EFFECTS OF INTERCROPPING SYSTEMS ON INCIDENCE AND DAMAGE TO COTTON BY *DIAPAROPSIS CASTANEA* HAMPSON (LEPIDOPTERA: ARCTIIDAE) IN MAGOYE, MAZABUKA DISTRICT OF ZAMBIA.

MUTIBO CHIJIKWA

A dissertation submitted to the University of Zambia in partial fulfillment of the requirements of the degree of Masters of Science in entomology

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DECLARATION

I, MUTIBO CHIJIKWA, hereby declare that this dissertation represents my own work and that it has not been previously submitted for a degree at this or any other university.

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Signature

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Date

CERTIFICATE OF APPROVAL

This dissertation by MUTIBO CHIJIKWA is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Entomology (Biological Sciences) University of Zambia

Name and Signature of Examiners

Name …………………………….. Signature ……………………..

Name …………………………….. Signature ……………………..

Name …………………………….. Signature ……………………..

Assistant Dean

Name …………………………….. Signature ……………………..

Dissertation Chairperson

Name…………………………….. Signature ……………………

ABSTRACT

The Red bollworm, *Diaparopsis castanea* Hampson, is an insect that has become a major pest of cotton in Zambia. This study was conducted in Magoye, Mazabuka district, Southern province of Zambia. The main objective of the study was to determine the effects of different types of intercropping patterns occurring among cotton farmers in Magoye area and their effects on the incidence and extent of damage caused to cotton by *D. castanea.* The study was conducted in two parts during the 2010/11 farming season. The first part involved conducting a survey among 80 randomly selected farmers in Magoye during the months of September and October 2010. This was to determine the different types of intercropping systems being used in the study area. Participatory rural appraisal (PRA) techniques, using questionnaires, interviews, focus group discussions (FGD), and transect walks were used to identify the various intercropping systems. The second part was an experimental field study to assess the relationships of the various intercropping systems, pest incidence and severity. The field trial was conducted at Cotton Development Trust (CDT) in Magoye, Zambia. It was laid out in a randomized complete block design (RCBD) with four replications. The six intercropping systems were randomized in main plots. Plot sizes were 4.8 m x 9 m with intercrops planted in between each row of cotton. Cotton cultivar CDT II (*Gossypium hirsutum sp*) was sown by hand in 100 cm spaced single rows on 1st November 2010. Maize (*Zea mays L.*), and Sorghum (*Sorghum vulgares* L.) were sown two weeks after cotton planting. Pigeon pea (*Cajanus cajan L.*) and Cowpea (*Vigna unguuiculata L.*) were planted three weeks after cotton sowing and Sunflower (*Helianthus annus L.)* was planted five weeks after cotton sowing. Observations on incidence of *D. castanea*, incidences of natural enemies, damage caused by *D. castanea*, average boll weight, plant height and seed cotton yield were recorded. The data collected were subjected to analysis of variance (ANOVA) and means were compared using Bonferroni's test. The survey revealed that farmers in Magoye area were using both chemical and cultural practises to control pests in their cotton fields. The chemicals used were mainly synthetic in nature as none of the farmers were recorded to be using naturally made pesticides. The survey further showed that all farmers interviewed were combining chemical control with various cultural practises such as crop rotation or intercropping. Only 28% of the farmers interviewed were using intercropping as a pest control strategy. The intercrops were grown either as a strip/single row pattern alongside the cotton crop or in between each row of cotton. Cowpea and beans were the most common combination (22%) of intercrops used, while maize was only used by one percent of the farmers. Analysis of variance (ANOVA) on the field trial showed significant reduction in incidence of *D. castanea* eggs ($P<0.001$), damage to cotton bolls ($P<0.001$) and seed cotton yield ($P<0.001$) in the intercropping patterns. Cotton-sunflower treatment recorded the highest yield of 303±59.1 kg/ha while cotton – maize treatment had the lowest yield of 169±25.60 kg/ha. The Experiment showed that even though none of the intercrops selected were alternative hosts for *D. castanea*, cotton – sorghum treatment was able to attract the widest range of predators. Among all the intercropping patterns, cotton – sunflower was the most effective intercrop as it produced the highest overall yields. It is recommended that the study be conducted for two more seasons in order to re-confirm the observations made in the study.

DEDICATION

To my first born daughter, Namukolo Mushenywa; my mother, Eithel Chijikwa; and loving husband, Mr Moola Mushenywa.

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ACRONYMNS

ANOVA = Analysis of Variance

MAL = Ministry of Agriculture and Livestock

CDT = Cotton Development Trust

GART = Golden Valley Agricultural Research Trust

ICAC = International Cotton Advisory committee

IPM = Integrated Pest Management

NPV = Nuclear Polyhedrosis Virus

RCBD = Randomized Complete Block design

SPSS = Statistical package for Social Sciences

WHO = World Health Organization

PRA = Participatory rural appraisal

FGD = Focused Group Discussion

GDP = Gross Domestic Product

M.a.s.l = Meters above sea level

CBZ = Cotton Board of Zambia

CFU = Conservation Farming Unit

OP= Organo phosphate

POPs = Persistent Organic Pollutants

CHAPTER 1 : INTRODUCTION

1.1 Background

Cotton, *Gossypium hirsutum* L, plant belongs to the family Malvaceae (Paterson, 2009). It is a shrub native to tropical and subtropical regions around the world, including Africa. Ideal growing conditions are in regions with long vegetation periods without frost, high temperatures (30°C), ample sunshine, and a relatively dry climate (Harvey, 1958). Sunshine is particularly important for boll retention as cloudy conditions can cause boll shedding at the bottom of the plant. Cotton requires a long growing season of 5 – 6 months and well-distributed rainfall within these months ranging from 600 to 900 mm (Venugopal *et al.*, 1999). In Zambia cotton is grown from about 750 to 1200 m above sea level. If grown above 1500 m altitudes, low night temperatures in April and May will prevent lint development and cause lower yields. Cotton is a deep-rooted crop that makes good use of natural soil fertility. The crop prefers fertile clay and sandy clay loam soils. However, drainage is important as cotton does not grow well in areas prone to flooding (Cotton Development Trust, 2005).

Zambia is divided into three agro ecological zones (Figure 1.1). Region I is characterised with rainfall less than 700 mm; region II has rainfall between 800 -1000 mm and region III has rainfall between 1000 -1500 mm. Cotton is mainly grown in Agro-ecological regions I and II; this includes Zambezi and Luangwa valleys, Eastern, Central, Lusaka and Southern provinces respectively (Cotton Development Trust, 2002). *D. castanea* has been recorded in all these areas.

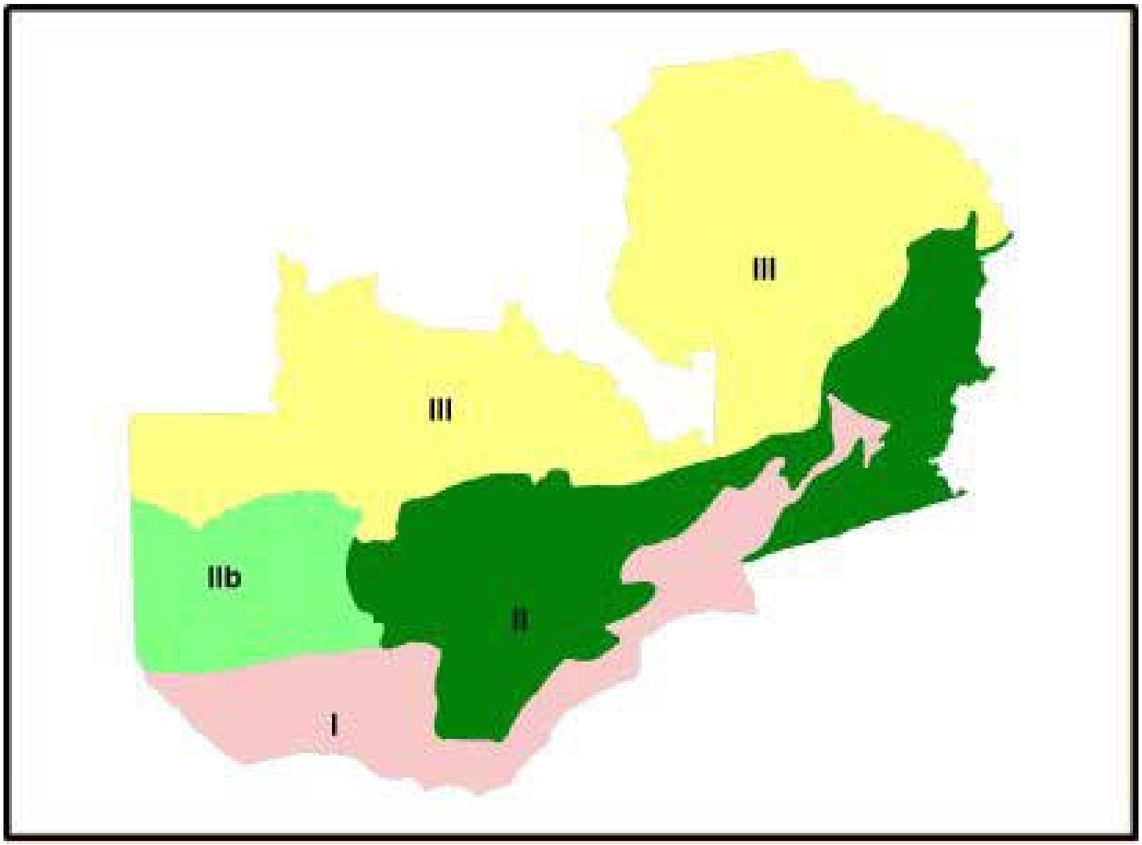


Figure 1.1. Zambia agro-ecological regions I, IIa, IIb, III

Sources:

www.fao.org/ag/AGP/AGPC/doc/Counprof/zambia/zambia.htm#_Toc131995468,

03/03/13

The largest producers of cotton currently are China and India, with annual production of approximately 36 million tonnes and 25 million tonnes respectively (International Cotton Advisory Committee, 2007). Cotton is mainly grown for lint which is used in the textile-industry and hospitals. Processed cotton seed is used for oil extraction that is used in cookery, machine lubrication and soap making and the cake is primarily used as stock feed (Prasad *et al*., 2011).

The cotton industry in Zambia has been transformed from a monopoly at independence to the current competitive private sector driven industry (Cotton Development Trust, 2005). The Zambian cotton sub-sector has in the last 15 years recorded tremendous growth in cotton production. Following liberalization in 1994 seed cotton production has risen from 42,000 metric tonnes (1994/1995) to a record high of 227,000 metric tonnes (2003/2004) (International Cotton Advisory Committee, 2007). A small improvement in farm yields has been recorded, but the growth in cotton production has been primarily as a result of an increase in the total number of farmers growing cotton in Zambia. The average contribution of the agricultural sector to Gross Domestic Product (GDP) is 18% of which cotton accounts for approximately 2.2% (Regional Agriculture Trade Expansion Support, 2003).

Cotton is a management intensive crop and it is attacked by many pests at every stage of the production cycle (Cotton Development Trust, 2005; Williams, 2000). The major cotton insect pests in Zambia include various cutworms (*Agrotis sp*), aphids (*Aphis gossypii*), stainers (*Dysdercus sp*), jassid (*Empoasca sp*), whiteflies (*Bemisia tabac*) and bollworms (Cauquil, 1988). There are four major types of bollworms that occur in cotton. These are: Red bollworm (*Diaparopsis castanea*), American bollworm (*Heliothis armigera*), Spiny bollworm (*Earias biplaga*) and pink bollworm (*Pectinophora gossypiella*). Of particular interest in this study was the Red bollworm (*Diaparopsis castanea,* Hampson*;* Lepidoptera: Arctiidae*)*. This insect is now a major pest of cotton, south of the equator including Zambia (Hill, 1983).

Diaparopsis castanea damages cotton by either attacking young buds to form a flared square or devouring the entire contents of the cotton fruiting structures. The damaged squares/buds and young bolls will usually drop off. The attacked parts are normally damaged completely (Braun, 1991). *D. castanea* usually feeds from inside the boll and this makes effective control of this pest even more challenging as being inside the boll protects it from application of non -systemic pesticides. A range of both chemical and cultural practices have been recommended for the control of *D. castanea* in Zambian cotton but with little success.

1.2 General Objective

The main objective of the study was to determine the relationship of intercropping systems on incidence and damage to cotton by *Diaparopsis castanea* in Magoye, Mazabuka district of Zambia.

1.3 Specific Objectives

i. to characterize various intercropping systems currently being used in cotton production;
ii. to determine the incidence and damage caused by *D. castanea* on cotton under various intercropping systems;
iii. to determine the incidence of natural enemies in the intercropped cotton in Magoye.

1.4 Hypotheses

i. There are significant differences in the incidence of natural enemies among the various intercropping systems.
ii. There are significant differences in the incidence and severity of damage caused by *D. castanea* to cotton among the various intercropping systems in Magoye, Mazabuka district.

1.5 Justification of study

The prospects for the use of Integrated Pest Management (IPM) in cotton are high due to the intensive application of pesticides in the cotton industry. Cotton receives more pesticide protection per season than any other crop. Cotton alone accounts for more than 25 per cent of all agricultural insecticides used world over (Pimentel *et al.,* 1993). This extensive use of pesticides carries with it negative external effects, such as damage to human health and the natural environment. Furthermore, the use of pesticides is costly and often kills the natural enemies of the pests intended for their management. Intercropping is a strategy that is not only environmentally safe but it also allows the farmer to harvest two crops (a food and cash crop) at the end of the season as opposed to just one.

Understanding the interaction between the various pests and natural enemies is the key foundation for IPM and this is vital to the long term sustainability of the cotton industry (Naranjo, 2001). Providing an effective intercrop, which can attract the right kinds of natural enemies, may assist in controlling the Red Bollworm thereby reducing the use of pesticides. Using an intercrop allows the natural enemies, such as *Trichogramma spp,* braconid wasps (*Bracon spp*) and earwigs (*Euborellia spp*) to be fully operational in the field since the main crop seldom needs to be treated with insecticides (Whitman and Eller, 1990).

This study was aimed at contributing to the development of cotton production practices that avoid the use of agrochemicals in the control of cotton pests. Studies on this pest were being conducted in Zambia for the first time and it is hoped that the results from the study will significantly contribute to the knowledge and future studies on *D. castanea* in Zambia within the context of integrated cotton pest management.

CHAPTER 2 : LITERATURE REVIEW

2.1 Taxonomy of the Red bollworm, *Diaparopsis castanea*

Diaparopsis Castanea, Hampson (Lepidoptera: Noctuidae) is commonly known by two different names; Red bollworm and Sudan bollworm (Hill, 1983). It is a lepidopteran insect that belongs to the Super family Noctuoidea, family Arctiidae, and subfamily Arctinae (Chu, 1949). The Noctuidae or owlet moths are a super family of robustly-built moths that constitute the largest super family in the Lepidoptera. Most noctuids larvae feed at night, resting in the soil or in crevices in their food plants during the day. The Arctiidae are the richest family of moths in the tropics. The small to medium-sized adults are often white, yellow, orange, or red with black markings on the forewings. Some adults are day-fliers, while others are nocturnal. Larvae are typically very hairy. Several species of this family have larvae that live in the soil and are agricultural or horticultural pests. Pupation takes place in cocoons made of matted larval hair and little or no silk (Chu, 1949).

2.2 Origin and Geographical Distribution of *D. castanea*

Diaparopsis castanea is confined to Africa, except for a single area in South Yemen, Asia. It was first recorded in Sudan in 1908 as the Sudan bollworm and two years later it was described in Nigeria as the Red bollworm (Pearson, 1958). The genus *Diaparopsis* comprises of three important species: *D. watersi* which is found north of the equator from Senegal to Somalia and northward to the Sahara desert, the Sudan and

Ethiopia; *D. castanea* which is found in the southern hemisphere; and *D. tephragramma* which is found in Angola (Munro, 1987). The habits and life history of the two main species *D. castanea* and *D. watersi* are similar as regards their main features. In South America, *Sacadodes pyralis* Dyar is closely related to *Diaparopsis*, both morphologically and biologically (Pearson. 1958).

In Zambia *D. castanea* was first recorded in Eastern Province back in the 1960s when cotton was introduced in Zambia. A cotton free zone was created in Kafue area to prevent the spread of the pest from Eastern to Southern province. This method was ineffective because from as far back as 1983, the pest was recorded as a common cotton pest in Southern province. (Marcoux and Chola, 1983).

