pest Management of Diamondback Moth: Practical Realities. Pests and Beneficial Organisms Unit, Fundamental Research Division, MARDI, Serdang, Selangor, Malaysia.

62. Lingappa, S., Basavanagoud K., Kulkarni K.A., Roopa S. and Kambrekar D.N., 2006. Threat to Vegetable Production by Diamondback Moth and its Management Strategies. Springer, Netherlands, pp. 357-396.

63. Liu, M. Y., Tzeng, Y.J, and Sun, C. N. 1981. Diamondback moth resistance to several synthetic pyrethroids. *J. Economic. Entomol.,* **74:** 393-396.

64. Liu, Y.B, Tabashnik, B.E., Masson, L., Escriche, B. and Ferre, J. 2000. Binding and toxicity of *Bacillus thuringiensis* protein Cry 1C to susceptible and resistant diamondback moth (Lepidoptera: Plutellidae). *J. Economic. Entomol., **93**(1): 1-6.*

65. Liu, T. X, Sparks, A.N and Chen, W. 2003. Toxicity persistence and efficacy of indoxacarb and two other insecticides on *Plutella xylostella* (Lepidoptera; Plutellidae) immatures in cabbage. *Int. J. Pest Manage .,* **48** (30): 235-241.

66. Liu, T. X, Hutchison W.D., and Chen, W. 2003.Comparative Susceptibilities of Diamondback moth (Lepidoptera;Plutellidae) and Cabbage looper (Lepidoptera: Noctuidae) from Minnesota and South Texas to λ-Cyhalothrin and Idoxacarb. *J. Economic. Entomol.,* **94** (4): 1230-1236.

67. Löhr, B., Gathu. R., Kariuki, C., Obiero, J. and Gichini, G. 2007. Impact of an exotic parasitoid on *Plutella xylostella* (Lepidoptera: Plutellidae) population dynamics, damage and indigenous natural enemies in Kenya. *Bulletin of Entomological Research*, **97**: 337-350.

68. Manyangarirwa, W. M. 2009. Population dynamics and parasitism of brassica insect pests in Zimbabwe, with emphasis on the diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), PhD Dissertation. Clemson University. pp 105.

69. Manyangarirwa, W., Zehnder, G. W., McCutcheon, G. S., Smith, J.P., Adler, P.H. and Mphuru, A.N. 2009. Parasitoids of the diamondback moth on brassicas in Zimbabwe*. Proceedings of the African Crop Science Conference,* **9**: 565 – 570.

70. Meyer, W. 2007. Asia Brief Cabbage for All in DPR Korea Partnership Result. Swiss Agency for Development and Cooperation, Bern, Switzerland.

71. Minitab Inc., 2006. Minitab® Version 15 for Windows®. Minitab, USA.

72. Minja, E.M. J. Ogecha, J.K.O. Ampofo and H.A. Mziray, 2003. Integrated pest management training workshop report. Training of Adult Education Teachers on General Principles of Crop Husbandry and Integrated Pest Management. International Centre for Tropical Agriculture (CIAT), KARI-Kisii, Kenya.

73. Makumbi, H. 1996. Ifoam 96 book of abstracts. Proceeding of the 11th IFOAM Scientific Conference. August 11-15. Copenhagen, Denmark.

74. Muniappan, R. and Lali, T. 2000. Management of cabbage pests of the Asia Pacific lowland tropics. College of Agriculture and Life Sciences, University of Guam, Guam.

75. Nyambo, B., and Löhr, B. 2005. The role and significance of farmer participation in biocontrol-based IPM for brassica crops in East Africa. In: Hoddle, M.S. (Ed.), pp.

290–301. Proceedings of the Second International Symposium on Biological Control of Arthropods, Davos, Switzerland. pp. 12–16.

76. Oduor, G.I.; Lohr, B. and Seif, A A. 1997. Seasonality of major cabbage pests and incidence of their natural enemies in central Kenya. In: (eds Sivapragasam A., Loke W.H., Hussan A.K. and Lim G.S.) The management of diamondback moth and other crucifer pests. Proceedings of the Third International Workshop, 29 October 1 November 1996, Kuala Lumpur, Malaysia, Malaysian Agricultural Research and Development Institute (MARDI), pp. 37-43.

77. Ofuya, T.I. 1991. Observations on insect infestation and damage in cowpea, *Vigna unguiculata* intercropped with tomato, *Lycopersicon esculentum* in a rain forest area of Nigeria. *Exp. Agric*., **27**: 407-412.

