REPELLENT EFFECTS OF ONION, GARLIC AND MARIGOLD INTERCROPPED WITH POTATO (*Solanum tuberosum* L.) AGAINST POTATO TUBER MOTH (*Phthorimaea operculella* ZELLER)

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF PHILOSOPHY IN CROP PRODUCTION

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ABSTRACT

The potato tuber moth, *Phthorimaea operculella* (Zeller)(Lepidoptera; Gelechiidae*)* is a cosmopolitan, oligophagous insect pest of solanaceous crops. It attacks potatoes, tomatoes, tobacco, eggplant, pepper and wild solanaceous plants. A study was conducted to quantify the effects of intercropping of potato (*Solanum tuberosum* L.) with insect-repellent crops on PTM larval infestation and foliage-feeding insects, tuber infestation intensity, infestation preferences on the canopy and larval parasitism. The study was conducted at Solusi Farm (18.583^0S 32.757^0E, 1200 m altitude), Solusi University, Zimbabwe. The potato variety Montclare was used in three consecutive field trials. Potatoes were intercropped with onion, garlic and marigold. Sole potato was included among the treatments, with a Nuvacron 40 WSC insecticide (monocrotophos) treatment as the control. Each treatment was replicated three times in a randomized complete block design. Every seven days from plant emergence to pre-harvest defoliation, three plants were randomly selected from each treatment plot. The stems and leaves were inspected for presence of larvae and their developmental stages, aphids and leafhoppers. For PTM larval canopy infestation preferences, the plants were divided into three categories; the leafy canopy, the upper stem and the bottom stem. The PTM larvae and their developmental stages were determined. The degree of tuber infestation by larvae was determined at harvesting. Samples of ten plants were selected from each plot and classified into two categories, the infested tubers and the green tubers. The parasitism of the PTM was also assessed. The larvae in leaves and stems were each kept in plastic containers with cloth lids until adult moths or parasitoids emerged. Mean populations of adult parasitoids were square root transformed (p = √(x +1). Percentage parasitism was calculated. The numbers of larvae per plot were transformed and means subjected to ANOVA using the GenStat software, Release 14.1.There were no significant differences (P¿0.01) in the PTM larval density on foliage between the garlic and marigold intercrops. A significant difference (P¿0.01) was noted between the Nuvacron-treated potatoes and the sole potato. There were no significant differences (P¿0.01) in the density of aphids among the garlic, marigold intercrops and the Nuvacron-treated potatoes. A significant difference (P¿0.01) was noted between onion intercrop and the marigold intercrop in the leafhopper density. There was also no significant difference (P¿0.01) in the large larval density within the leafy canopy, upper stem and bottom stem regions of the potato plant in all the treatments. One mechanism that may account for low PTM larval density and foliage-feeding pests in onion, garlic and marigold intercrops, could be mortality in the eggs, thus preventing larval eclosion. Garlic compounds may toughen the structure of the egg, preventing hatching in a way similar to that in which dehydration can act, with embryos apparently developing normally but hatching inhibited. The green tubers in all plots were more vulnerable to PTM infestation as the larvae could access these easily. The sandy soils in Solusi farm provide easy entry of the larvae into the soil to damage the tubers. During three season trials, in the Nuvacron-treated-potatoes, it was found that 22.33% to 44.80% of the PTM larvae were parasitized by *Apanteles subandinus and Copidosoma koehleri,* which indicated that the parasitoids could tolerate relatively severe pesticide spray regimes. Garlic and marigold intercrops are effective insect-repellent crops that suppress the PTM larval density, foliage-feeding insects and reduce tuber infestation intensity and can be used to replace Nuvacron insecticide. The repellent properties of onion, garlic and marigold have no direct influence on the plant infestation preferences of PTM larvae. *A. subandinus* and *C. koehleri* PTM parasitoids are promoted by intercropping.

DECLARATION

I, Lawrence Hastings Matshazi, hereby declare that this research is an outcome of my own investigation under the supervision of Dr. W. Manyangarirwa, and has not been previously submitted to any university for the award of any other degree. Reference to other researchers' work and any assistance rendered, has been dully acknowledged in the text.

Lawrence Hastings Matshazi : .... Date............................

Supervisor:.. Date............................

Dr. W. Manyangarirwa.