2.3 Insect pests of cotton in Zambia

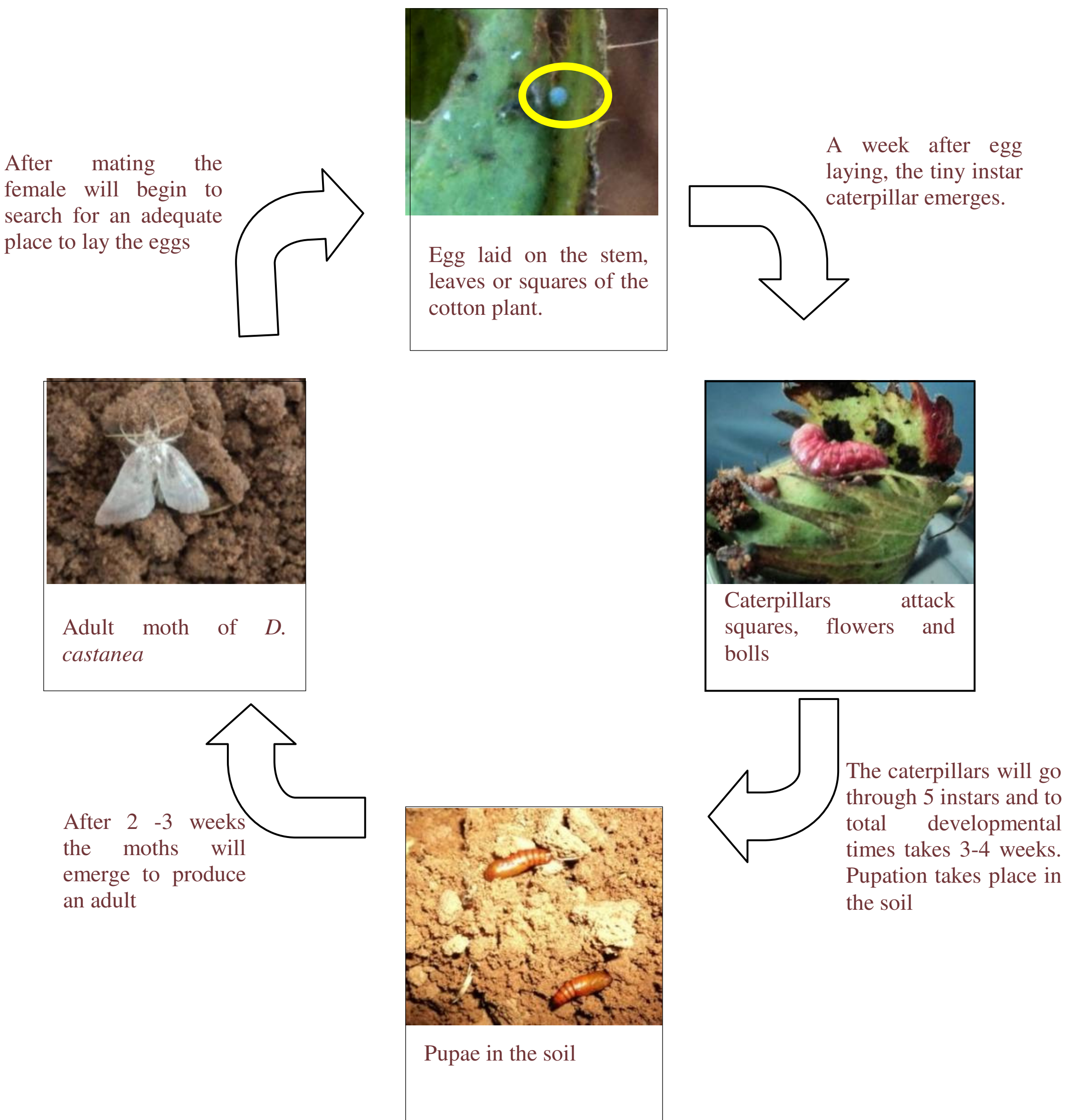
Cotton, considered as white gold, is one of the most important cash crops that are cultivated among small and medium scale farmers in Zambia. As mentioned earlier cotton in Zambia is grown in agro-ecological region two which covers eastern, central and southern provinces of Zambia (Cotton Development Trust, 2005). One of the major constraints to increasing cotton production is that it is attacked by many pests at every stage of the production cycle (Williams, 2006).

Cotton pests can be divided into two groups: early and late season pests. Early pests are those which attack the plant from planting until peak flowering and then gradually decline in numbers. They have a major effect on the yield quantity. These include: Aphids (*Aphis gossypii*), Jassids (*Empoasca spp),* and Cotton white fly *(Bemisia* *tabaci).* Late pests are those which begin their attack at the peak of flowering and continue up to harvesting. They affect mainly the quality of cotton. The major late pests in Zambia include Cotton stainers (*Dysdercus spp***),** American bollworm *(Heliothis armigera),* Spiny bollworm (*Earias biplaga)* and Red bollworm (*Diaparopsis castanea)* (Braun, 1991).

2.4 Biology and life cycle of *D. castanea*

Adult moths of *D. castanea* are nocturnal and they have a wing span ranging from 25 – 35 mm; the fore wings are usually more densely coloured than the hind wings. Females mate soon after emerging from their cocoons and lay their eggs singly on young leaves or stems of the cotton plant (Vaissayre and Cauquil, 2000). The eggs range between 0.5 – 0.7 mm in diameter. They are sub spherical in shape and slightly flattened at the base. The eggs have mesh markings and bear minute spines on the surface. They have a characteristic sky - blue colour (Figure 2.1), changing to grey just before hatching.

The young eggs will hatch after 4-10 days of oviposition and produce larvae with a pale head and black legs. This is the feeding stage of the insect and therefore the most damaging stage to the cotton plant. The caterpillar will go through five instars reaching a length of 25 – 30 mm before pupation. The newly hatched larvae are pale cream or greyish white, with the head and some other parts black. The characteristic red markings appear in the second and subsequent instars. Three dorsal red lines will appear to form a forward- pointing arrowhead on each segment of the body except the first and last segment (Munro, 1987). The pupae are enclosed in an irregular earthen cell, consisting of soil particles cemented together, with a slivery silk lining. Detailed pictures of the lifecycle are shown in figure 2.1.



Photos: M. Chijikwa

Figure 2.1. Lifecycle of *D. castanea*

2.5 Feeding behaviour and damage to cotton

The larvae prefer to attack the reproductive parts of the cotton plant, feeding on flowers, squares and bolls. If the squares are not available, the larvae may occasionally bore into the terminal bud of a shoot forcing the larvae to become a stem borer. Using the mandibles, the young larvae will penetrate the nearest squares or flower and eat out the entire contents. The flower bud will wilt and fall from the shoot but remain hanging by a silk thread (Munro, 1987). In other instances, once a square has been attacked by this bollworm it turns yellow and opens up forming a 'flared square'. The damaged squares/buds and young bolls will usually drop off. The attacked parts are normally damaged completely (Braun, 1991). The bolls attacked by the older caterpillars often rot due to infection by various micro-organisms such as viruses, fungi or bacteria. Damage can be identified by the circular holes that range in diameter from 3-4 mm (figure 2.1) and the droppings which remain inside the capsule (Cauquil, 1988).

What is unique about this caterpillar is that during feeding the caterpillar remains hidden inside the cotton square/boll. It will only emerge once it has devoured the entire contents of the fruiting structure and drops to the ground for pupation (Munro, 1987; Hill, 1983). This presents a challenge in the control of this pest as remaining in the fruiting structure protects it from the action of non-systemic pesticide once applied.


Source: www.agropedia.iitk.ac.in

Figure 2.2. Small cotton square damaged by *D. Castanea*

2.6 Control of *D. castanea*

Some of the control methods for the management of *D. castanea* include chemical, biological and cultural methods etc. Detailed descriptions of these control methods are outlined below:

2.6.1 Chemical control

Chemical control is the destruction of insects by insecticidal action. This is a curative method that can rapidly eradicate insect pests once they have been detected (Fenmore, 1982). Chemical application is a popular method of control because the active ingredient easily penetrates the exoskeletons of insects causing paralysis of the organism. The chemical toxin keeps the sodium channels open in the neuronal membranes preventing the nerves from de-exciting, therefore paralyzing the insect (Soderlund *et al.,* 2002). Chemical control is most effective when pest outbreaks are evident. However, not all pesticides are beneficial over the long term.

In the late 1960s and early 1970s pest management in Zambian cotton was based around the use of broad-spectrum insecticides, in particular DDT, endrin and parathion, all of which are generally very disruptive to beneficial insect populations. These were applied weekly from the moment the first flower buds appeared (Herrona *et al.*, 1998). Due to the build-up of resistance, these organo phosphates (OPs) were replaced by monocrotophos and profenofos. Although resistance to monocrotophos was suspected early in its use, the resistance to profenofos and monocrotophos remained fairly stable until the late 1980s. Profenofos was used to control both mites and bollworms, although, it was more expensive than effective alternatives, in particular endosulfan or pyrethriods (Forrester *et al*., 1993).

With the ban of persistent organic pollutants (POPs) by the World Health Organization (Mörner *et al.,* 2002: United Nations Environment Programme, 1997), pyrethriods were encouraged and these remain in use up to date. Two classes of synthetic pyrethriods are recommended for the control of bollworms and cotton stainers: The first is *Lambda cyhalothrin*, sold under the trade name Kang fu or Karate, and the second is *Cypermethrin* and *fenvalerate*, sold under the trade name Cypermethrin or Cyrux (Javaid, 1993).

Chemical control may have some short term benefits, but complete reliance on insecticides to control pests is likely to be unsustainable for the small scale farmer. The cost of the recommended pesticides is often unaffordable to the majority farmers and farmers have complained on the low efficacy of these pyrethriods (Kalapa, 2010 personal communication). Though these implied problems of resistance remain scientifically unverified in Zambia, bollworm resistance to pesticides has been observed in many parts of the world (Regupathy *et al.*, 1998; Martin *et al.,* 1989; Gunning *et al.*, 1984). The indiscriminate use of pesticides also presents a hazard to human health and the natural environment, and is inversely related to sustainable cotton production (Bos *et al*., 2006). Annually, pesticides are thought to cause 20,000 deaths and 3 million cases of acute poisoning worldwide, and most victims are agricultural workers and people living in rural areas (Dinham, 1993).

2.6.2 Biological control

Biological control is an environmentally sound and effective means of reducing or mitigating pests and pest effects through the use of natural enemies. Any organism that feeds on another organism is its natural enemy (Cortesero *et al.,* 2000). Natural enemies in cotton include among others, ladybirds, spiders, ants, lacewings, wasps, parasitic nematodes, predatory mites and bacteria. There are two main types of natural enemies, predators and parasitoids. Predators, such as ladybugs and spiders, are insects that feed on several different kinds of insect, and will consume prey throughout their life cycle. Parasitoids are organisms that lay their eggs on or inside other arthropods (Smith and Capinera, 2000). The eggs hatch and the immature parasitoid feed on the victim, called a host, eventually killing it. Each developing parasitoid kills only one host in the course of its life cycle, but parasitoids are more specific in the insects they attack than predators.

Natural enemies of bollworms, such as *Trichogramma* , have shown great potential in being able to control bollworms in cotton IPM, but success is dependent on the weather conditions that prevail at the time of release. (Verma and Shenhmar, 1998). This is particularly true for *Trichogramma* egg parasitoids that generally fail to suppress *Heliothis* pests when released alone in established cotton-growing regions. Factors hindering parasitiod success include: indiscriminate use of detrimental broad spectrum insecticides, compensation for minimal pest larval hatch due to parasitiod activity via reduced larval cannibalism or mortality in general, singly laid *Heliothis* eggs avoiding detection and asynchronous development benefiting the host than the parasitoid (Pluke, 2004). Yet, despite these limitations, relatively large *Trichogramma pretiosum* populations pervade and effectively suppress *Heliothis spp* in *Bt* (*Bacillus thuringiensis*) cotton in Australia (Davies *et al.*, 2011).

Biological control of bollworms is a very attractive strategy, because generally there is no development of resistance as is the case when using pesticides (Van den Berg *et al.,* 1993). It has not yet been exploited in Zambia for the control of bollworms in cotton. Parasitoids and predators could be important natural enemies in Red bollworm management in Zambia. Verification of their occurrence, identity and how changes in the usual cropping system might possibly affect them need to be explored for possible inclusion into Red bollworm management programmes in cotton fields.

2.6.3 Legislative measures

These are methods of control where the government legislation (laws) has been passed so that certain control measures are mandatory, with failure to comply being a legal offence (Sakala, 2011). The Plant Pests and Diseases Act No.13 of 1994 Cap 76, is the main statutory instrument that is being used for the control of *D. castanea* in Zambia (http://www.vertic.org/media/National%20Legislation/Zambia/ZM_Plant_Pests_Diseases_Act.pdf, The act provides for the eradication and prevention of the spread of plant pests and diseases in Zambia.

This entails that before any plant material can be imported in the country, an International phytosanitary certificate has to be obtained from the Plant Quarantine and

Phytosanitary Services (PQPS) under the Ministry of Agriculture and Livestock (MAL). Also under the act, a legal closed season has been imposed to limit cotton ratooning and enforce early uprooting of the plants before 31st September of every year. Furthermore, cotton free zones are used to prevent the spread of cotton plant materials from areas where *D. castanea* incidence is high to areas where it has not yet been recorded.

While legal and regulatory frameworks to prevent the spread of *D. castanea* exist, the lack of capacity and capability to implement and monitor adherence to the law have done little to prevent the spread of this pest to all parts of the country. The Ministry of Agriculture and livestock (MAL) is heavily under staffed with inspectors who can monitor the movement of infected plant materials between various districts (Ngona and Dube, 2013). Many times agriculture extension personnel are not adequately trained to monitor for the presence/absence of cotton pests in their catchment areas. This has led to *D. castanea* entering new areas where it did not exist and eventually becoming a major pest of cotton in Zambia (Kalinda *et al*., 1998).

2.6.4 Host-plant resistance

Production of crop plants with heritable arthropod resistance traits has been recognized for more than 100 years as a sound approach to crop protection (Smith 2005; Painter, 1951). Using plants that are resistant to attack by insect pests is clearly an attractive option, particularly if the resistance is complete in the sense that the attacking insect is no longer able to cause economic damage to cotton bolls. Numerous authors have chronicled the development of plant resistance as a science and a valuable tool in integrated pest management (IPM) (Dhaliwal and Singh, 2004; Panda and Khuh, 1995; Smith et al., 1994; Snelling 1941)

In Least Developed Countries (LCD), like Zambia, not enough attention is paid to breeding for pest resistance. A notable exception was the early use of pubescence for jassid control (Russel, 2004). This led to the selection of hairiness in Zambian cotton varieties, when breeding for tolerance against sucking pests. In 1994, the USA introduced the first field releases of transgenic cotton that were resistant to bollworm attack. Since then the cotton industry has been revolutionized by the use of genetically modified cotton to control bollworms such as *Heliothis spp, D. castanea and P. gossypiella* (Nelson, 2001). In Africa, only South Africa and Burkina Faso have fully commercialized Bt-cotton for use for small scale farmers. At present, no Bt-cotton varieties have yet been developed for Zambia (Hilloacks, 2009).

2.6.5 Cultural control

Cultural control is the deliberate alteration of the production system, either the cropping system itself or specific crop production practices, to reduce pest populations or avoid pest injury to crops (Kogan, 1986). The primary aim of these cultural techniques is to reduce colonization of a crop by a pest and/or to increase pest dispersal from that crop. It also helps to reduce reproduction or survival of a pest in a crop once colonization has occurred. Often these are by far the best methods of control since they combine effectiveness with minimal extra labour costs. Cultural practices include:

2.6.5.1 Time of planting

Alterations in planting date and harvest date can frequently result in plants escaping from damaging pest infestations. Many pests have periods during the year when they are at their most dispersive, i.e. when they are most able to disperse and colonise crop plants. The aim therefore with planting date manipulation is to avoid this peak period for crop colonization (Abate *et al*., 2000; Fero, 1996). Buntin *et al* (1990) showed that by delaying the planting date of wheat, in the fall, the Hessian fly, *Mayetiola destructor* (Say) was unable to find wheat seedling at the time of emergence. Infestations of fall and winter wheat by this pest, declined without enhancing spring infestations or reducing wheat yields. In cotton it has been shown repeatedly that early planting can protect crops against pest attack because plants are able to establish themselves before the pest arrives. For example, early planted cotton suffers less damage from bollworms per plant than normal or late cotton as the crop is able to evade peak periods of pest attack (Koul *et al,* 2004).

2.6.5.2 Modifying Plant Density

Crop plant density in cotton can have an effect on pest infestation in at least two different ways. First, a higher density in cotton production will encourage a faster rate of multiplication of bollworms and other pests of cotton (Thacker, 2002). Meanwhile increasing the spacing between adjacent plants decreases the chances of migrating larvae coming into contact with neighbouring plants (Minja, 1990). This may in turn affect the relative rate of development of a plant and its pest population as well as the behaviour of the pest in searching for food or an oviposition site (Lawani, 1982).