78. Oruku, L., and Ndun'gu, B. 2001. Final socio-economic report for the peri-urban vegetable IPM thematic cluster. CABI Africa Regional Centre Report, Nairobi, 49 p

79. Perez, F.R.B., Shelton, A.M. and Nault, B. A. 2004. Evaluating crops for Diamondback moth, *Plutella xylostella* (Lepidoptera, Plutellidae). Entomological *J.f Economic. Entomol.*, **97**(4): 1365-137.

80. Richardson, P. 1997. Polyculture makes the most of biodiversity. HRM of Texas Newsletter. Summer. pp 5-7.

81. Roberts. R. E. 2000. Vegetable Rotations, Successions and Intercropping: Extension Vegetable Specialist Texas Agricultural Extension Service *Am. J. of Food Techn*, **8**: 33-52.

82. Said, M., and Itulya F.M. 2003: Intercropping and nitrogen management effects on diamondback moth damage and yield of collards in the highlands of Kenya. *African Crop Science Journal*, **1**, (11): 35-42.

83. Sarfraz, M., Keddie, A. B, and Dosdall, L.M. 2005. Biological control of the diamondback moth, *Plutella xylostella:* A review, *Biocontrol Sci. and Techn.* **15** (8): 763-789.

84. Seif, A.A., and Löhr, B. 1998. Brassica planning meeting for east and southern Africa region. GTZ IPM Horticulture, Nairobi, 16 pp.

85. Shelton, A.M., Turner, A., Giga, D. Wilkinson, P., Zitsanza, E. and Utete, D. 1995. Diamondback moth. Zimbabwe Horticultural Crops Pest Management. NYSAES, Geneva NY. pp 2.

86. Shelton, A.M. 2004. The Management of Diamondback Moth and Other Crucifer Pests. Proceedings of the Fourth International Workshop on Diamond Back Moth, 26–29 November 2001, Melbourne, Australia. pp 3-8.

87. Shelton, A.M. 2007. Considerations on the use of transgenic crops for insect control. *J. Dev. Stud.,* **43**, 890–900.

88. Shelton, A.M., Roush, R.T., Wang, P., Zhao, J. Z. 2007. Resistance to insect pathogens and strategies to manage resistance: An update. In: Lacey, L., Kaya, H.K. (Eds.), Field Manual of Techniques in Invertebrate Pathology, second ed. Kluwer Academic Press, pp. 793–811.

89. Shelton, A.M., Fuchs, M., Shotkoski, F. 2008. Transgenic vegetables and fruits for control of insect and insect-vectored pathogens. In: Romeis, J., Shelton, A.M., Kennedy, G.G. (Eds.), Integration of Insect-Resistant, Genetically Modified Crops within IPM Programs. Springer, Dordrecht, The Netherlands, pp. 249–271.

90. Schuler, T.H, Denholm,I., Clark,S.J, Neal Sktewart, C., and Poppy, G.M. 2004 Effects of Bt plants on the development and survival of the parasitoid Cotesia plutellae (Hymenoptera: Broconodae) in susceptible and Bt-resistant larvae of the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *J. Insect Physiol.,* **50**: 435-443.

91. Shepard, B.M., Carner, G.R., Barrion, A.T., Ooi, P.A.C. and van den Berg, H. 1999. Insects and their natural enemies associated with vegetables and soybean in Southeast Asia. Quality Printing Company, Orangeburg, SC. 108 p.

92. Sibanda, T., Dobson, H.M., Cooper, J.F., Manyangarirwa, W. and Chiimba, W. 2000. Pest management challenges for smallholder vegetable farmers in Zimbabwe. *Crop Protection* **19:** 807-815.

93. Silva-Aguayo, G. 2007. Botanical insecticides in Radcliffe's IPM world textbook. University of Minnesota, USA.

94. Sithole, R. 2005. Life history parameters of *Diadegma mollipla* (Holmgren), competition with *Diadegma semiclausum* Hellen (Hymenoptera: Ichneumonidae) and spatial and temporal distribution of the host, *Plutella xylostella* (L.) and its indigenous parasitoids in Zimbabwe. PhD thesis, University of Zimbabwe.

95. Smith T.J. and Villet M.H. 2004 Biological Control of the Diamondback Moth, *Plutella xylostella*, in Cabbage Fields in the Eastern Cape, South Africa. Department of Zoology and Entomology, Rhodes University, Grahamstown, South Africa.