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Contents

LIST OF TABLES

LIST OFPLATES

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

The Potato Tuber Moth (PTM), *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae*)* is a cosmopolitan, oligophagous pest of solanaceous crops. It attacks potatoes, tomatoes, tobacco, eggplant, pepper and wild solanaceous plants (Coll *et al*. 2000).The damage on potatoes is mainly by larvae boring into leaves, stems and tubers, leading to the infection of tubers by fungi or bacteria, particularly *Penicillium* spp. fungi, rendering the tubers unmarketable. Insecticides are usually applied to potatoes on a fixed schedule, without regard to actual pest pressure. In Zimbabwe, the pest is controlled primarily by calendar application of insecticides. The problems associated with excessive reliance on insecticides include the development of pest resistance to insecticides, accumulation of insecticide residues in potato tubers, the killing of non-target organisms and the general costs associated with insecticide application, which is a constraint to resource-limited small-scale farmers (Palacios *et al*. 1998). Azodrin 40 and Nuvacron 40 WSC (active ingredient monocrotophos) are the most commonly used insecticides to control the potato tuber moth by farmers (ZCFU, 2003).

The small-scale farmers in and around Solusi farming community who used to be potato producers have been driven out of the enterprise by severe infestation of their potato crop by potato tuber moth larvae. Often, more than 10% of the harvested tubers are infested and unmarketable. Harvested tubers are commonly stored for up to four months before marketing. Storage is usually compromised and this leads potato growers to use traditional storage methods under ambient conditions, both indoors and outdoors. Indoor stores include rustic buildings constructed of wood, mud or other local materials. Outdoor storage consists of heaping the tubers in a shady location in or near the field, and covering them with straw. The accidental introduction of infested tubers into these stores allows development and reproduction of tuber moth (Hanafi, 1999). The moth's life cycle is completed within three weeks at 27^0C. Summer storage of potatoes in hot areas such as Solusi, can thus enable several successive generations of the pest to develop during the storage period. Outdoor stores are also prone to migration of adult moths from adjacent fields (Keasar *et al*., 2005). These factors indicate the need for alternative strategies for the management of PTM. Biological control of this pest was started in Australia since 1960, with wasps including two braconid, solitary, endoparasitoids, *Apanteles subandinus* Blanchard and *Orgilus lepidus* Muesebeck (Horne, 1993). Assessing the efficiency of a parasitoid is important in developing successful biological pest control. Host finding by a parasitoid depends on responses to cues from the host habitat and the host itself consists of five steps (Vinson, 1991):

1) host-habitat location,
2) host-location,
3) host acceptance,
4) host suitability and

5) host regulation.

There is considerable evidence that some parasitoids use chemical stimuli associated with interactions between the host and its food (Takabayashi *et al*. 1994). Odours from host products or host plants can be important ones used by parasitoids to locate the habitats of their hosts and the hosts themselves (Kitt and Keller, 1998). A better understanding of the host-finding behaviour of *A. subandinus* and *C. koehleri* may play an important part in developing a more effective biological control programme for PTM. The objective of this study was to quantify the effects of intercropping of potato with repellent crops on PTM larval infestation on foliage, tubers and the infestation preferences. There is a need to develop innovative and simple systems for effective pest management that can be applied by resource-limited potato farmers. This study explored the importance of onion, garlic, and marigold as possible intercrops of potato to reduce the potato tuber moth population density, the effects of intercropping on insect pests and natural enemies in potato and the diversity of the arthropod community in the intercropping system.

Aside from its immediate impacts on the farmers on whose farms it was carried out, this study had broader applications. It hoped to provide an example that can be generalized within the small-scale and resource-limited potato producers in the country; ways to increase production whilst decreasing the risk of insecticides to the environment and humans. In the end, the study represents a move towards the widespread inclusion of intercropping strategy in integrated pest management.

1.2. Justification of the study

Smallholder potato farmers in the Plumtree district of Zimbabwe have been producing the crop for family consumption and local markets. The production of potato has been, however, reduced due to the effects of the PTM. The smallholder farmers generally do not have access to costly insecticides and subsequently suffer losses to the PTM in the field, and particularly in storage where 100% of the crop can be lost due to pests and inadequate storage facilities. Environmentally-friendly strategies of intercropping potatoes with insect-repellent crops stand to benefit resource-poor farmers in Zimbabwe. In the long term, the study represents a move towards the widespread inclusion of intercropping strategy in integrated pest management. There is a need to develop innovative and simple systems for effective pest management that can be applied by resource-limited farmers.