2.6.5.3 Crop rotation

Crop rotation is the practice of growing a series of different types of crops in the same area in sequential seasons. Crop rotation interrupts normal life cycle of insect pests by placing the insects in a non-host habitat. Rotation is generally most successful against arthropod pest species with long generation cycles and with limited dispersal capabilities (Zehnder *et al.*, 2007; Fero, 1996; Hill, 1983). Historically the use of rotations represents one of the earliest techniques for pest control. Continuous cultivation of one crop induces a pest or disease build up and also depletes minerals and trace elements in the soil. For effective pest control, crop rotation has to separate crops both spatially and in time. In soya beans, the white fringed weevil complex, *Graphognathus leucoloma* and *G. peregrinus* , adults lay many eggs when fed on soya beans and cause heavy damage to this crop. However, the grass crops, including mauze, are in some way nutritionally deficient to support feeding, and do not suffer damage from this pest. So, a soya bean/corn rotation is effective and economical (Pedersen and Lauer. 2002).

Using the same principles, small scale famers in Zambia are encouraged to ensure that cotton is followed by crops which are not favourable or are less preferred by cotton pests. Cotton followed by cereals like maize / sorghum reduce the incidence of whitefly, bollworms, soil born insects and nematodes (Conservation Farming Unit, 2007).

2.6.5.4 Nutrition and water management

Plants that are well managed (fertilized and well watered) are, in very general terms better able to tolerate a limited amount of pest damage (Bailey, 2007). This is because healthy plants are usually better able to increase their overall productivity in response to pest attack in contrast to stressed or unhealthy plants. In addition, it is well known that well-fertilized plants are often able to increase their growth rate and so decrease the time available for pest attack. In cotton, fertilization should be done following the recommendations made after soil analysis tests as high doses of nitrogenous fertilizers cause excessive vegetative growth (luxuriant green growth) which otherwise attracts more pests (Chen *et al.,* 2009).

Investigations by Proctor (1962) in Nigeria showed that water could be used to manage the emergence of diapausing larvae of *D. wasteri*. When land is watered, emergence from diapause by the pupae is almost completed within six weeks; it is thought that rainfall reduces soil temperature below the threshold level and the low temperatures appear to inhibit diapause development throughout the hot season. Therefore, irrigating or water logging the fields before planting the crop, will cause many of the adult moths to emerge from diapause. Many of these moths may not survive as they will find that the cotton plant has not yet established, therefore the initial pest population on the crop is low. (Geering and Baillie, 1954; Tunstall, 1954).

2.6.5.5 Intercropping

Intercropping is growing two or more crop species simultaneously on the same piece of land. (Hokkanen, 1991; Capinera *et al.,* 1985). Intercropping is an approach that is favoured in many developing countries, particularly among small-holder farmers. Intercropping offers a diversity of food items that can be grown and farmers are protected against loss of any one of these if a specific pest outbreak occurs. The intercrop also provides shelter for natural enemies which in turn feed on the insect pests that attack the main crop. The presence of a more diversified flora has a negative effect on the ability of the insect pests to find and use their host plant (Dent, 1991).

Sullivan (2001) argued that intercropping would be beneficial in pest management, because an increase in the diversity of the plant community tended to increase predator populations. Crops differ in their potential to harbour natural enemies. Differences are brought about, at least in part, by differences in the semio-chemicals that are released by the different crops. Several researchers have studied the effect of intercropping cotton on different insect pest populations (Jambhrinkar *et al*., 1998; Shanower *et al*., 1997; Andow, 1991; Fang *et al.,* 1984). One of the most successful intercropping systems that have been developed in Africa is the use of the push-pull strategy in the control of stem borers and striga weed in Maize ([a]Khan *et al.,* 2001). The push-pull strategy is based on a combination of a trap crop (pull component) with a repellent intercrop (push component). The trap crop attracts the insect pest and, combined with the repellent intercrop, diverts the insect pest away from the main crop.

Though push-pull has greatly succeeded in maize, the term was first conceived as a strategy for insect pest management (IPM) by Pyke *et al* (1987) in Australia. They investigated the use of repellent and attractive stimuli, deployed in tandem, to manipulate the distribution of *Helicoverpa spp* in cotton, thereby reducing reliance on insecticides, to which the moths were becoming resistant.

Epieru (1997) studied the potential of different crops to attract predators of cotton bollworms in Uganda. He compared the populations of generalist predators on cotton grown adjacent to sorghum, maize and beans with those on sole crops of cotton, sorghum, maize and beans. He reported that cotton grown in various combinations with other crops increased the occurrence of common predators, such as *Chelomenes lunata* (Fabricius) (Coleoptera: Coccinellidae), *Scymnus* spp. (Coleoptera: Coccinellidae), *Orius* spp. (Hemiptera: Anthocoridae), ants, spiders, earwigs and to lesser extent syrphid larvae, rove beetles and chrysopids. He further noted that cotton grown adjacent to sorghum had more spiders than cotton grown adjacent to maize and beans.

Most of the studies that have been conducted on intercropping in cotton have been to control the Lepidoptera *Heliothis sp* (Chamuene, *et al.,* 2007; ICIPE, 2003; Rasool *et al.*, 2002; Sithanantham *et al.*, 2002; Parajulee and Slosser. 1999; Nyambo, 1990; Nyambo, 1986). Studies on *D. castanea* have been very limited as its distribution is not widely known and so far it has been found on very few alternative hosts (Pearson, 1958). Since the pest has become a major pest, more research is required to find an effective control method in cotton fields. There is currently very little information on the population densities of *D. castanea* on cotton in Zambia. Therefore evaluating possible intercropping patterns that can be used to control *D. castanea* would form the baseline data for future work on this pest. Intercropping is the hallmark of modern Integrated Pest Management (IPM) systems (Chinsembu, 2012).

CHAPTER 3 : MATERIALS AND METHODS

3.1 Study Area

This section discusses some aspects of the general physical characteristics of the study area.

3.1.1 Location of study site

The study was conducted in Magoye area which is situated in the Southern Province of Zambia in Mazabuka district. Mazabuka district lies at an altitude of approximately 975 Meters above sea level (m.a.s.l). Magoye is located at latitude 16° 2' 0" South and longitude 27° 37' 0" East. This area was selected because it is the location of the main cotton research station in Zambia. The map below shows Cotton Development Trust situated at plot 670/m (Figure 3.1).

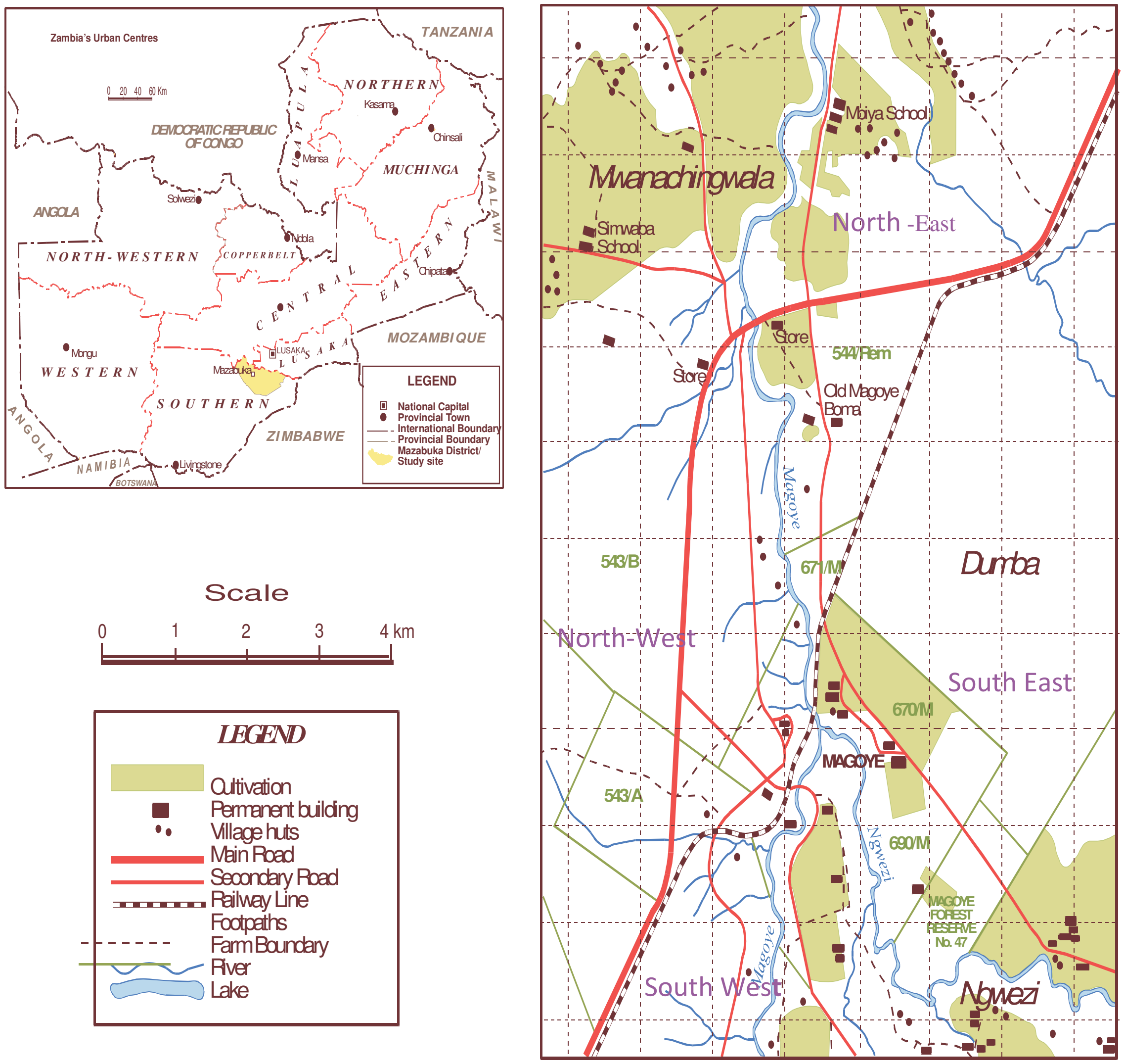


Figure 3.1. General map showing surveyed area and location of field study site
(Source: Cartography department, Geography department, UNZA)

3.1.2 Climatic and general weather conditions

Magoye is located in Agro-ecological region II. This region is characterized by medium rainfall, with mean annual rainfall ranging from 800 – 1000 mm per annum (Magande, 1975). Temperatures are low to medium and the growing season ranges form 100 – 140 days. During the 2010/11 farming season, Magoye had approximately 74 rainy days and the total amount of rain received the whole season was 973 mm of rain. Mean temperatures, ranged from a minimum of 14.23°C to 28.61°C from October 2010 to May 2011 (Table 3.1). The mean relative humidity for the period of October 2010 – May 2011, was approximately 66%.

Table 3.1. General weather condition for Magoye during the 2010/11 farming season

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Rain days	2	11	17	21	11	9	3	0
Monthly total (mm)	16.8	74.3	299.5	267.2	178.5	104.7	30.9	0.6
Cumulative seasonal total(mm)	16.8	91.1	390.6	657.8	836.3	941	971.9	972.5
Mean Max temperature(°c)	35.59	31.42	28.14	27.49	27.24	21.87	29.4	27.73
Mean Minimum temperature (°c)	15.61	17.27	16.80	16.98	15.01	11.83	12.4	7.96
Mean Relative humidity (%)	35.38	59.65	72.86	79.04	72.57	76.60	68.40	59.65

Source: Magoye Meteorological station, 2011

3.1.3 Soil Type

Under this Agro-ecological Region, soils are moderately leached sandy loams. The soils are characterized by high acidity, poor nutrient retention, low water holding capacity, dominance of coarse textured top soils (abrupt textural change) and severe topsoil capping which results in seedling emergence problems (Kasali, 2001). Soil analysis tests revealed that Magoye soils are 71% sand, 13% silt and 16% clay. The pH of soil ranged from 4.2 – 5.2 indicating that the soils are acidic in nature. The total nitrogen availability in the soil was approximately 16 mg/kg, phosphorus levels were 7 mg/kg (very low), and potassium levels were 160 mg/kg (very high).

3.1.4 Vegetation type

The munga woodland, which was the dominant woodland is an open, park-like 1-storeyed deciduous woodland characterized particularly by species of *Acacia, Combretum* as well as *Adansonia digitata* (baobab tree). This woodland, like other vegetation types follows a sequence from woodland to shrub to savannah to grassland. Small trees and shrubs are frequent especially where the canopy is open. There appears to be no secondary munga woodland recognized as such, probably because munga woodland is an invasive type (Fanshawe, 1971).

This striking vegetation gives way to stretches of mopane (*Colophospermum mopane*) with a sparse ground cover of ephemeral grasses. The mopane woodland had the appearance of an invader, which occupies unstable and actively eroding soils, some perhaps covered with thicket growth (Trapnell and Clothier, 1996).

Flooding of the alluvial soils and on the flats, assisted by the ravages of fire, leads to purity stand. When flooding is very slight and very temporary, or even absent in some years, termite mounds are usually absent and shrubs not adapted to flooding are scattered throughout the woodland. Where flooding increases in depth and duration, termite mounds are present and the shrubs, which are not adapted to flooding retreat to the mounds, which may be low or high (Fanshawe, 1971).

3.2 Human Activities of the People in the area

The people found in this area are Tonga by tribe and their main occupation is subsistence farming. These are an agricultural tribe; herding cattle and crop growing being two of the most important aspects of their traditional economy. The main food crops cultivated are sorghum, millet and maize (Kasali, 2001). These are grown for household food security with only a little local trade within the area. Cotton was the major cash crop grown in this area. Sunflower was also another cash crop grown but to a limited extent due to lack of a definite market. Other traditional crops grown in Magoye area were groundnuts, sorghum, sweet potatoes, sunflower, cowpea, vegetables and fruits.

The main livestock kept are cattle, goats, pigs and chickens. Cattle are an important asset to farmers in this area, as it cushions against shocks and shortfalls in consumptions: since they can be sold to smooth food consumption, pay for school fees or buy medicines, etc (Siegel, 2008). Cattle are also used as animal draft power.

Over 90% of smallholder crop production in this area is rain fed, therefore rainfall is a critical factor for selecting crops, their planting time, the timing and intensity of input and labour use. This area is prone to weather extremes where both droughts and floods are regular problems. Since 1990, about three out of every five years have essentially been drought years in Zambia (Bwalya, 1999). The occurrence and impact of drought is not equally distributed in the country but Southern Province, including Magoye, has been most severely impacted by the droughts (Sichingabula and Sikazwe, 1999).

3.3 Study design

The study was conducted in two parts during the 2010/11 farming season. The first part involved a survey using questionnaires (Appendix A). The survey was aimed at identifying the different types of intercropping systems that are practised in Magoye area and the farmer's attitudes towards intercropping. Information on intercropping practices identified in the survey were included in the field study, the second part of the study. The field study aimed at assessing the effects of intercropping systems on incidence and damage of cotton by *Diaparopsis castanea*.

3.4 Part A (survey)

The study was carried out primarily through a survey of 80 randomly selected small holder cotton farmers in the months of September and October 2010. In obtaining the sample for the survey, stratified random sampling was used. Using the main rail line and secondary feeder road running through CDT, Magoye was divided into four stratas namely North-East, North-West, South-East and South-West (Figure 3.1). Twenty farmers were interviewed from each of the four areas to make a total of eighty farmers. Farmers were selected using the registers provided by the extension officer from each strata. Farmers were selected from the registers using computer generated random numbers. Participatory Rural Appraisal (PRA) techniques, using questionnaires, interviews, focused group discussion (FGD), and transect walks were used to identify the various intercropping patterns that were being used in cotton production in Magoye area. The questionnaire was divided into four sections:

i. Section 1: this was related to the description of the farms and included questions meant to win the farmer's confidence.

ii. Section 2: this was designed to extract maximum information from the farmers about pest management practices.

iii. Section 3: this was concerned with actual cultural practices that farmers were using to control pests in cotton fields

iv. Section 4: this section was for official use. It was aimed at ensuring that the supervisor checked each question, to ensure that all the relevant data was correctly collected

3.5 Part B (field study)

For the field study, five plant species were selected as intercrops. These were: Sunflower *(Helianthus annuus L.),* Pigeon pea (*Cajanus cajan L*), Maize (*Zea mays L.*), Sorghum (*Sorghum vulgare L.*) and Cowpeas (*Vigna unguiculata L.*).

These intercrops were selected based on:

i. Ability to either attract effective natural enemies or repel lepidopteran pests from cotton. Sunflower, sorghum and pigeon have been reported be able to have repellent properties against caterpillars (Shelton and Badenes-Perez, 2006)

ii. Economic importance of the intercrop to the small-scale farmer in Magoye. Maize was an important food crop in many smallholders' households while cowpea was an important food and rotation crop in conservation agriculture (Conservation Farming Unit, 2007).

iii. Results of part A survey on intercrops traditionally used by farmers in Magoye to control pests in cotton. The crops that were identified were maize and cowpea, which we incorporated in the field trial.

3.5.1 Field Design

The field trial was prepared, in a Randomized Block Design (RBD) with four replications and six treatments (Figure 3.2). The treatments consisted of cotton - maize, cotton – sorghum, cotton - pigeon peas, cotton - cowpea, cotton – monocrop (control) and cotton – sunflower (control) intercropping patterns. The total area used for the field study was 0.1472 ha.