96. Smith, T.J., Villet, M.H. 2004. Parasitoids associated with the diamondback moth, Plutella xylostella (L.), in Eastern Cape, South Africa. In: Endersby, N., Ridland, P.M. (Eds.). The Management of Diamondback Moth and Other Crucifer Pests, Pp. 249–253. Proceedings of the Fourth International Workshop on Diamond Back Moth, 26–29 November 2001, Melbourne, Australia.

97. Spence, N.J., Phiri, N.A., Hughes, S.L., Mwaniki, A., Simons, S., Oduor, G., Chcha, D., Kuria, A., Ndirangu, S., Kibata, G.N., and Marries, G.C. 2007. Economic impact of turnip mosaic virus, cauliflower mosaic virus and beet mosaic virus in three Kenyan vegetables. *Plant. Pathol.,* **56**, 317–323.

98. Srinivasan, K. and Krishna, M. P. N. 1991. Indian mustard as a trap crop of major lepidopterous pests of cabbage trap. *Pest Manage*. **37**: 26-32.

99. Srinivasan, K., and Moorthy, P. N. K. 1992. The development and adoption of integrated pest management for major pests of cabbage using Indian Mustard as a trap crop, pp. 10-14 *in* Talekar, N. S. [ed.], Diamondback moth and other cruciferous pests: Proceedings of the second International Workshop. Shunhua, Taiwan. Asian Vegetable Research and Development Center.

100. Steiner, K.G. 1982. Intercropping in tropical smallholder Agriculture with Special Reference to West Africa. German Agency for Technical Cooperation (GTZ), Eschborn, Germany.

101. Stoll, G. 2000. Natural crop protection in the tropics. Letting information come to life. Margraf Verlag. pp 375.

102. Stoll, G. 2003. Natural Crop Protection in the Tropics. Margraf Publishers, Weikersheim. Pp 65-120.

103. Sullivan, P. 2003. Intercropping Principles and Production Practices. Ecological Agriculture Projects. Mixing Crop Species. McGill University, Macdonald Campus. Production 135.

104. Talekar, N.S. and Shelton, A.M. 1993. Biological and Management of the Diamondback moth. *Ann. Rev. Entomol.,* **38**:275-301.

105. Talekar, N.S. 2004. Biological control of diamondback moth in Asia. In: Bordat, D., Kirk, A.A. (Eds.), Improving Biocontrol of *Plutella xylostella*. CIRAD, Montpellier, Proceedings of the International Symposium in Montpellier, France, 21–24 Oct 2002 France, pp. 103–113.

106. Theunissen**,** J., Booij, C.J.H. and L.A.P. Lotz. 1994. Effect of intercropping white cabbage with clovers on pest infestation and yield. *Entomol. Exp. Appl.*, **74**: 7-16.

107. Trevor, G. F. 1990 Successful Organic Pest Control: Environmental friendlyWays to Deal with unwanted Garden Pest and Diseases. Thorsons Publishers Ltd, Wellingborough, England.

108. Varela A M., Seif A. and Lohr B. 2003. A Guide to IPM in Brassicas Production in Eastern and Southern Africa. The International Centre of Insect Physiology and Ecology, Nairobi, Kenya.

109. Waladde S. M, Leutle M. F and Villet, M. H. 2001. Parasitism of *Plutella xylostella* (Lepidoptera, Plutellidae): field and laboratory observations. S. Afri. *J. Plant. and Soil.,* **18**:32-37.

110. Walia. S, and Parmar, B,s. 1995. Pesticides crop protection and environment. Oxford and IBH publishing Co. New Delhi. India. Pp 600.

111. Williamson, S. 2003. Pesticide provision in liberalized Africa: out of control. Network paper. Agricultural Research and Extension Network (AgREN), 15 pp.

112. Williamson, S. 2005. Breaking the barriers to IPM in Africa: evidence from Benin, Ethiopia, Ghana and Senegal. Pesticide use in Africa. In: Pretty, J. (Ed.). The Pesticide Detox. Towards a More Sustainable Agriculture. Earth scan, UK, pp. 165–180.

113. Wolfe, M.S. 2000. Field Guide to Non- chemical Pest Management Production. Crop strength diversity nature. pp 681-682.

114. Youdeowei, A. 2002. Integrated Pest Management practices for the production of vegetables: Integrated pest management extension guide 4. Directorate of Plant Protection and Regulatory Services, Ministry of Food and Agriculture, Ghana/German Development Cooperation (GTZ). pp: 49.