1.3. Objectives of the study

1.3.1. General objective

To evaluate the effectiveness of potato intercropped with onion, garlic and marigold in suppressing potato tuber moth population density in potatoes.

1.3.2. Specific objectives

The specific objectives of the study were to:

1. quantify the effects of intercropping on potato tuber moth larval infestation on potato foliage, infestation preferences and larval infestation on tubers,
2. assess the effects of intercropping on the abundance of other arthropod insects, and parasitoids of PTM in potato, and

3. determine the possible effects of intercropping strategy on potato yield.

1.4. Hypotheses

1. Intercropping insect-repellent crops in potatoes significantly reduces the potato tuber moth population density.
2. Intercropping insect-repellent crops in potatoes reduces the abundance of other insect pests while increasing that of parasitoids.
3. Intercropping insect-repellent crops with potato significantly increases tuber yields in potato.

CHAPTER TWO

LITERATURE REVIEW

2.0. Introduction

Larvae of the PTM attack both the potato foliage and tubers. The damage renders the tubers unmarketable and unfit for consumption. This chapter focuses on the literature on the damage intensity on the foliage and potato tubers, the scientific basis of intercropping in pest population suppression and possible effects of onion, garlic and marigold intercrops on the PTM population density.

2.1. Potato tuber moth larval damage on potato plants

Upon hatching, the PTM larva is 1-2 mm long. In about 10-20 days, it is fully grown and about 13mm long and dirty white in colour (Dube *et al*., 1994). The larval stage is of economic importance because of the damage it causes to plants (Coll *et al*., 2000). The larvae feed as leaf miners until they are half-grown. The larvae generally bite and chew the plant tissues. Their feeding action leads to the disruption of plant physiological functions. In extreme cases, the attacked leaves senesce and drop off resulting in defoliation of the plant. Some larvae mine stems causing the entire terminals to die (Harris, 1992). Damaged leaves have silver blotches caused by larvae tunnelling between the upper and lower epidermis and eating out the soft mesophyll. The larvae may be seen in these blotches (Dube *et al*., 1994). Larvae also damage the stem, especially when plants are young or have new shoots whose tissues are still soft. Severe damage of young stems causes sap flow to the new shoots to cease and the plant soon withers and dies (Agrios, 1997).

Larvae descend from the aerial parts of the plant and invade tubers, particularly when the soil is dry and deeply cracked. This path of infestation leads to severe crop losses which can be up to 45% in the field (Stoll, 2000). The tuber-mining larvae usually enter through the 'eyes' from either eggs laid nearby or from aerial plant parts, and make slender, dirty-looking tunnels throughout the tuber (Foot,1998). An infested tuber can be identified by mounds of fray droppings at the tunnel entrances, and usually have a foul odour and is unfit for consumption or seed. Directly infested tubers are a very important source of infestation of stored crops and often become infested with fungi or bacteria, particularly *Penicillium* spp. fungi (Stoll, 2000).

2.2. Effects on water and nutrient translocation

The damage on the stem tissue has a negative impact on the plant's physiological functions. The severe boring and mining of the potato plant stems by the larvae damages the phloem tissues and thus interferes with the translocation of nutrients. If the plant parts are deprived of nutrients, they become stressed, a condition that makes them more susceptible to pathogen attack. The tubers do not grow and develop to their maximum potential size and that reduces the yield (Agrios, 1997).

2.3. Economic Threshold levels

The economic threshold level is an important decision of how far a particular pest population can be allowed to grow before insecticide must be applied to prevent crop loss. Insecticide applications can then be restricted to treatments which are as selective as possible and applied only when absolutely necessary. Van Emden (1992) defined the 'economic threshold' as the density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level. It is therefore a threshold for action, related by experience and/or experiment to the economic injury level, which is the lowest population level that will cause economic damage. The potato crop has a very limited acceptance of potato tuber moth larvae. Only one mine per two plants about 40 days after planting is the threshold that calls for action (Stoll, 2000).

2.4. Available PTM management strategies

There is a high correlation between leaf infestation and tuber infestation. Effective control of leaf infestation reduces tuber infestation. The control measures are required both in the field and in storage. Through strict prevention of leaf infestation, the build-up of a potato tuber moth population is reduced, and thus also the infestation of the tubers (Stoll, 2000). The management strategies include biological control, chemical control, use of pheromones and cultural methods.