Rep I					
101 cotton - maize	102 cotton - sorghum	103 cotton-pigeon pea	104 cotton-cowpea	105 cotton monocrop	106 cotton - sunflower
Rep II					
201 cotton - sorghum	202 cotton monocrop	203 cotton - maize	204 cotton- pigeon pea	205 cotton - sunflower	206 cotton-cowpea
Rep III					
301 cotton - sorghum	302 cotton monocrop	303 cotton - sunflower	304 cotton-cowpea	305 cotton - maize	306 cotton- pigeon pea
Rep IV					
401 cotton - sunflower	402 cotton - sorghum	403 cotton monocrop	404 cotton - maize	405 cotton-cowpea	406 cotton- pigeon pea

Figure 3.2. Field plan and randomization

3.5.2 Land preparation

Minimum tillage method using animal draft power was used to prepare the land as this is recommended under conservation farming. The Magoye ripper was used to open furrows in the field in order to facilitate the planting of the cotton crop. The furrows were made at 90cm from each other (Plate 3.1). The field was marked according to the field plan (Figure 3.2).

3.5.3 Planting of cotton intercrops

Planting holes for cotton were made in the ripped furrows at a distance of 30 cm from each other. The acid delinted cotton variety CDT II (*Gossypium hirsutum*) was planted on 1st November 2010 using supplementary irrigation. The seed was planted at a depth of 2 cm and a seed rate of 15 kg of acid delinted seed per hectare was used. A week after planting, the cotton began germinating (see plate 3.2 a). Two weeks after planting (16th November 2010) the first intercrops (maize and sorghum) were planted in between each row of cotton according to the randomization. A planting stick was used to make a shallow furrow for the planting of the intercrops (Plate 3.2b). A week later, pigeon pea and cowpea (22nd November 2010) were also planted in between each row of cotton according to the randomization. Approximately two weeks later, sunflower (10th December 2010) was planted according to the randomization. Sesame was initially selected as an intercrop, but due to failure of the seed to germinate, sunflower was planted in its place. Planting of intercrops was staggered so as to synchronise the fruiting stages of the cotton and intercrops. This is when cotton is most vulnerable to attack by *D. Castanea*.

Plate 3.1. Planting of cotton; the furrows of cotton were planted at a distance of 90 cm of each other

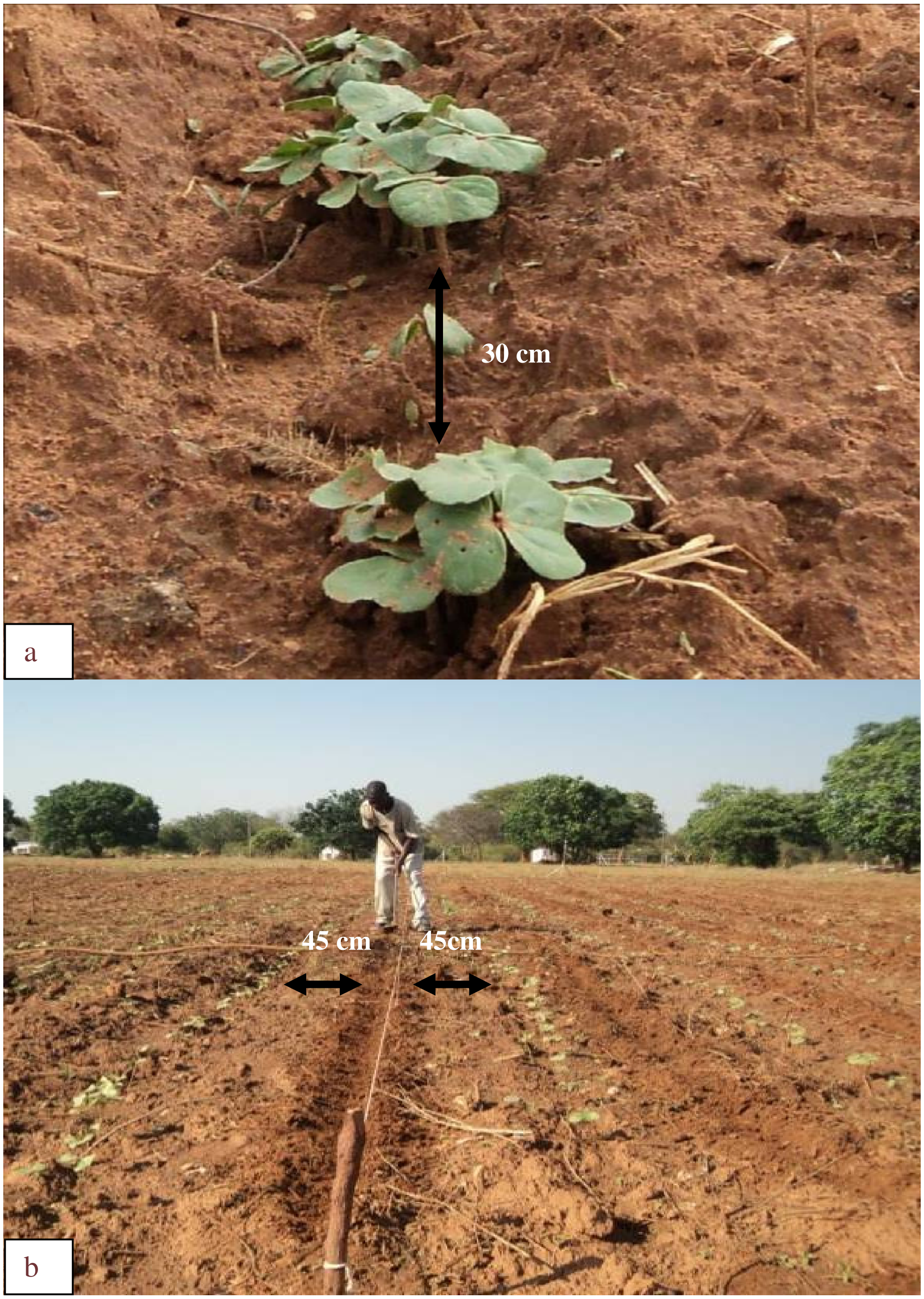


Plate 3.2. Planting of intercrops: (a) Furrows of germinating cotton were spaced at 30 cm; (b) intercrops were planted in between each row of cotton at a distance of 45cm from the furrow of cotton

3.5.4 Gap-filling and thinning

Germination was good and no gap- filling was required. The cotton crop was thinned two weeks after germination (16th November 2010) to make sure that there was only two plant per station, which is the recommended spacing for cotton (Cotton Development Trust, 2005).

3.5.5 Weeding and fertilization

Hand weeding was conducted a week after germination (8th November 2010). This was done to facilitate the planting of intercrops and also in readiness to apply fertilizers. Compound D fertilizer (N = 10.00%, P_2O_5 = 20.00% and K = 10.00%) was applied to the cotton crop, at a rate of 200 kg/ha, two weeks after germination (18th November 2010). The crop was top dressed with urea (N=46%), at a rate of 100 kg/ha, at the appearance of the first cotton flower (23rd December 2010).

3.6 Sampling

For the field trial, a stratified random sampling design was used as described by Cochran (1977). This is where a field study area is divided into several strata and the sampling portions within each stratum are selected randomly. This method ensures that the population mean estimates are unbiased and precise. Therefore six cotton plants and six intercrop plants were sampled from the three middle rows of cotton and intercrops within each treatment (Plate 3.3). The samples were randomly selected using computer generated random numbers. This was in order to obtain population estimates of *D.*

castanea using the standardized procedure described by Allen *et al* (1972). Besides observing for *D. castanea*, thorough examinations were also conducted for different natural enemies of this pest. Estimations of percentage damage to fruiting structures were carried out in the laboratory. The assessments conducted are described in detail below:

3.6.1 Incidence of *D. castanea* and natural enemies

When the cotton plant reached 8 weeks (29th December 2010), a full plant scouting technique (Stewart, 2007) was used to determine the incidence of *D. castanea* and natural enemies in each treatment. This technique begins with examining the growing points of the plant to check for insects which feed on tender growth parts. Next, two fully expanded leaves were selected and turned over gently. The leaves being examined were held at the stalk to avoid the flight of insects before observing them. The leaves were turned over slowly by twisting their petioles until their under-surfaces were clearly visible. Lastly the whole cotton plant was examined from bottom to top, checking all fruiting structures for presence of *D. Castanea* or other natural enemies. Mobile insects were only recorded present if they were found on or around the plant at the time of scouting.

Scouting was conducted at least once a week between 05:30 – 7:00 hours. The information collected was recorded on specially designed scouting forms (Appendix B). If scouting results revealed that a treatment plot had exceeded the economic threshold (Appendix C), the plots were treated by handpicking the pests. An economic threshold level is the point at which control measures are needed to prevent the target pest from reaching its economic injury level (when control costs equal damage caused by the pest). No pesticides were applied throughout the growing season so as not to affect the presence of natural enemies.

Scouting was conducted from week 8 to week 31. Every week, 252 plants of cotton and intercrops were examined to determine incidence and damage levels. A total number of 6072 cotton plants and intercrop were examined for the entire duration of the field study.

Plate 3.2. cotton - pigeon pea treatment; only the three middle rows of cotton and two rows of the intercrop were selected for sampling during scouting

3.6.2 Determination of damage caused by *D. castanea* on cotton plants

Damage was determined by examining the number of squares and bolls that were damaged on the cotton plant. During scouting all the squares and bolls were examined to assess for damage. Plant damage was recorded if a hole was found on the square or boll. The hole was an indication of bollworm damage. In order to confirm that the observed damage was caused by *D. Castanea,* the damaged boll or square was opened using a scalpel. Only fruiting structures that were found to contain *D. castanea* were considered as damaged.

3.6.3 Observation of Parasitoid emergence.

During scouting, all *D. castanea* larvae found in the field were collected in jars (plate 3.7) with cotton wool and taken to the laboratory for further observation for the presence of parasitoids. Larvae collected from different treatments were separated and reared in separate jars. The jars were filled with soil and fruiting structures from which the larvae were collected. The jars were kept at temperatures of 25-30°C and relative humidity of 60-70%. Fresh cotton squares and bolls used as feed were changed every three days until the larvae pupated or parasitoids emerged. If the larvae pupated and no parasitoid emerged, the rearing jar was discarded and fresh larvae were collected during the next scout.

Plate 3.3. Rearing jars used to rear live larvae of *D. castanea* for observation of emerging parasitoids.

3.6.4 Assessment of crop performance

All crops were harvested by hand. Seed cotton was harvested after the bolls had fully burst open and were dry. Harvesting data was collected from the three rows in the centre of the plots, irrespective of whether the plot was intercropped or planted to cotton only. The first and last plants in each row of cotton were discarded before harvesting of the bolls occurred. To assess for the crop performance six parameters were chosen: Average plant height, average boll weight, average number of squares/bolls, number of interventions, average damage of squares/bolls and average cotton yield.

i. Average Plant height

Using computer generated random numbers, six mature cotton plants were randomly selected from the three middle rows of each treatment. Using a measuring tape, the height of the each plant was taken from the base to the tip using the main stem of the cotton plant. The heights of the six plants were averaged to get the average plant height.

ii. Average boll weight

Twenty mature bolls of cotton were randomly selected from the three middle rows of cotton within each treatment using computer generated random numbers. . The bolls were randomly selected using random numbers that were computer generated The bolls were harvested and weighed on a balance (Scientech sp 1000) in the laboratory to obtain the mean weight of each individual cotton boll.

iii. Average number of squares and bolls,

A full count of the total number of bolls and squares found on six randomly selected cotton plants was conducted. The plants were selected using computer generated random numbers. The six plants selected were taken from the three middle rows of cotton within each treatment. The data collected was averaged in order to determine the mean number of squares and bolls

iv. Number of times handpicked

Each time scouting was conducted, results were used to determine if the treatment plot had exceeded the recommended threshold levels as shown in Appendix C. When threshold levels were exceeded, the cotton bollworms were handpicked. The total number of times each treatment plot was handpicked was averaged in order to get the mean number of hand pickings for each treatment.

v. Average damage of squares and bolls

Six cotton plants were randomly selected from the three middle rows of each treatment. The squares and bolls were selected using computer generated random numbers. Each plant was examined to determine total number of damaged squares and bolls found on the cotton plant. The data collected was averaged in order to determine the mean number of damaged squares and bolls.

vi. Average Seed Cotton yield

All the mature cotton bolls in the three middle rows of each treatment were harvested and placed in different bags and labelled. For each plot the full harvest of seed cotton was weighed using an electronic scale (Scientech sp 1000) with an accuracy of 1 g and a capacity of 5000 g. This was used to determine the average yield in kilograms per hectare of cotton.

3.7 Data Analyses

3.7.1 Survey

The survey data was summarized into frequency tables using the statistical package SPSS 16. The summarized data on number of farmers using intercropping, type of intercrops and intercropping patterns used in Magoye was entered into Microsoft excel to generate tables and bar graphs. Chi-square test was used to determine which socio-economic factors had any influence on farmers' attitude towards intercropping.

3.7.2 Field Study

Analysis of variance (ANOVA) of means using the Statistical package Genstat discovery (Van Ark, 1981) was used to analyse the population estimates of *D. castanea* egg and larvae, different natural enemies, mean number of interventions (hand pickings) applied, percentage damage to squares and bolls, total number of squares and bolls, average boll weight and average seed cotton yield. When ANOVA identified treatment effects that were statistically significant (p < 0.05), treatment means were separated using Bonferroni's test.

Genstat was also used to carry out ANOVA on the intercrops among the various intercropping patterns. Within each treatment plot a comparison of the different types of natural enemies and number of *D. castanea* larvae and egg were used to determine the most effective intercrop.

CHAPTER 4 : RESULTS

4.1 Assessment of intercropping patterns in Magoye

A total number of 80 households were surveyed to determine the type of intercropping patterns used by cotton farmers to control bollworms in Magoye (Table 4.1). Seventy-five percent of the farmers interviewed were males while 25% were females. The farmers interviewed ranged from ages 27 to 77 years old, with 44% of the respondents falling in age group 48 -57 years old. The farm size of each individual farmer ranged from 1 to 160 hectares, though most of the farmers interviewed had farm establishments ranging between 1 – 40 hectares. In terms of literacy level, 81 % of the farmers interviewed attained primary education with 2.5 % having no formal education. The survey revealed that farmers in Magoye area were using both chemical and cultural practises to control pests in their cotton fields. The chemical used were mainly synthetic in nature as none showed evidence of having used naturally made pesticides.

Table 4.1. Background information on small holder famers who participated in the survey.