APPENDICES

Appendix A: Brassica Insect Population Data Sheet, Zimbabwe

Field……………………………….. Date / / Variety ………………………………

Number	Replicate 1									Replicate 2									Replicate 3								
	DBM				CW		A		O	DBM				CW		A		O	DBM				CW		A		O
1																											
2																											
3																											
4																											
5																											
6																											
7																											
8																											
9																											
10																											
11																											
12																											
13																											
14																											
15																											
16																											
17																											
18																											
19																											
20																											
Total																											
Score																											

Notes

Key: s = small larva; l = large larva; p = pupa; ps = parasitized larva/pupa; n=aphid nymphs pn = parasitized aphid nymphs; O = other insect species; A = Aphid; CW= Cabbage worm

Appendix B: Diamondback Moth population Data Sheet, Pooled Results

Field or plot area _____________________________

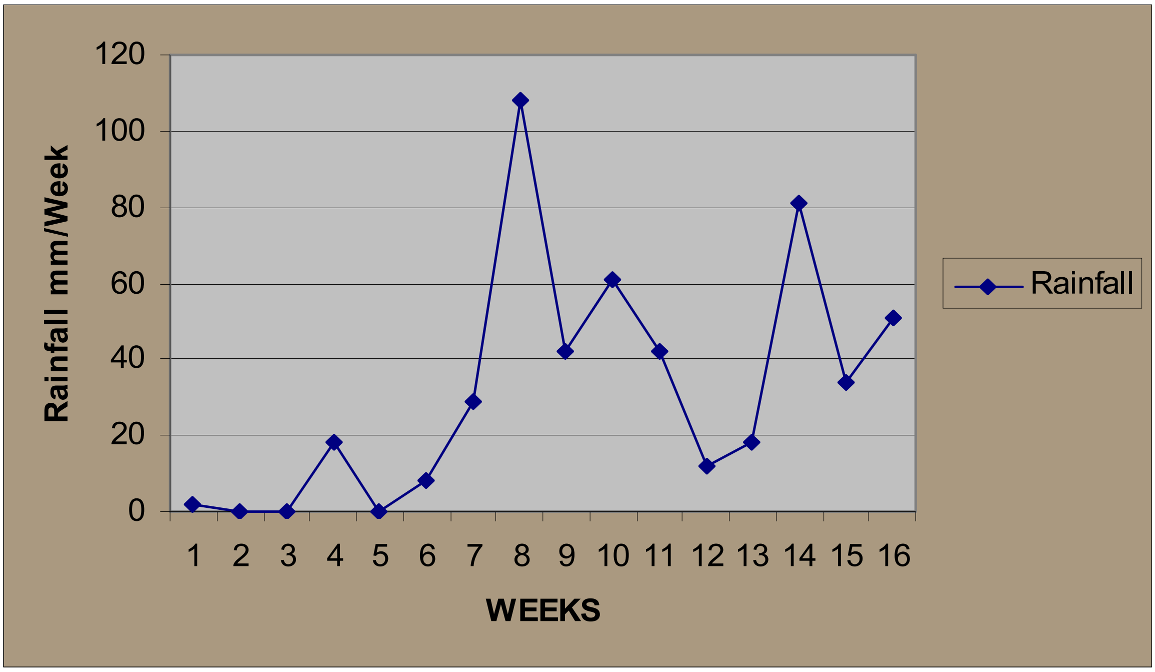
Cultivar______________________________________

Date	**Replicate 1**				**Replicate 2**				**Replicate 3**			
	DBM				**DBM**				**DBM**			
	s	**l**	**l**	**ps**	**s**	**l**	**p**	**ps**	**s**	**L**	**p**	**ps**
MEAN												

Notes……………………………………………………………………………………………
……………………………………………………………………………………………..

Key: s = small larva; l = large larva; p = pupa; ps = parasitized larva/pupa;

Appendix C: Rainfall pattern (mm/week) for the duration of the study.



Appendix D: Scoring scale used to determine Disease Severity.

Scale	Description
1	No disease
2	25% of cover leaves infected
3	50% of cover leaves infected
4	75% of cover leaves infested
5	whole plant dying

Appendix E: **Bacterial Black Rot Disease Score on Brassica**

Site:____
Trial____
Plot Number____________________________________
Cultivar or Treatment:______________________________
Date / /

Plant Number	**Replicate 1**			**Replicate 2**			**Replicate 3**		
	Disease			Disease			Disease		
	Incidence	Severity	Index	Incidence	Severity	Index	Incidence	Severity	Index
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
Mean									

NOTE

1 = No disease
2 = 25 % of cover leaves infected
3 = 50 % of cover leaves infected
4 = 75 % of cover leaves infected
5 = Whole plant dying