2.4.1. Biological control

Biological control is a synergistic collection of cross-disciplinary efforts to control pests of food, cultivated crops and plants in natural settings through the development and utilization of organisms and/or their products that are antagonistic to pests (Fusire, 2008). Biological control helps to optimize the use of available resources, promote indigenous solutions in pest and disease-control and environmental management. A classified approach requires the introduction of exotic beneficial organisms into the area of infestation and as the pest numbers diminish, the beneficial organisms increase in number so that they keep the pest in check. The method is rather slow in action, as it needs time for the beneficial organisms to adapt to the environment and increase in number (Stoll, 2000).

Effective biological control occurs when the action of parasitoids, predators and pathogens temporarily controls or continually regulates pest populations below the level they would otherwise cause economic damage. Known parasitoids of PTM attack the larvae, eggs or pupae by placing their eggs inside the body of the eggs, the larvae or pupae, respectively. When the egg hatches, the larvae devour the organs of the eggs, the larvae and the pupae (Fusire, 2008).

In South Africa, prior to 1965, a granulosis virus and several insect predators were recorded as attacking PTM, but they did not sufficiently reduce the pest to prevent severe crop loss (Cooksey, 2002). Between 1965 and 1967, four parasitoid species of South American origin were introduced into South Africa and two parasitoids, *Copidosoma koehleri* and *Apanteles subandinus* became established. Since their establishment, *C. koehleri* and *A. subandinus* have complemented each other. *A. subandinus* predominates at the start of the potato-growing season, and as the tuber moth numbers build-up, *C. koehleri* assumes dominance towards the end of the season. Both parasitoids were also successfully introduced from South Africa into Zambia and Zimbabwe, where they became established (Cooksey, 2002). In Zambia the financial returns from this biological control programme gave an increase yield of 22%, while in the Zimbabwe highveld where PTM was once regarded as the most injurious potato pest, it was relegated within a matter of two years to an insect of minor importance (Cooksey, 2002).

Parasitoid wasps such as *Copidosoma* and *Apanteles* are important in PTM control in other parts of the world (Johnson, 2007). These have greatly reduced the pest incidence in Zimbabwe (Dube *et al*., 1994). *Copidosoma* female lays its eggs in the tuber moth eggs thus destroying the insect. Besides *A. subandinus* and *C. koehleri,* other PTM parasitoids include *Temulucha* spp. (Hymenoptera: Ichneumonidae), *Orgilus lepidus, Diadegma mollipla* and *Chelonus phthorimaea* (Stoll, 2000).

Among the predators, there are birds, frogs and beetles. Pathogens that are important in managing the PTM are naturally occurring granulosis viruses. Through biotechnology, South Africa is benefiting from transgenic potatoes having resistance to PTM. An environmentally-safe protein that is toxic to the PTM and derived from the naturally-occurring bacterium, *Bacillus thuringiensis* (Bt) has been introduced into potatoes to benefit resource-limited farmers in South Africa (Johnson, 2007).

2.4.2. Chemical control

Throughout historical times, the overriding methods for pest control were cultural controls, such as leaving fields to lay fallow and rotating crops. Other cultural controls included practices such as altering planting dates, using trap crops and intercropping (Hajek, 2004). Between World War 1 and 2, several developments took place, setting the stage for major changes in pest control. Industries developed methods for large-scale production and chemists vastly improved their ability to synthesize chemicals. Since that time, a cascade of different compounds belonging to an increasing number of chemical classes, have been synthesized for pest control.

Most of the early compounds were effective against a broad spectrum of all pests, killed pests very quickly, and were relatively easy to apply using spray equipment (Hajek, 2004). Availability of these synthetic chemical pesticides changed the potential for successful harvests, and consequently, use of these compounds skyrocketed (Hajek, 2004). Use of pesticides overtime increased but, however, pesticides are not always the correct answer; sometimes they cannot control pests effectively for a variety of reasons.