Background characteristics	Description of group	Frequency	Percentage (%)
Gender	Male	60	75
	Female	20	25
Age	27-37	7	8.8
	38-47	23	28.8
	48-57	35	43.8
	58-67	11	13.8
	68-77	4	5
Farm Size (Ha)	1-40	57	71.2
	41-80	20	25
	81-120	2	2.5
	121-160	1	1.2
Literacy level	No formal education	2	2.5
	Primary	65	81.25
	Secondary	6	7.5
	Tertiary	7	8.75
Pest management practises used	Chemical	0	0
	Cultural	0	0
	Chemical + Cultural	80	100
	None	0	0
Type of chemicals used	Synthetic	80	100
	Natural pesticides	0	0
	Synthetic + Natural pesticides	0	0
	None	0	0

Two types of cultural practices were used to control insect pests in their cotton fields (Figure 4.1). These were; crop rotation (72.5%), intercropping plus crop rotation (27.5%). Among the 28% of farmers who had used intercropping to control cotton pests, the intercrop was grown either as a strip or single row pattern alongside the cotton crop or in between each row of cotton. The majority of farmers (72 %) did not use any form of intercropping (Figure 4.2)

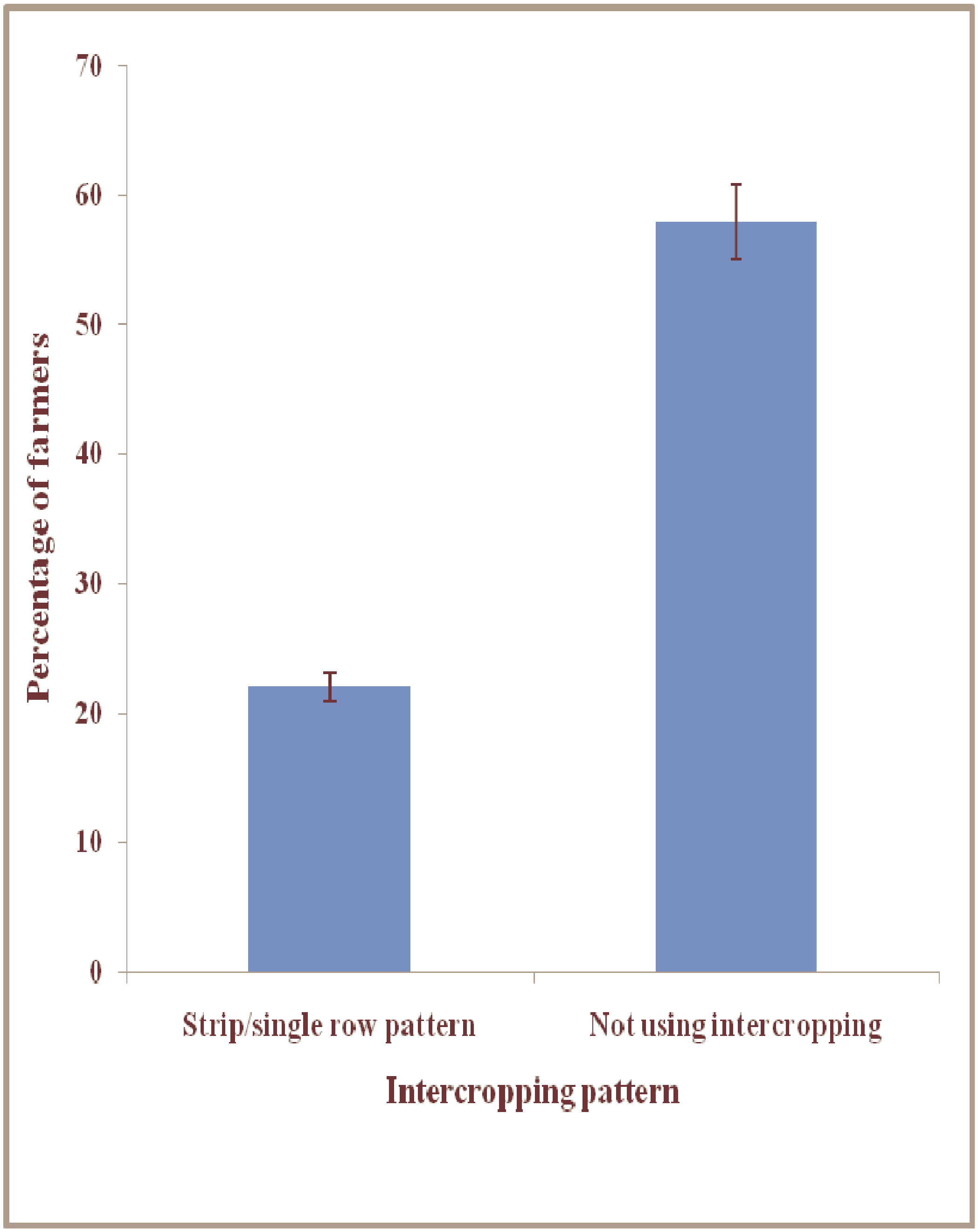


Figure 4.1. Percentage of farmers using different types of cultural practices in Magoye, Mazabuka district, Zambia.

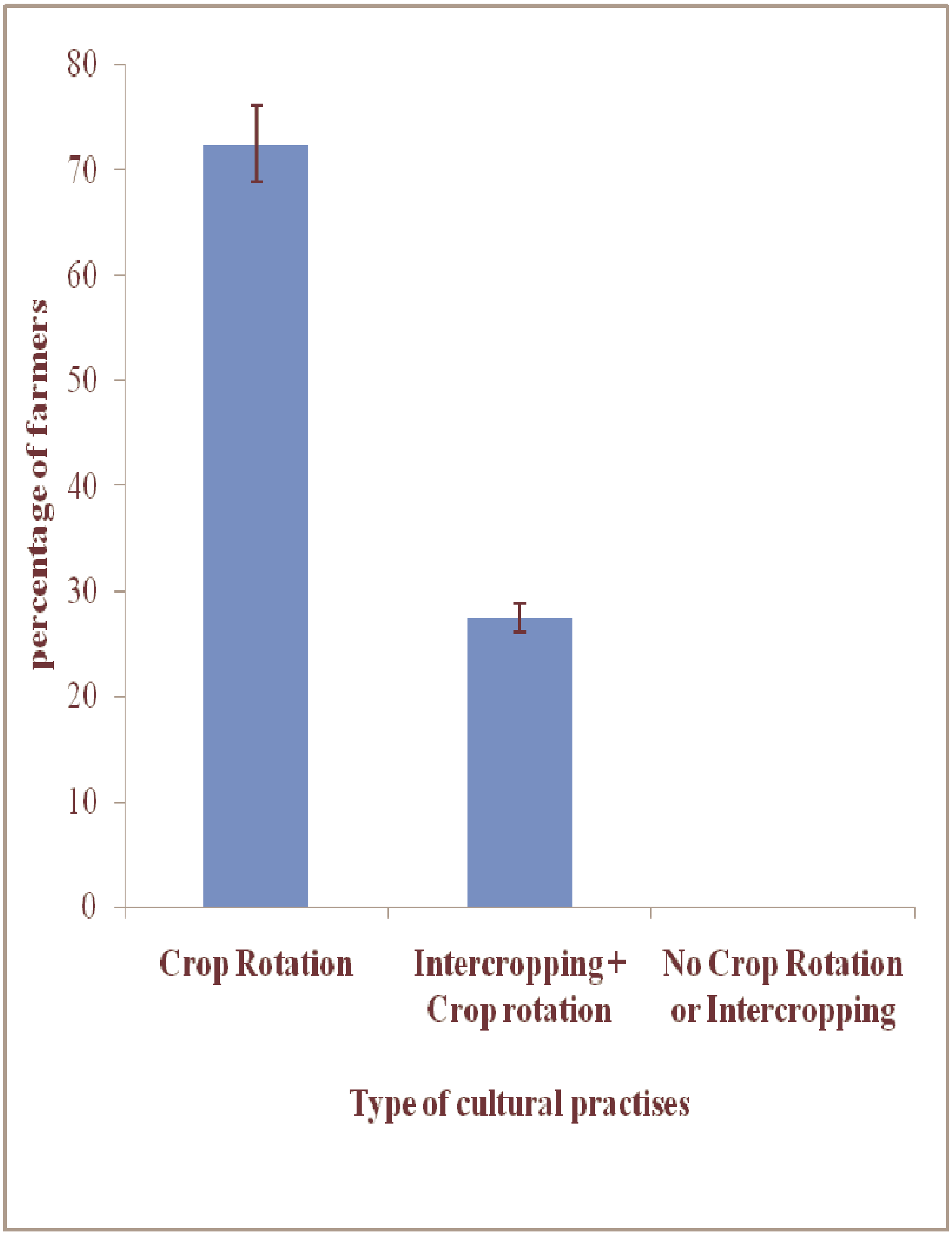


Figure 4.2. Percentage of farmers using row pattern intercropping pattern in Magoye, Mazabuka district, Zambia.

Farmers using intercropping indicated four different types of crops that served as intercrops in their fields. These were maize, cowpea, beans and groundnuts. The crops were either grown as a single intercrops or a combination of multiple intercrops grown along with cotton. Cowpea with beans was the most common combination practice (22%), while the combination of groundnuts, cowpea and beans; maize and cowpea were only used by two percent of the farmers (Figure 4.3). Among the five intercrops identified, only cowpea and maize were selected to be incoroporated in the experimental field study, alongside sorghum, pigeon pea and sunflower.

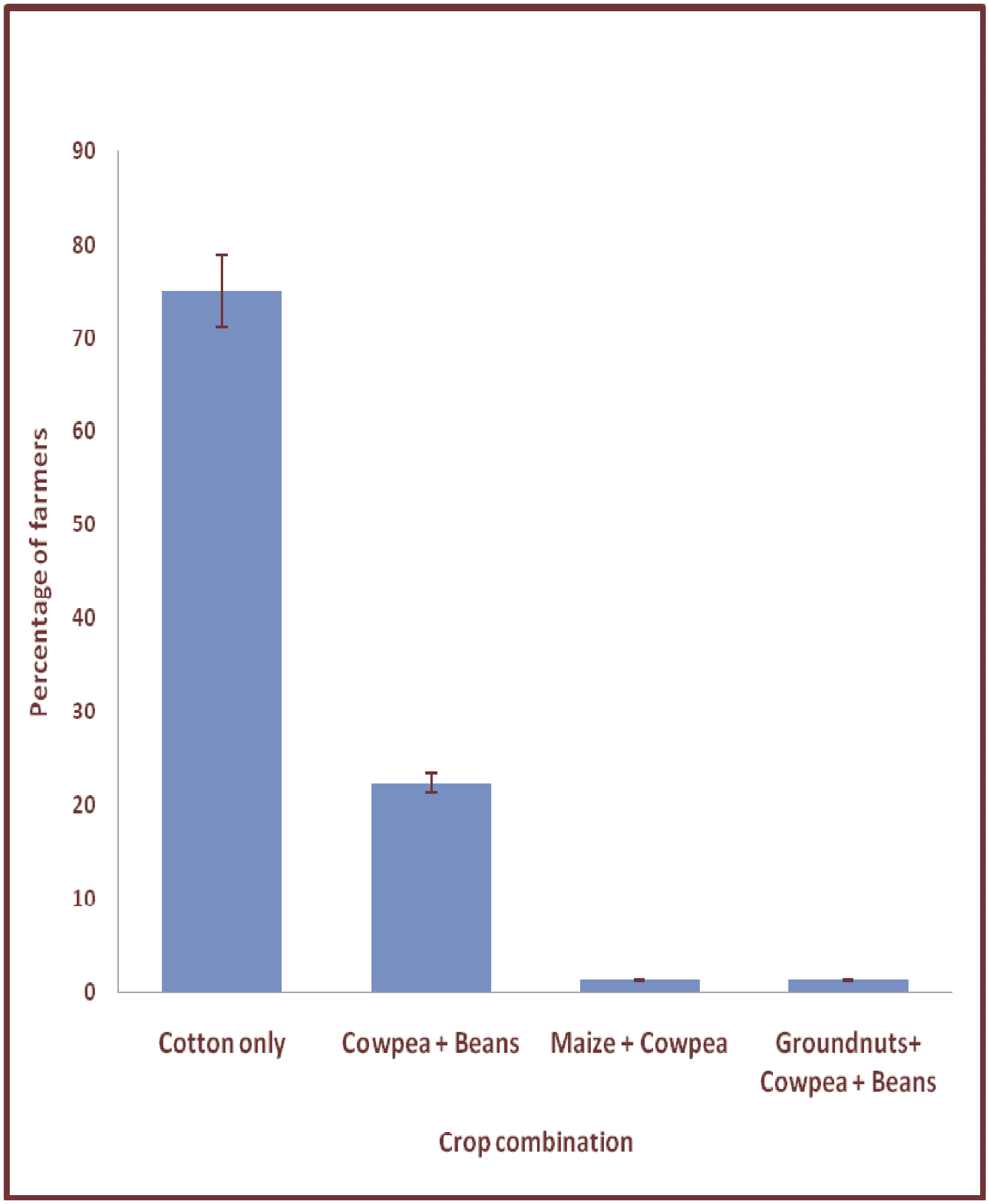


Figure 4.3. Crops used by farmers in intercropping with cotton Magoye, Mazabuka district, Zambia.

4.1.1 Farmers attitude towards intercropping

Table 4.2 showed that the probability of gender (X^2=5.938, df = 1, P = 0.015) and literacy level (X^2= 14.618, df= 3, P = 0.002) of the farmer, affected the farmers' willingness to incorporate intercropping into his/her farming system. Farmers with no formal education showed no willingness to incorporate intercropping into their farming systems even if a suitable intercrop was identified (Figure 4.4). Farmers who have attained secondary and tertiary education were more willing to use intercropping. Figure 4.5 showed that among all the farmers interviewed, male farmers had a higher percentage (92%) of willingness to adopt intercropping as compared to female farmers (70%) who showed less interest.

Table 4.2. Attitude of farmers towards intercropping.

Background characteristics	**Probability (*P*)**
Region in Magoye where farmer resides	P = 0.319
Literacy level of the farmer	P = 0.002**
Agricultural camp affiliated with	P = 0.298
Ginning company affiliated with	P = 0.672
Gender of farmer	P = 0.015*
Ownership type of farm land.	P = 0.235
Age of farmer	P = 0.608
Hectarage of farm	P = 0.822

Where $P \leq 0.05$ there is a significant probability; where $P>0.05$ there is no significant probability

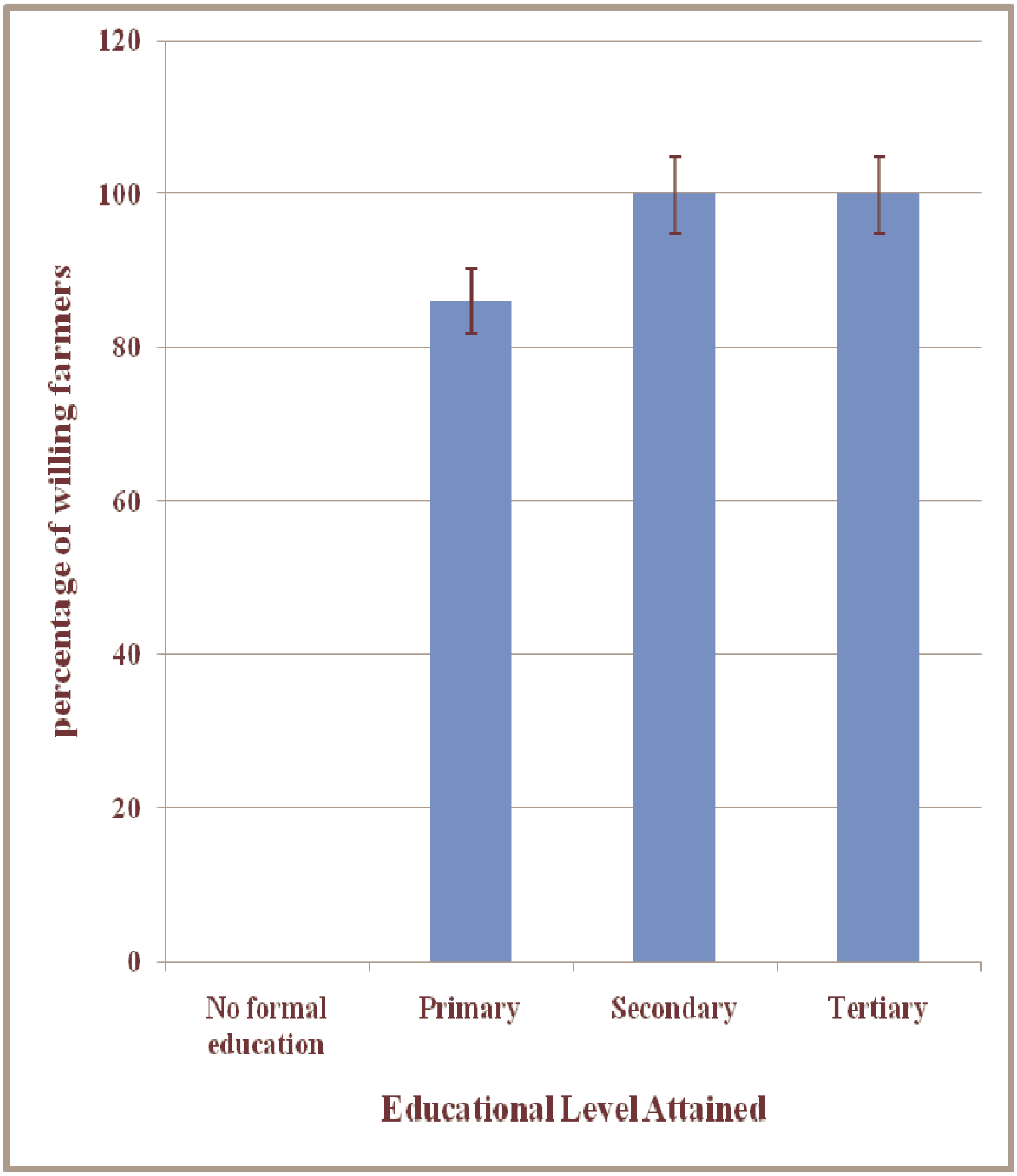


Figure 4.4. Educational level and the willingness of farmers to adopt intercropping if a useful intercrop is identified.