When pesticides are applied to control pests (arthropods), naturally-occurring enemies normally living by consuming a pest are no longer abundant, or even present. Therefore, when the target pest reinvades the area, there are no natural enemies present and the target pest population increases again, frequently to higher densities than were present initially (Hajek, 2004). Another effect of extensive use of pesticides can be development of pesticide resistance. Resistance can develop when a pesticide is extremely effective and the majority of the pest population dies after an application. However, sometimes a few individuals that are physiologically different do tolerate the pesticide. The new strain of the pest that has been created is resistant to the pesticide and the population can then increase, even when the pesticide is reapplied. Eventually the pesticide applied has no effect on the pest and a different control strategy must be used (Visser and Majola, 2010). Due to the development of resistance to several classes of pesticides, there is a constant demand for new types of pesticides. However, the costs of developing and registering new pesticides have increased overtime (Stoll, 2000).

2.4.3. Use of pheromones

Sticking religiously to a rigid chemical treatment schedule results in unnecessary insecticide applications which are undesirable to man. Establishing a monitoring mechanism that determines the presence of economically important populations reduces the amount of chemicals used in the management of potato tuber moth. A pheromone is a substance that is secreted by an organism to the outside and causes a specific reaction in a receiving organism of the same species (Hajek, 2004). There are basically three different types of pheromones used in insect control:

- sex pheromone, which is a substance generally produced by the female to attract males for mating purposes,

- aggregation pheromone which is a substance produced by one or both sexes, and bringing both sexes together for feeding and reproduction, and
- alarm pheromone, which is a substance produced by an insect to repel and disperse other insects in the area. It is usually released by an individual when it is attacked (Gautam and Prasad, 1998).

Sex pheromones are the most exploited in the management of potato tuber moth. Pheromones have several characteristics making them particularly suitable for use in insect pest management. They are effective in very small amounts, unlike conventional insecticides; they are target specific. The use of pheromones in potato pest control has developed along three main pathways:

- monitoring of insect populations with pheromone-baited traps,
- control by mass trapping using large numbers of traps to reduce population levels, and
- control by mating disruption in which a synthetic pheromone is used to permeate the atmosphere so that an insect will be unsuccessful in finding a mate (Alma, 2005).

The female sex pheromone of PTM consists of two substances: (i) trans-4, cis-7, trideca-dienyl acetate, [CH_3 $(CH_2)_4$ CH^C = $CHCH_2CH^+$=CH $(CH_2)_3$ $OCOCH_3$], also known as PTM1, and (ii) trans-4, cis-7, cis-10 tridecatrienyl acetate, [$CH_3CH_2{}^C$ $CHCH_2$ $CH^{Ch}(CH_2)_3COCH_3$], also known as PTM2 (Voerman, 1984). The use of female sex pheromones in PTM is elaborated in the preceding sections 2.4.3.1 to 2.4.3.4.

2.4.3.1. Monitoring

Synthetic sex pheromones are used as bait in traps to attract and capture male insects, and they provide the basis for a survey tool. Pheromones of *P. operculella* have been used extensively in monitoring potato tuber moth populations (Alma, 2005). Pheromone monitoring systems can thus provide vital intelligence for the timing of insecticidal control measures.

2.4.3.2. Mass-trapping

This is the use of large numbers of pheromone traps to catch a large proportion of the pest population (Gautam and Prasad, 1998). This technique provides an effective means of controlling insect populations. When insect populations are low, it controls by slowing down population build-up to an acceptable level. For an economic approach, a limited number of traps can be used per unit area to catch selected target insects compared with spraying conventional insecticides (Alma, 2005).

For effective mass-trapping, it is essential to have a cheap effective trap with minimum maintenance, a pheromone blend which would be attractive for a long period of time, and the cost of the pheromone should be low. Some laboratory techniques are used to impregnate the pheromone PTM1 +PTM2 in rubber stoppers. However, for mass-trapping to be effective, it has to be organized on an area-wide basis and there is need for farmer co-operation, otherwise mated female moths may move into treated areas from outside. Mass-trapping is more appropriate with aggregation pheromones, since they attract both males and females (Gautam and Prasad, 1998). Unfortunately, as a PTM management recommendation at the small scale farmer level, mass-trapping is largely impractical due to the difficulty of implanting it on an area-wide basis as well as non-affordabilty of PTM1 + PTM2 pheromones.

2.4.3.3. Mating disruption

The technique is based on the premise that male insects would be unable to locate females if the environment around the female is permeated with sex pheromone (Hajek, 2004). The method involves blanketing the treated area with synthetic pheromone so that males cannot detect the pheromone produced by female moths and mating does not occur (Hajek, 2004). The exact mechanism of the process is not really known. Shorey (1977) (in Dent, 1991) proposed three factors that may act alone or in combination to produce the mating disruption effect:

1. sensory adaptation may occur because after prolonged exposure the olfactory sensory neurons no longer detect pheromone.
2. habituation may occur in which insects stop responding to a stimulus if earlier responses did not lead to proper result, and
3. direct competition may occur if males are flying to pheromone sources instead of females, which reduces the chances of successful mating.

Carde (1990) (in Dent, 1991) proposed a further three factors:

1. camouflage of natural pheromone by a high concentration of synthetic pheromone,
2. an imbalance in the sensory input where the synthetic pheromone has unnatural ratios of compounds, and
3. pheromone antagonists that reduce the attractiveness of pheromones.

There are basically two formulations of pheromones that have been developed for mating disruption: (i) multi-layered lure trap, and (ii) microencapsulation.

(i) Multi-layered lure trap

This is manufactured as a 3-layer plastic strip with the PTM1 + PTM2 pheromone concentrated in the inner layer. The two outer layers act to regulate the release of the PTM pheromone and protect the pheromone from degradation by weather elements. The concentration of PTM1 and PTM2 pheromone per unit being tested is 2mg, 1mg and 2mg pheromone and 40mg permethrin. The presence of an insecticide, permethrin, which is highly effective against adult PTM would, besides causing mating disruption, kill the male moths attracted to the dispenser (Alma, 2005).

(ii) Microencapsulation

This strategy was deployed by the UK firm Imperial Chemical Industries (ICI), in collaboration with research organizations. The pheromone is contained in minute polymeric capsules about two microns in diameter. It is easily prepared on a large scale and is easily applied to the crop with conventional ground and aerial spray equipment (Alma, 2005).

2.4.3.4. Lure and kill

This involves attracting the insect to a pheromone source that is treated with insecticides or biological control agents. The insect picks up a lethal dose of the insecticide and subsequently dies. This technique offers a number of advantages as it allows the efficient use of insecticides without blanket coverage, thereby saving the natural enemy fauna. It could also be used as a means of control in areas where the native fauna needs to be preserved (Gautam and Prasad, 1998). Mating disruption techniques, have the same limitations as those for mass-trapping.

2.4.4. Cultural control

Cultural methods reported to reduce potato tuber moth include: (i) elimination of cull piles and volunteer plants, (ii) soil moisture at and after vine kill, (iii) rolling or covering hills and (iv) intercropping.

2.4.4.1. Elimination of cull piles and volunteers

The cull piles and volunteer potatoes are destroyed to reduce overwintering stages which are a source of next crop's populations (Rondon *et al*., 2007).

2.4.4.2. Soil moisture at and after vine kill

Irrigating the soil prevents soil from cracking. The daily irrigation probably closes cracks, reducing tuber moth access. The PTM may die from oxygen reduction due to water saturation, and/or their mobility may be reduced by wet soil, decreasing their ability to find a tuber to infest (Rondon *et al*., 2007).

2.4.4.3. Rolling or covering hills

Tubers that are exposed or close to the surface are at high risk of PTM damage as the larvae has easy access.

2.4.4.4. Intercropping

Considerable evidence has emerged over the past two decades to suggest that pest populations and problems are much greater in crops grown in monoculture than in those grown in polyculture (Stoll, 2000). Intercropping is growing of more than one crop in the field. This increases plant diversity in the field and in turn reduces the impact of pests. Pest-reducing effects would be maximised in mixed cropping systems because plants of the same species are more distributed and hence more isolated from their own kind than under monocropping systems (Raymundo, 1984). Risch *et al*., (1983) (in Raymundo, 1984) noted that plant diversification of agricultural habitats frequently lowers pest populations. The effects of diversified cropping systems on pest populations are varied. Stoll (2000) hypothesized that there are two hypotheses underlying the effectiveness of intercropping as a pest management strategy: (i) the resource concentration hypothesis, and (ii) the natural enemy hypothesis.