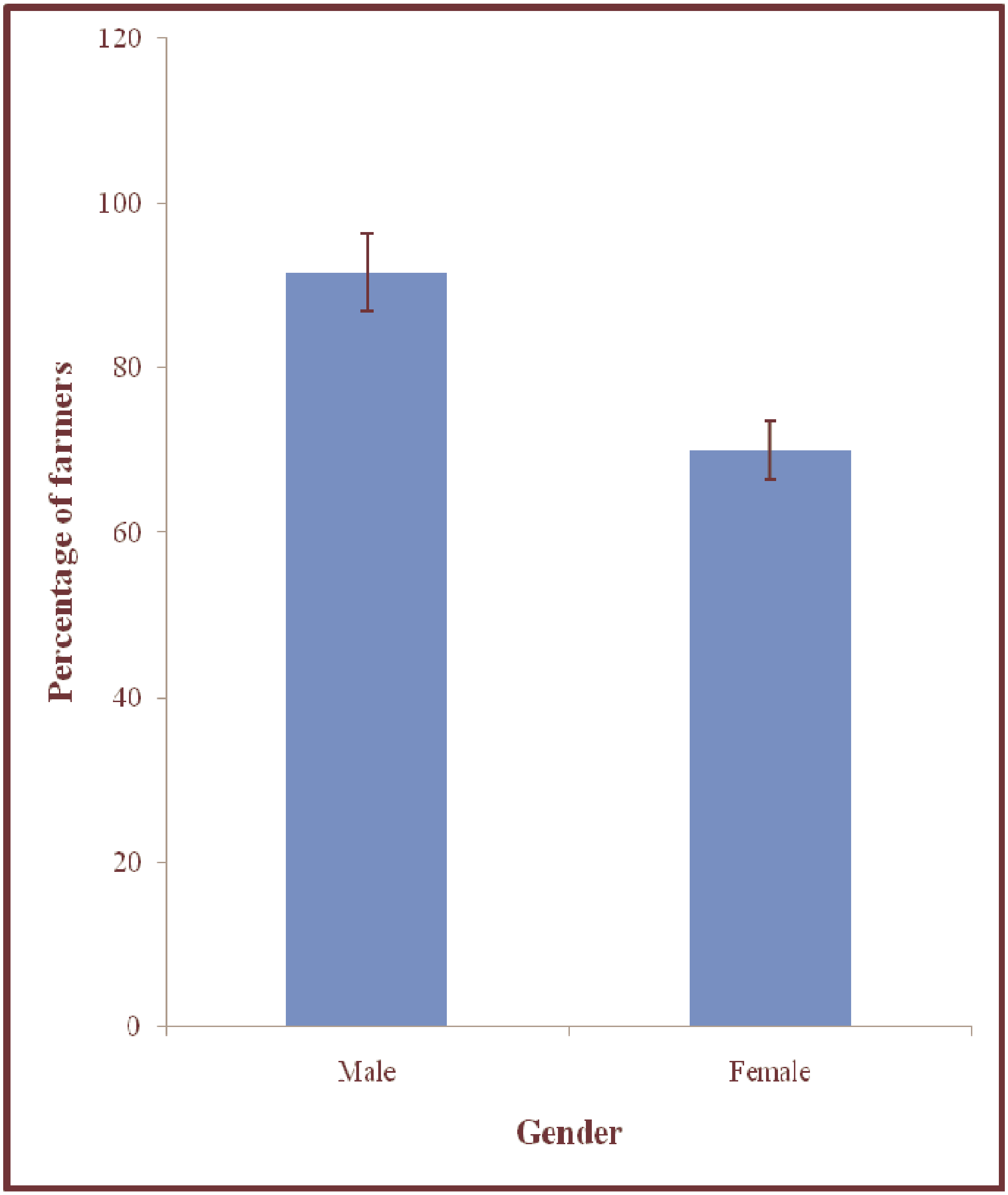


Figure 4.5. Gender of farmers and the willingness to incorporate intercropping into their farming system.

4.2 Field Experimental study

4.2.1 Incidence of *Diaparopsis castanea*

During the field trial, a total of 3456 cotton plants and 2880 intercrops were examined for the presences/absence of *D. castanea* throughout the duration of the study. Four hundred and fourteen larvae were collected from the field for laboratory examination for the presence/absence of parasitoids.

4.2.1.1 Cotton

The average number of *D. castanea* eggs ranged from 0.5 – 2.25 egg per plant across all the treatments (Table 4.3). Cotton – sorghum recorded the highest number of eggs (2.25±0.70) while cotton – pigeon pea and cotton-monocrop treatments had the lowest incidence (0.5±0.41). The number of *D. Castanea* eggs in cotton sorghum were significantly different to the number of eggs in cotton – pigeon pea (0.5±0.41), cotton – monocrop (0.5±0.24) and cotton – sunflower (0.75±0.39) intercrops, while the rest were not significantly different. The incidence of *D. castanea* larvae was not significantly different across the various treatments (Table 4.3).

4.2.1.2 Intercrop

Whereas *D. Castanea* eggs and larvae were recorded on the cotton, no records of either *D. castanea* eggs or larvae were found present on the individual intercrops that were selected for this study.

Table 4.3. Average number (±SE) of *D. castanea* egg and larvae per plant (n=6) on cotton

Treatment	**Red bollworm egg**	**Red bollworm Larvae**
Cotton – Maize	1.25(±0.61) ^{ab}	10.75(±1.68)^{a}
Cotton – Sorghum	2.25±(0.70) ^{a}	6.75(±1.39)^{a}
Cotton – Pigeon pea	0.5±(0.41) ^{b}	9.75(±3.08)^{a}
Cotton – Cowpea	1±(0.33)^{ab}	6.5(±1.65)^{a}
Cotton – Monocrop	0.5±(0.24) ^{b}	5.5(±1.22)^{a}
Cotton – Sunflower	0.75±(0.39) ^{b}	9.25(±3.06)^{a}

Means bearing different letters in a column differ significantly at 0.05 probability levels

4.2.2 Plant damage caused by *Diaparopsis castanea*

Damage caused by *D. castanea* was evident by the entry holes seen from the outside of the cotton fruiting structure or the frass left by the pest during feeding (see plates 4.1).

4.2.2.1 Square damage

Mean square damage was relatively high with a range of 5.5 - 9.5 across the various treatments (Table 4.4). The square damage index was statistically significant among the intercropping patterns. The cotton – pigeon pea (9.5±0.78) and cotton – sorghum (8.25±1.65) treatment suffered the most damage to its squares. Cotton – cowpea (5.50±1.72), cotton – maize (7.25±1.17), cotton monocrop (6.00±1.45)) and cotton-sunflower (7.25±1.74) intercrops showed similar damage levels.

4.2.2.2 Boll damage

Apparent differences were also observed in the damage caused to the cotton bolls across the various treatments. The cotton – maize (7.00±2.56 %) and cotton – sunflower (6.00 ±1.91%) treatments had the largest number of damaged bolls. Cotton – pigeon pea (2.75±0.91 %) and cotton – cowpea (3.75±1.02), treatment had the least amount of damaged bolls among the various treatments (Table 4.4). Comparison of damage caused by *D. castanea* for cotton squares and cotton bolls showed a similar trend for cotton – cowpea, cotton – monocrop and cotton sunflower. However, cotton- sorghum and cotton - pigeon pea intercrops showed very high number of damaged squares but the boll damage was very low. Cotton – maize treatment had the same number of damaged squares as damaged bolls.

Plate 4.1. ***D castanea*** **larvae feeds from inside the cotton square while deposting its frass outside**

Table 4.4. Average number (±SE) of squares and bolls damaged by *D. Castanea* per plant (n=6)

Treatment	Damaged Squares	Damaged bolls
Cotton – Maize	7.25(±1.17)[ab]	7.00(±2.56)[a]
Cotton – Sorghum	8.25(±1.65)[ab]	4.75(±0.70)[ab]
Cotton - Pigeon pea	9.5(±0.78) [a]	2.75(±0.91) [b]
Cotton – Cowpea	5.50(±1.72) [b]	3.75(±1.02)[ab]
Cotton – Monocrop	6.00(±1.45)[ab]	4.25(±1.17)[ab]
Cotton – Sunflower	7.25(±1.74)[ab]	6.00(±1.91)[ab]

Means bearing different letters in a column differ significantly at 0.05 probability levels

4.2.3 Incidence of natural enemies

During the field study 3456 cotton plants and 2880 intercrops were inspected for the presence of natural enemies for *D. castanea*. Inspections conducted from 17th January 2011 to 7th March 2011 showed ten different species of natural enemies, namely: ladybird beetles (Coleoptera), hoverflies (Diptera), lace wings (*Chrysopa spp.*), spiders (*Lycosa* spp., *Aranews* spp.) wasps, rove beetles, praying mantis, housefly and earwigs. Plates of all the natural enemies collected during the field study are shown in Appendix I to Q. The total numbers of natural enemies observed in cotton and various intercrops are summarized in table 4.5.

Table 4.5. Total number of natural enemies/predators counted in cotton and the intercrops.

Natural enemies/ predators		Cotton	Intercrop
Spiders		181	126
Lace wings	Eggs	179	92
	Larvae	9	10
Hoverflies	Syrphid (larvae)	23	18
	Adults	59	380
Ladybirds	Larvae	64	32
	Adults	157	146
Wasps		6	59
Earwigs		17	51
Ants		0	111
Rove beetles		7	9
Praying Mantis		2	26

4.2.3.1 Natural enemies found in cotton

Cotton sorghum treatment recorded several types of natural enemies among all the various intercropping patterns (table 4.6). These included: spiders, lacewings (eggs and larvae), hoverfly (surphids and adults), ladybird beetles (larvae and adult), wasps, praying mantis, rove beetles, and earwigs. Cotton – cowpea treatment recorded relatively few natural enemies.

Among all the natural enemies that were recorded in the various intercropping patterns, only ladybird beetles (larvae and adult), lacewing (eggs) and wasps showed significant occurrence among (Table 4.7). The cotton – maize intercrop attracted the largest mean number of wasps (1±0.33), while cotton – sorghum intercrop had an incidence of 0.5±0.24 wasps/plant. Lacewing eggs were more prevalent in cotton – sorghum treatment (13.3±3.04) and less prevalent in cotton – sunflower (5±0.33) and cotton – cowpea (5.3±0.84) treatments. Ladybird larvae were commonly found in cotton – sunflower (4.75±2.01) and cotton pigeon pea (4.5±1.84) while cotton – sorghum (1 ±0.82) and cotton – cowpea (2.25±1.31) treatments had the least occurrence. Meanwhile, ladybird beetle (adult) had the highest incidence in cotton – cowpea treatment (11±2.69) and lowest incidence in cotton – maize intercropping pattern (3.8±0.70).

Table 4.6. Types of natural enemies recorded on cotton under the various intercropping patterns in Magoye, Mazabuka district.

	Intercropping pattern					
Natural enemies	Cotton – Maize	Cotton – Sorghum	Cotton – Pigeon pea	Cotton – Cowpea	Cotton – Monocrop	Cotton – Sunflower
Spider	✓	✓	✓	✓	✓	✓
Lacewing egg	✓	✓	✓	✓	✓	✓
Lacewing larvae	✓	✓	✓	×	✓	✓
Syrphids	✓	✓	✓	✓	✓	✓
Hoverflies	✓	✓	✓	✓	✓	✓
Ladybird larvae	✓	✓	✓	✓	✓	✓
Ladybird Beetles	✓	✓	✓	✓	✓	✓
Wasps	✓	✓	×	×	×	×
Preying mantis	×	✓	×	×	✓	×
Rove beetles	✓	✓	✓	×	×	✓
Housefly	✓	✓	✓	✓	✓	✓
Earwigs	✓	✓	✓	✓	✓	✓

✓ = present and x = absent

Table 4.7.Average number (±SE) of natural enemies found on cotton per plant (n=6)

Treatment	Wasp	Lacewing egg	Ladybird larvae	Ladybird beetle
Cotton-maize	1(±0.33 ^{a}	8.8(±1.98) ^{ab}	2(±0.94) ^{abc}	3.7(5±0.70) ^{b}
Cotton-sorghum	0.5(±0.24) ^{ab}	13.3(±3.04) ^{a}	1 (±0.82)^{c}	6(±1.37)^{ab}
Cotton-pigeon pea	0(±0.0)^{b}	6.3(±1.39) ^{b}	4.5(±1.84) ^{ab}	5(±1.45) ^{b}
Cotton-cowpea	0(±0.0)^{b}	5.3(±0.84)^{b}	2.25(±1.31) ^{abc}	11(±2.69) ^{a}
Cotton-monocrop	0(±0.0)^{b}	6.3(±0.39) ^{b}	1.5±(1.22) ^{bc}	6.75(±1.35) ^{ab}
Cotton-sunflower	0(±0.0) ^{b}	5(±0.33) ^{b}	4.75±(2.01) ^{a}	6.75(±1.58) ^{ab}

Means bearing different letters in a column differ significantly at 0.05 probability levels

4.2.3.2 Natural enemies in the individual intercrop

Ten different types of natural enemies were recorded on the individual intercrops in the various treatments (Table 4.5). These included lacewings (eggs and larvae), hoverflies (surphids and adults), ladybird beetles (larvae and adults), spiders, wasps, praying mantis, rove beetles, earwigs, ants and houseflies. Among the ten natural enemies, only hoverflies, ladybird beetles, lacewings, surphids and wasps showed significant occurrences on the individual intercrops in the various treatments (Table 4.8). Sorghum (15.25±2.39) and pigeon pea (13.75±1.47) intercrop showed a high population of hoverflies. Sunflower (5.5±1.35) together with cowpea (6.75±2.34) had the lowest incidence of hover flies while sorghum (0.25±0.20) intercrop attracted the lowest number of lady bird beetles. Wasps were most prevalent in Sorghum (3.5±1.07) and least in pigeon pea (1.25±0.51), cowpea (1.25±0.77) and sunflower (0.5±0.41) .

Table 4.8. Average number (±SE) of natural enemies found on each intercrop per plant (n=6)

Treatment	Hoverfly	Ladybird beetle	Lacewing egg	Syrphid	Wasp
Cotton-maize	12.5(.±0.539)[b]	4.25(±1.35)[ab]	2.75(±0.70)[ab]	0.75(±039)	1.5(±0.71)[ab]
Cotton-sorghum	15.25(±2.39)[a]	0.25(±0.20)[b]	4.25(±1.07)[a]	1.25(±0.39)	3.5(±0.53[a]
Cotton-pigeon pea	13.75(±1.47)[a]	3.5(±1.58)[b]	2.75(±0.39)[ab]	0.25(±0.20)	1.25(±0.51)[ab]
Cotton-cowpea	6.75(±2.34)[c]	8.5(±2.04)[a]	0.75(±0.39)[c]	0.25(±0.20)	1.25(±0.77)[ab]
Cotton-sunflower	5.5(±1.35)[b]	1.75(±1.17)[b]	0.75(±0.33)[bc]	0±(0.00)	0.5(±0.41)[b]

Means bearing different letters in a column differ significantly at 0.05 probability levels

4.2.4 Observation for Parasitoid emergence

A total of 414 *D. castanea* larvae were collected during the study period. The larvae were reared in the laboratory to check for the emergence of parasitoids (Plate 3.3). No parasitoids were recovered from D. *castanea* larvae during the experimental laboratory study.

4.2.5 Cotton performance with intercrops

Four out of the six parameters that were chosen to assess intercrop performance were significantly different among the various treatments. These were the total number of squares, average number of damaged bolls, total number of times handpicked and the average seed cotton yield (Table 4.9).

The cotton- cowpea treatment had the highest total number of squares (40.6±3.60) per six plants while cotton – maize intercrop had the least number of squares (31.5±3.27). Despite the significant differences in the total number of squares, cotton – cowpea and cotton – pigeon pea intercrop had statistically similar results (40.6±3.60 and 39.7±3.54 respectively). The cotton – maize treatment had the highest number of damaged bolls (7±2.56) while cotton – pigeon pea treatment had the least number of damaged bolls (2.75±0.91) among the various treatments (Table 4.9). The cotton – maize treatment was handpicked 8.25±0.51 times throughout the whole cotton season, while cotton – sunflower treatment only had 4±0.58 interventions. Cotton – maize, cotton pigeon pea, cotton – cowpea, cotton sorghum and cotton – monocrop all had statistically similar number of interventions (Table 4.9).

Table 4.9. Average number (±SE) of squares, damaged bolls and handpicking in each treatment plot

Treatment	Squares per plant (n=6)	Damaged bolls per plant (n=6)	Handpicking
Cotton-maize	31.5(±3.27) [b]	7.00(±2.56)[a]	8.25(±0.51) [a]
Cotton-sorghum	35.2(±2.14) [ab]	4.75(±0.70)[ab]	7.75(±0.20) [a]
Cotton-pigeon pea	39.7(±3.54) [a]	2.75(±0.91) [b]	6.5(±0.53) [a]
Cotton-cowpea	40.6(±3.60) [a]	3.75(±1.02)[ab]	7.75(±0.51) [a]
Cotton-monocrop	37.7(±1.74) [ab]	4.25(±1.17)[ab]	6.75(±0.84) [a]
Cotton-sunflower	35.7(±2.33) [ab]	6.00(±1.91)[ab]	4(±0.58) [b]

Means bearing different letters in a column differ significantly at 0.05 probability levels

4.2.6 Average Seed Cotton Yield

Cotton - maize intercrop produced the lowest average seed cotton yield (160±25.60kg/ha) among all the treatments while cotton-sunflower produced the highest average seed cotton yield of 303±35.29 kg/ha among all the various intercrops (Table 4.10). Though the seed cotton yield for cotton – maize and cotton - sunflower were significantly different from each other, the mean seed cotton yield for cotton - sorghum, cotton – pigeon pea, cotton – cowpea and cotton - monocrop treatments were statistically similar. Seed cotton yield showed a negative or insignificant correlation between incidence of *D. castanea* and most damage parameters among the various intercropping patterns, with the exception of average boll weight (Table 4.11).The correlation results showed a significant and positive correlation between average boll weight and average seed cotton yield.

Table 4.10. Average yield (±SE) for seed cotton yield per hectare

Treatment	Yield (kg/ha)
Cotton-maize	169(±25.60)^{b}
Cotton-sorghum	235(± 32.51)^{ab}
Cotton-pigeon pea	240(± 43.84)^{ab}
Cotton-cowpea	260(±14.15)^{ab}
Cotton-monocrop	275(±43.38)^{ab}
Cotton-sunflower	303(±35.29)^{a}

Means bearing different letters in a column differ significantly at 0.05 probability levels

CHAPTER 5 : DISCUSSION

5.1 Assessment of intercropping patterns in Magoye

From the survey, the single – strip or row intercropping pattern, used among farmers in Magoye, is usually encountered in small-scale agriculture. Traditional agriculture, as practiced through the centuries, has usually included different forms of intercropping. Farmers grew a variety of crops, often intermingled in the same field, to sustain themselves and their families (MacRoberts *et al*, 2007). Farmers using intercropping have a more sustainable approach to cotton production as compared to modern monocropping systems (Ecological Agriculture Projects, 1997).

Despite some farmers in Magoye using intercropping, it was clear from this study that there was no definite pattern in how the intercrops were planted; row(s) of the intercrop were planted either beside the cotton field or in single rows in-between several rows of cotton. These types of intercropping patterns are more traditional practices used over many generations than the refined intercropping systems being promoted in sustainable agriculture (Jalloh, 2001). This suggests a low adoption rate for modern intercropping systems among farmers in Magoye. This is despite the efforts made by the government and Non-governmental organizations (NGOs) such as Conservation farming unit (CFU) to introduce intercropping as a pest management strategy to cotton farmers in Southern province (Haggblade and Tembo, 2003).

The study further showed that gender and literacy level of a farmer had a significant influence on the attitude of a farmer towards intercropping. Figure 4.4 showed that with higher level of education attained, the farmer was more likely to practice intercropping. Adeoti (2009), working with Ghanaian small-scale farmers reported similar results. Gender also had a significant effect on the likelihood of a farmer to adopt intercropping. Ninety- two percent of the male farmers and only 70% of the female farmers in the study area were willing to adopt intercropping. In the African set - up, gender inequalities in agriculture means that women farmers have limited access to financial resources and they have no or minimal involvement in the decision making process regarding agricultural development at household level.

Therefore female farmers are less likely to adopt intercropping as they may not have the financial resources to experiment with the technology, the required labour to manage the crop and the power to make the decision about the technology (Adeoti, 2009). Availability of labour is a major socio economic factor that affects the adoption of agricultural technology among African small -scale farmers (Kwesiga *et al*., 1999). Therefore the dominance of gender inequality in the agricultural sector could present a bottleneck to the development of IPM cotton in Zambia.

The survey further showed that multiple-cropping was not practised among small holder farmers in Magoye during the study. As more and more farmers are encouraged to enter market systems by planting monocrops to produce marketable surplus, intercropping becomes unfavourable. This is despite all the information available on the negative effect of monocultures concerning insect pest problems (Perrin, 1997; Pimentel and

Goodman, 1978; Smith,1973) and the positive attributes of crop diversity for decreasing pest impact (Perrin, 1997; Cromartie, 1981; Litsinger *et al* 1980). The 22 farmers who were using intercropping used five different crops (Figure 4.3). These included: - Cowpea; Beans; Maize; and Groundnuts. Cowpea and beans were the most commonly practiced combination of intercrops among small-holder farmers in the area. These crops were economically important to the farmers as they acted as a food source for the household (Kombiok *et al.,* 2005). Since cowpea had the additional advantage of being able to fix nitrogen in the soil, it was selected alongside maize, sorghum, pigeon pea and sunflower for the testing in the field trial.

Farmers generally avoid taking unnecessary risks unless the advantages are clearly visible (Eponou, 1996). Farmer adoption of intercropping methods are usually strongly constrained by the need for the intercrop to show significant direct economic benefits and this will depend on many factors that are unrelated to cotton pest management (Russel, 2004).

5.2 Incidence of *Diaparopsis castanea* in cotton and intercrop

From the field study there was variability in the incidence of *D. castanea* egg on the cotton under the various intercropping patterns. Therefore, this supports the hypothesis that they are significant differences in the incidence of *D. castanea* among the various intercropping patterns. There were more *D. castanea* eggs in the cotton - sorghum treatment than any of the other intercropping pattern. This behaviour suggests that *D. castanea* adults exhibited oviposition preference for cotton – sorghum treatment. Though, *D. castanea* larvae did not show any feeding preference for cotton – sorghum treatment as it was similarly distributed among the treatments in the various intercropping patterns.

Cotton - Sorghum treatment can therefore be postulated to be a dead-end intercropping pattern. This term describes plants that are highly attractive to insects but on which they or their offspring cannot survive (Shelton and Nault, 2004). In this case cotton - sorghum treatment serves as a sink for *D. castanea*, since the pest showed high ovipositional preference for it, but the eggs did not produce larvae that were able to survive. Van den Berg *et al.,* (1993) also reported that intercropping cotton with sorghum does not suppress the red bollworm population relative to that in sole cotton.

Diaparosis castanea was not found to freely occur on any of the actual intercrops that were selected for this study. This result re-confirms earlier works which suggest that *D. castanea* has only been recorded on very few alternative hosts that are confined to the genus *Gossypium* and *Gossypioides* (Pearson 1958, Green *et al*., in press).

Plant damage

They were significant differences in the damage caused by *D. castanea*, as was evident by the variation in cotton square and boll damage among the intercropping patterns. Cotton – pigeon pea intercrop suffered the most damage to the squares while cotton – maize had the highest damage to the bolls. Using its ability to fix nitrogen, pigeon pea is able to make nitrogen in the soil available for use by the nearest plant (Adu-Gyamfi *et al.*, 1997), in this case cotton. This results in a healthy cotton crop which is more susceptible to pest attack (Thacker, 2002) and in turn suffers high plant damage.

Maize on the other hand, is naturally attractive to lepidopteran pests, especially *Heliothis spp*. De souse (2007) in Mozambique reported high occurrences of the American bollworms in cotton intercropped with maize. The bollworms fed on the silks found on developing cobs of maize. The drying of maize, which coincided with the formation of bolls in the cotton, resulted in a depletion of food resources, shelter, mating and oviposition sites for bollworms and this may have inclined the pests to move from the maize to the cotton (Mensah, 1999). This partly explains the reason as to why boll damage was highest in cotton – maize intercropping pattern.

5.4 Incidence of natural enemies in cotton and intercrop

Cotton, in cotton – sorghum treatment attracted the widest range of natural enemies (table 4.6). These included; spider spp, lacewings, surphids, hoverflies, ladybirds, wasps, praying mantis and rove beetles. Intercrops can also reduce insect pest populations by enhancing populations of natural enemies within the field. Virk *et al.,* (2004) reported that, a sorghum trap crop used to manage cotton bollworm, *Helicoverpa armigera*, also increases rates of parasitism by *Trichogramma chilonis*. The increase in parasitism further enhances the effectiveness of habitat manipulation strategies.

The most important effect of intercropping cotton with sorghum appeared to be that it enhanced the abundance of natural enemies harboured by cotton. Sorghum has been known to act as a sink source of generalist insect predators for cotton pests (Prasifika *et al*., 1991). Intercropping studies conducted by Mamogobo *et al* (2008) in South Africa also indicated that intercropping cotton with sorghum increased the number of spiders and predatory ant populations.

Examination of the actual intercrops showed that hoverflies, ladybird beetles, lacewing eggs, rove beetles, surphids and wasps had significant incidence under the various intercropping patterns. Hoverflies, lacewings and surphids are all predators of aphids but will not prey on bollworms. Only wasps and rove beetles may act as general predators for *D. castanea* (Williamson, 1998).

Some of the wasps observed were identified as hunting wasps *(Hymenoptera: Vespidae*) and these are hunters of caterpillars. Hunting wasps may take their prey, whole or in pieces, back to the mud, soil or nests to feed the immature wasps (Cranshaw, 1998). Wasps were commonly recorded in sorghum, maize and cowpea intercrops. This can be attributed to the abundant floral nectar, alternative prey, shelter, and mating and oviposition sites harboured within the crops as compared to lesser biodiversity in the cotton - monocrop. (Udayagiri and Jones, 1992; Elzen *et.al.*, 1984;).

It is important to bear in mind that in order to take full advantage of the attractiveness of generalist predators to sorghum, the flowering of the intercrop must occur at the same time with cotton flowering. Otherwise the intercrop will be unable to compete successfully with cotton for the pest (Russel, 2004).

5.5 Incidence of parasitoids

Braconid and *Ichneumonid* wasps are a large and diverse group of small insect parasitoids that are commonly used as predators of bollworms (Rasool, *et al*., 2002). Laboratory observations of collected field specimens of *D. castanea* did not show the presence of any of these parasitoids. The constant use of pesticides by farmers located around the study site could have negatively affected the occurrence of these parasitoids in the various intercropping patterns. The indiscriminate and wide spread use of disruptive broad-spectrum pesticides by farmers in an area will usually constrain the contribution of predators and parasitoids to pest suppression (Desneux., *et al* 2007; Naranjo, 2001; Talekar and Shelton, 1993).

5.6 Intercrop performance

The cotton in the cotton-cowpea treatment recorded the highest number of cotton squares, while cotton – maize treatment had the least number of squares (Table 4.8). Cowpea is a unique crop in that it is both a crawler and a nitrogen fixing plant. This entails that it does not compete for sunlight with the nearest crop, which in this case was cotton. It is also able to provide food for the cotton in the form of nitrogen. (Kombiok *et al*, 2005). This increase in nutrition provides the cotton with an adequate environment for it to grow and produce more squares, flowers and bolls. On the other hand reduction in squares in cotton- maize treatment can be ascribed to the competition between the cotton and maize for essential growth factors such as water, nitrogen and light ([b]Khan *et al* 2001).

The number of interventions refers to the number of times handpicking of *D. castanea* was carried out in a treatment before it reached economic threshold level. Cotton – maize treatment received the highest number of interventions used throughout the growing season while cotton - sunflower intercropping pattern had the least number of interventions applied among all the various treatments. Table 4.3 shows that the incidence of *D. castanea* larvae was highest in cotton – maize intercropping pattern. This high incidence resulted in cotton-maize treatment having the highest number of interventions in an effort to minimise cotton plant damage.

5.7 Seed cotton yield assessment

Seed cotton yield differed significantly among the various intercropping systems. Based on overall seed cotton yield, cotton-sunflower treatment was the most effective intercropping pattern as it produced the highest yield of 303±59.1 kg/ha. However when the means were separated using Bonferroni's test, the mean seed cotton yield of cotton – monocrop, cotton –sorghum, cotton – cowpea and cotton – pigeon pea and cotton - sunflower intercrops were all statistically similar. Table 4.9 also shows that certain treatments, apart from cotton – sunflower, had a reduction in overall yield when compared to the cotton – monocrop (control) treatment. Similar results have been recorded by previous authors (Mohammad, *et al.,* 1991 and Van der Berg *et al.*, 1993). Cotton - maize intercropping pattern showed the highest reduction in seed cotton yield (169±59.1 kg/ha). This could be attributed to the shadow - shading effect of maize on cotton due to its fast growth during the early stages. Similar intercropping results were also reported by Gardner and Craker (1981) and Chandravanshi (1975).

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The present study indicated that intercropping was being used by few small-scale farmers in Magoye, Mazabuka district of Zambia. The intercrops were grown as strips or single row intercropping patterns. The most common combination used was cowpea and beans. This study shows that this technology is not common among small holder farmers in Magoye.

Intercropping patterns had a significant effect on the seed cotton yield. Cotton – sunflower intercrop had the highest yield while cotton – maize intercrop had the lowest yield. Therefore based on overall yield, cotton – sunflower was the most effective intercrop among all the various intercropping patterns.

Results from the study also showed that *D. castanea* laid eggs were peak in cotton – sorghum treatment and the lowest incidence occurred in cotton – pigeon pea and cotton – monocrop (control) intercropping patterns. Consequently cotton - sorghum was among the crops that had very high square damage.

Furthermore the study revealed that cotton - sorghum attracted the widest range of predators. Apart from general hunting wasps, none of the other natural enemies identified were predators of *D. castanea*. None of the intercrops selected in this study were effective alternative hosts for *D. castanea*.

6.2 Recommendations

1. Future studies could possibly be carried out in the study area to compare incidence of *D. castanea* among the various intercropping patterns over several seasons. This will be important as it will take into account the seasonality effects.

2. The study should also be replicated in several sites apart from Magoye. Environmental factors play an important role in the behaviour of the pest and its natural enemies. It will provide more information on how these insects behave in the valley and plateau areas of Zambia.

3. A similar study should be carried out in an insecticide free area. This will confirm the absence or presence of naturally occurring parasitoids in the various intercropping patterns.

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APPENDICES

Appendix A. Cotton intercropping questionnaire

PART I: IDENTIFICATION OF PARTICULARS

1. Strata in Magoye: _____ North East =1
   South East = 2
   South West = 3
   North West = 4

2. Name of agricultural camp: _________________
3. Farm number: __________________
4. Name of Ginning company affiliated with: _______________________
5. Farm Owner Name: ______________________

6. Household head sex: ________ Male=1
   Female = 2
7. Farm owner's NRC: _________
8. Farm owner Age: ___________
9. Farm Hectare: ____________

10. Ownership type: _________ Owned = 1
    Rented/leased = 2
    Others = 3

11. Educational level: __________ Illiterate = 1
    Primary = 2

Secondary = 3

Tertiary = 4

12. Household size: ___________

13. Type of Farming: _________ Livestock = 1

    Crops = 2

    Livestock and crops = 3

14. Crops grown apart from cotton: ____________

Maize = 1	Groundnuts = 2
Cowpea = 3	Sorghum = 4
Sunflower=5	Sesame = 6
Pigeon pea = 7	Sweet potato = 8
Beans = 9	Soya beans = 10
Others (specify) =11	

PART II: MANAGEMENT PRACTICE

15. Do you use irrigation on your farm? ________

    Yes = 1 NO = 2

16. Do you use any fertilizers on your crop? _________

    Yes = 1 NO = 2

    a. If yes, what type?______ Mineral = 1

       Organic = 2

       Both = 3

       None = 4

17. Do you practice any soil fertility measures? _____

Yes = 1 NO = 2

a. If yes, which of the cultural practices do you use? _______

Crop rotation = 1 Mulching = 2

Leaving crop residues = 3 Intercropping = 4

PART III: PEST MANAGEMENT

18. What type of pest management practice to you use on your farm? _________

Chemical control= 1 Cultural = 2

Both = 3 None of the above = 4

a. If you are using chemical control, which of the following are you using? ________

Synthetic chemicals = 1 Natural pesticides = 2

Both = 3 Other (specify) = 4

b. If you are using cultural practices, which of the following are you using?_____

Crop rotation = 1 Intercropping = 2

Both = 3 Other (specify) = 4

19. If you are using intercropping, what type of intercropping pattern are you using? _____

Strip =1 relay = 2

Refugia= 3 Row = 4

Which of the following crops do you use for intercropping? ________

Maize = 1 Groundnuts = 2

Cowpea = 3 Sorghum = 4

Soya beans = 5 Sunflower = 6

Sesame = 7 Pigeon pea = 8

Sweet potato = 9 Beans = 10

Other (specify) = 11

a. In your opinion has intercropping been effective? ____________

Yes = 1 No =

20. If an effective intercrop was identified, are you willing to in-cooperate it into your farming system? ______

Yes = 1 NO = 2

Part IV: Official Use

Form number: _______

Name of official: __________

Supervisor name: ______________________________

Date: __________________

Signature: _________________________

Appendix B. Cotton scouting form

Date and scouting number: …………………………………	Plot name: …………………………	Name of scout: …………………………………	

COTTON																
Plant no	Red boll-worm egg	Red boll-worm larvae	N1	N2	N3	N4	N5	N6	N7	N8	Number of damaged squares	Total number of squares	% square damage	Number of damaged bolls	Total number of bolls	% boll damage
1																
2																
3																
4																
5																
6																
Total																
Average																

INTERCROP																
Plant no	R/bollworm (egg)	R/bollworm (larvae)	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14
1																
2																
3																
4																
5																
6																
Total																
Average																

N= natural enemy

Appendix C. Recommended threshold for the control of bollworms in cotton

(After Dunavant, 2004)		
Pest	**Threshold**	
Bollworms	Larvae (caterpillar)	Eggs
	6 larvae/24 plants	6 eggs/24 plants
	Note: if square and boll damage are above 5% then a spray interventions should be used	

Appendix D. Background characteristics of the small-scale farmers that participated in the questionnaire from the four areas of Magoye, Mazabuka district

Background Characteristics		Strata				Mean	Sum	Percentage
		1	2	3	4			
Sex	Male	15	16	14	15	15	60	75
	Female	5	4	6	5	5	20	25
Age	27-37	4	1	2	0	1.75	7	8.75
	38-47	1	9	6	9	6.25	25	31.25
	48-57	3	10	9	10	8	32	40
	58-67	8	0	3	1	3	12	15
	68-77	4	0	0	0	1	4	5
Size of farm (Ha)	0-40	13	15	15	12	13.75	55	68.75
	41-80	4	5	4	7	5	20	25
	81-120	1	0	0	1	0.5	2	2.5
	121-160	2	0	1	0	0.75	3	3.75
Farm ownership type	Owned	18	15	16	12	15.25	61	76.25
	Rented/Leased	2	5	4	8	4.75	19	23.75
Literacy level	Illiterate	0	0	1	1	0.5	2	2.5
	Primary	15	18	14	18	16.25	65	81.25
	Secondary	3	1	1	1	1.5	6	7.5
	Tertiary	2	1	4	0	1.75	7	8.75
Ginning company affiliated with	Dunavant	14	14	17	13	14.5	58	72.5
	Continental	0	1	0	0	0.25	1	1.25
	Alliance	6	5	3	7	5.25	21	26.25
Household size	0 – 4	2	1	0	0	0.75	3	3.75
	4 8	10	11	14	11	11.5	46	57.5
	9 – 12	6	6	3	4	4.75	19	23.75
	13 – 16	1	2	3	5	2.75	11	13.75
	>16	1	0	0	0	0.25	1	1.25
Pest management practise	Chemical	0	0	0	0	0	0	100
	Cultural	0	0	0	0	0	0	0
	Chemical + Cultural	20	20	20	20	20	80	0
	None	0	0	0	0	0	0	0
Type of chemical control	synthetic	20	20	20	20	20	80	100
	Natural pesticides	0	0	0	0	0	0	0
	Synthetic +Natural pesticides	0	0	0	0	0	0	0
	None	0	0	0	0	0	0	0
Cultural practices used for pest management	Crop rotation	19	14	14	11	14.5	58	72.5
	intercropping + crop rotation	1	6	6	9	5.5	22	27.5
	None	0	0	0	0	0	0	0
Intercropping pattern	Strip/single row	1	6	6	9	5.5	22	27.5
	None	19	14	14	11	14.5	58	72.5
willingness to use intercropping	Yes	15	17	18	19	17.25	69	86.25
	Maybe	5	3	2	1	2.75	11	13.75

Appendix E. Important background characteristics that determine the willingness of a farmer to incorporate intercropping into their farming system in Magoye, Mazabuka district.

Background characteristic		Willingness to incorporate intercropping in cotton			Percentage of farmers willing to use intercropping	Significance test (chi-square)
		Yes	Maybe	No		
Age of farmers	27-37	5	2	0	71	0.281 NS
	38-47	22	3	0	88	
	48-57	29	3	0	91	
	58-67	6	0	0	100	
	68-77	7	3	0	70	
Farm ownership type	Owned	54	7	0	89	0.29 NS
	Rented/Leased	15	4	0	79	
Literacy level	Illiterate	0	2	0	0	0.002 *
	Primary	56	9	0	86	
	Secondary	6	0	0	100	
	Tertiary	7	0	0	100	
Gender of farmer	Male	55	5	0	92	0.015 *
	Female	14	6	0	70	
Ginning company affiliated with	Dunavant	51	7	0	88	0.672 NS
	Continental	1	0	0	100	
	Alliance	17	4	0	81	
Agricultural camp affiliated with	Dumba	15	5	0	75	0.298 NS
	Chiziyo	18	2	0	90	
	Ngwezi	15	1	0	94	
	Oliver	4	0	0	100	
	Mbiya	16	2	0	89	
	Mwanchigwala	1	1	0	50	
Strata Magoye	North East	15	5	0	75	0.297 NS
	South East	17	3	0	85	
	South West	18	2	0	90	
	North West	19	1	0	95	
Size of farm	0-40	48	9	0	84	0.478 NS
	41-80	18	1	0	95	
	81-120	2	1	0	67	
	121-160	1	0	0	100	

Appendix F. Mean incidence (±SE) of natural enemies on the cotton in the various intercropping patterns in Magoye, Mazabuka district.

Natural enemies	Intercropping pattern						LSD
	Cotton – Maize	Cotton – Sorghum	Cotton – Pigeon pea	Cotton – Cowpea	Cotton – Monocrop	Cotton – Sunflower	
Spider	7.3(±2.55)	8.3(±1.81)	6.8(±1.31)	9(±1.91)	8.3(±1.43)	5.8(±1.68)	4.2^{NS}
Lacewing egg	8.8(±1.98)	13.3(±3.04)	6.3(±1.39)	5.3(±0.84)	6.3(±0.39)	5(±0.33)	6.5^{*}
Lacewing larvae	0.5(±0.41 0	0.3(±0.20)	0.3(±0.20)	0(±00)	0.5(±	0.8(±0.39)	1.2^{NS}
Syrphid	0.8(±0.39)	1.8(±0.51)	0.5(±0.24)	0.3(±0.20)	1(±0.58)	1.5(±0.53)	1.6^{NS}
Hoverflies	3.5(±1.08)	0.8(±0.39)	3.8(±0.68)	2.3(±0.39)	2.8(±1.26)	1.8(±0.51)	3.2^{NS}
Ladybird larvae	2(±0.94)	1(±0.81)	4.5(±1.84)	2.25(±1.3 0)	1.5(±1.22)	4.75(±2.0 1)	3.1^{*}
Ladybird Beetles	3.8(±0.70)	6(±1.37)	5(±1.45)	11(±2.69)	6.8(±1.35)	6.8(±1.58)	5.3^{*}
Wasps	1(±0.33)	0.5(±0.24)	0(±00)	0(±00)	0(±00)	0(±00)	0.7^{NS}
Preying mantis	0(±00)	0.3(±0.20)	0(±00)	0(±00)	0.3(±0.20)	0(±00)	0.5^{NS}
Rove beetles	0.5(±0.41)	0.3(±0.20)	0.3(±0.20)	0(±00)	0(±00)	0.8(±0.39	0.9^{NS}
Earwigs	1.5(±0.97)	0.8(±0.39)	0.3(±0.20)	0.5(±0.24)	0.5(±0.24)	0.8(±0.39)	1.4^{NS}

LSD= Least Significant Difference
NS = non significance
*** = significance (0.05)**

Appendix G. Mean incidence (±SE) of natural enemies on individual intercrops under the various intercropping patterns

Natural enemies	Intercrop					L.S.D (0.05)
	Maize	Sorghum	Pigeon pea	Cowpea	Sunflower	
Ants	3.5(±1.55)	1.5(±0.71)	2(±0.67)	1.82(±0.39)	2.3(±0.91)	3.00^{NS}
Earwigs	2.0(±1.15)	1.3(±0.61)	1.5(±0.24)	1.5(±0.53)	0.8(±0.39)	2.51^{NS}
Hoverfly	12.5(±0.53)	15.3(±2.39)	13.8(±1.47)	6.8(±2.35)	5.5(±1.35)	5.21*
Syrphid	0.8(±0.39)	1.3(±0.39)	0.3(±0.20)	0.3(±0.20)	0(±00)	1.16*
Ladybird beetle	4.3(±1.34)	0.3(±0.20)	3.5(±1.58	8.5(±2.04)	1.8(±1.17)	4.36*
Ladybird larvae	0.5(±0.24)	1(±0.33)	1(±0.33)	1.3(±0.51)	0.3(±0.20)	1.30^{NS}
Lacewing egg	2.8(±0.70)	4.3(±1.07)	2.8(±0.39)	0.8(±0.39)	1.0(±0.33)	1.82*
Lacewing adult	0(±00)	0(±00)	0.5(±0.41)	0.35(±0.20)	0.5(±0.41)	1.03^{NS}
Preying Mantis	0(±00)	0.5(±0.24)	1.3(±0.51)	0.5(±0.41)	1(±0.82)	1.60^{NS}
Rove beetle	1(±0.33)	0.75(±0.61)	0(±0.00)	0(±00)	0(±00)	1.07*
Spider	4.5(±2.60)	4.8(±1.71)	2.8(±0.51)	3(±0.88)	0.75(±0.20)	4.86^{NS}
Wasp	1.5(±0.71)	3.5(±0.53)	1.3(±0.51)	1.3(±0.77)	0.5(±0.41)	2.32*
Housefly	2(±1.15)	4.5(±2.42)	2.3(±0.70)	1.8(±1.43)	0.8(±0.39)	5.76^{NS}
Red Bollworm Egg	0(±00)	0(±00)	0(±00)	0(±00)	0(±00)	-
Red bollworm larvae	0(±00)	0(±00)	0(±00)	0(±00)	0(±00)	-

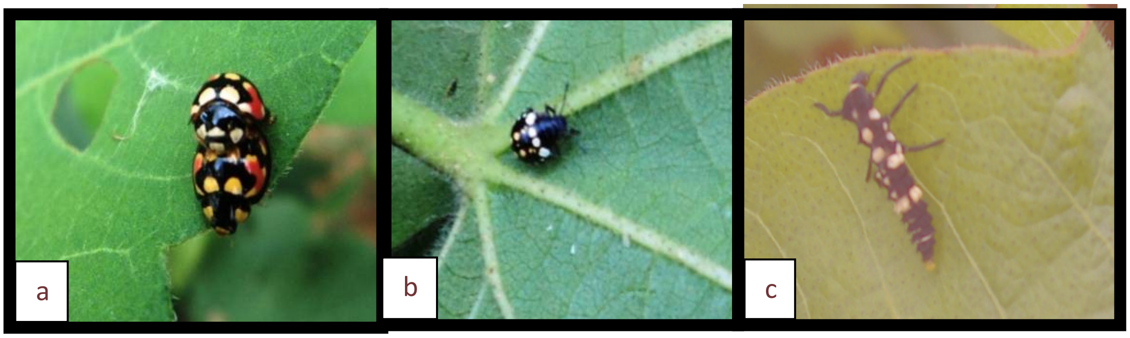
LSD= Least Significant Difference
NS = non significance
*** = significance (0.05)**

Appendix H. Significance test to determine the viability of intercropping in cotton plots

	Cotton - Maize	Cotton - Sorghum	Cotton - Pigeon pea	Cotton - Cowpea	Cotton - Monocrop	Cotton - Sunflower	L.S.D (0.05)
Number of squares/6 Plants	31.5(±3.27)	35.2(± 2.14)	39.7 (±3.54)	40.6(±3.60)	37.7(±1.74)	35.7(±2.33)	7.61 *
Number of bolls/6 plants	11(±1.87)	11.65(±0.98)	13.8(±1.77)	11.9(±2.34)	11.5(±1.01)	13.9(±1.31)	4.452 NS
Handpicking	8.25(±0.51)	7.75 (±0.20)	6.5 (±0.53)	7.75(±0.51)	6.75(±0.84)	4(±0.58)	2.035 *
Plant stand at harvest (%)	73.1(±4.81)	80.6(±4.99)	70.5(±6.84)	74.6(±5.81)	72.1(±3.60)	82.9(±2.95)	14.41 NS
Plant height (cm)	88.2(±13.82)	98(±1.91)	95(±3.84)	103(±3.00)	99.5(±1.08)	105.5(±8.24)	22.53 NS
Average Boll weight (g)	2.58(±0.18)	2.92(±0.41	2.88(±0.46)	3.42(±0.54)	3.75(±0.45)	3.25(±0.30)	1.172 NS
Yield (kg/ha)	169(±25.60)	235(±32.51)	240(±43.84)	260(±14.15)	275(±43.38)	303(±35.29)	127.3 *

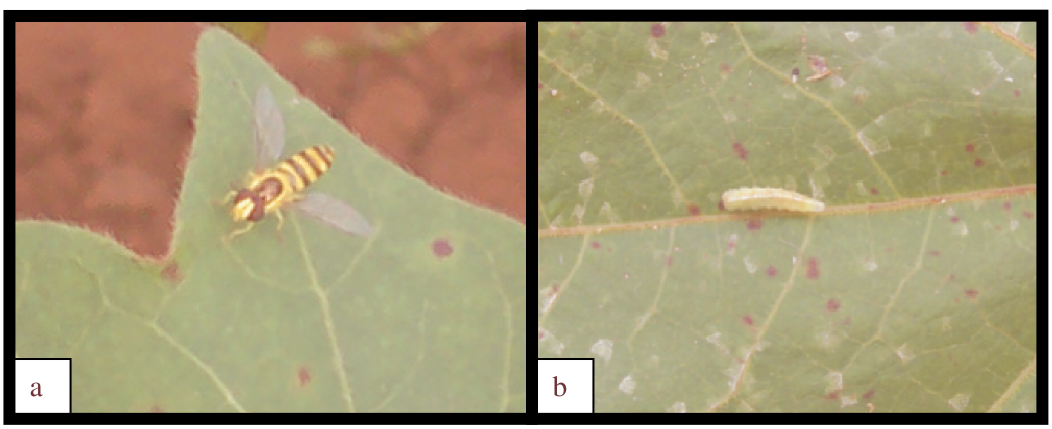
LSD= Least Significant Difference
NS = non significance
*** = significance (0.05)**

Appendix I. Coleoptera: Ladybird beetles: a=ladybirds mating, b= adult ladybird, c = larvae



23rd December 2010 21st January 2011 27th December 2010

Appendix J. Diptera; Syphidae; Hoverflies: a = adult, b = larvae (Surphid)



7th March 2011 **14th February 2011**

Appendix K. Neuroptera ; Chrysopidae; Chrysoperla spp (lacewing): a = adult, b = stalked egg

14th February 2011 6th January 2011

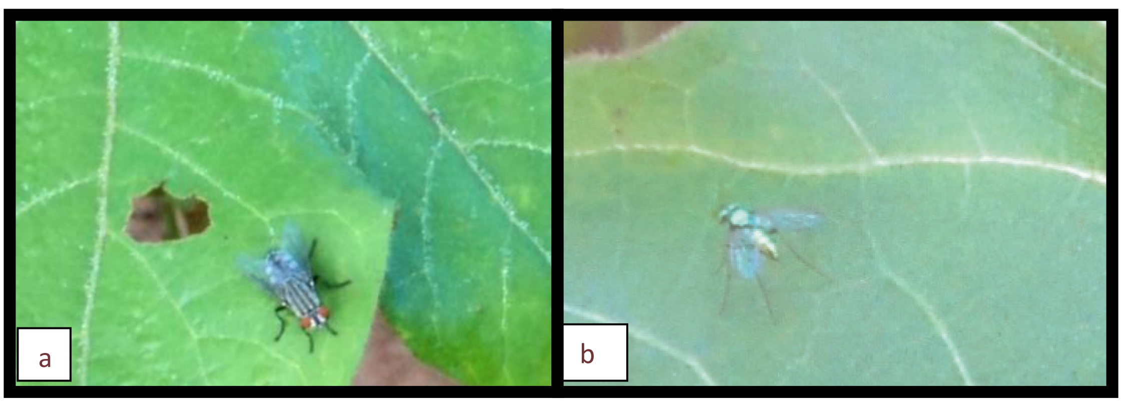
Appendix L. Hymenoptera; Formicidae; Ants

23rd December 2010

Appendix M. Staphylinidae; Rove beetle

13th January 2011

Appendix M. Diptera; Flies



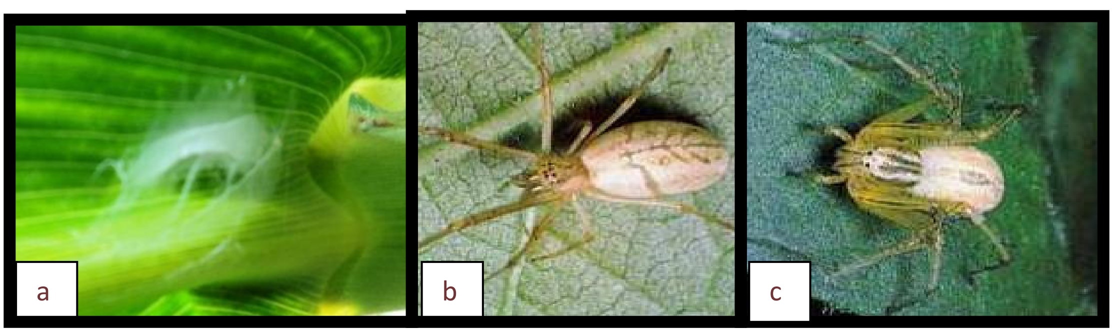
6th January 2011

28th December 2010

Appendix N. Dermaptera; Forficulidae; Common earwigs

21st January 2011 7th March 2011

Appendix O. Arachnida: Spiders



21st February 2011 1st February 2011 1st February 2011

Appendix P. Hymenoptera: Vespinae: Wasps

3rd March 2011

Appendix Q. Dictyoptera: praying mantis

10th March 2011