The resource concentration hypothesis

The resource concentration hypothesis predicts lower pest abundance in diverse communities because a specialist feeder is less likely to find its host plant due to the presence of confusing or masking chemical stimuli, physical barriers to movement or other environmental effects such as microclimate and shading (Hoy *et al*., 2000). The insect pest will tend to remain in the intercrop for a shorter period simply because the probability of landing on a non-host plant is increased. There is usually fear of lower chances of surviving in such intercrops. The extent to which this principle operates will largely hinge on the number of host plant species present and relative preference of the pest for each, the absolute density and spatial arrangement of each host species and the interference effects obtained from non-host plants. If density of a host species is low and it is well distributed among non-host plants, then an insect approaching the habitat will have greater difficulty in locating its host than if the host density is high relative to non-hosts and if its distribution is clumped (Hoy *et al.,* 2000).

The intercrop camouflages the main crop plant, such as onion planted or intercropped with potatoes. As a result, the adult tuber moth cannot locate the potato plant easily. The mixed leaf types may confuse insect pests. Changing the texture or colour of the crop background has a significant effect on the landing of insect pests. A number of insects are averse to red or opal-coloured plants, which when planted with green foliage, repel these insects. The masking or diluting attractant stimuli of host plants by intercrops also has an effect on pest control. The intercrop may produce repellent chemical stimuli, for example, the strong odour of garlic, onion, coriander or basil often repels insects (Dent, 1991).

Natural enemy hypothesis

This hypothesis attributes lower pest abundance in intercropped or more diverse systems to the higher density of the predators and parasitoids (Dent, 1991). The greater density of natural enemies is caused by an improvement in conditions for their survival and reproduction, such as achieved by the provision of food sources for adult parasitoids and predators, provision of refuge for beneficial insects for nesting or over unfavourable environmental periods such as cold weather spells.

Possible potato intercrops in small-scale farming

To manage the population of PTM density, some plants with insecticidal, repellent and deterrent properties need to be carefully selected to suppress the pest population. The principle of crop diversity is based on the understanding of the resource concentration and natural enemy hypotheses. Intercropping of garlic, onion and ginger with different crops have been reported to reduce the population of different target pests (Halepyati *et al*., 1987; Stoll, 1995). Plants not only repel by smell, some are able to emit toxic substances that poison pests. Marigolds are commonly used flowers that discharge toxins through their roots. The toxins affect nematodes and potato tuber moth (Fusire, 2008).

(a) Onion(*Allium cepa)*

(i) Effects of onion on the PTM

Onion is a cosmopolitan plant which grows in temperate zones as well as in the tropics and subtropics. Onions belong to the lily family, the same family as garlic, leeks, chives, scallions and shallots. The plants can be used as ornamentals, vegetables, spices, or as medicine. There are over 120 different documented uses of the alliums. Onion and other allium vegetables are characterized by their rich content of thiosulphates, sulphides, sulphoxides, and other odoriferous sulphur compounds. The cysteine sulphoxides are primarily responsible for the onion flavour and produce the eye-irritating compounds that induce lacrimation. The thiosulphates exhibit antimicrobial properties. Onion has the ability to protect crops against a wide range of pests including the PTM. The onion bulbs and leaves have insect-controlling properties through their insecticidal, repellent, antifeedant, bactericidal, fungicidal and nematicidal effects on insect pests (Stoll, 1995).

Onion contains volatile flavour compounds. When fresh onion tissue is damaged, flavour precursors react under the enzymatic control of aliinase (S-alk (en) yl-L-Cysteine sulphoxide lyase) to release the highly reactive sulphenic acids plus ammonia and pyruvate (Brewster, 2008). The aliinase enzyme is confined to the cell vacuole, and the flavour precursors to the cytoplasm. The enzyme accesses the precursors only when there is cell disturbance. Once the highly reactive sulphenic acids are released, they undergo spontaneous rearrangement and inter-reactions to produce a wide range of volatile, strongly-smelling products (Singh *et al.,* 1996).The I-propenyl sulphenic acid produced in onion spontaneously rearranges its chemical structure to form tear-inducing thiopropana lS-oxide. The flavour precursors give rise to many compounds with strong physiological effects on other organisms, and it is likely that they are important in chemical defense mechanism, by deterring phytophagous animals (Baidoo *et al.* 2012). These volatile sulphenic acids repel the PTM. Intercrops of onion designed such that they are perpendicular to the wind direction have a great potential of repelling insect pests from the area and from moving further into the fields. The strongly-smelling sulphenic acids are responsible for reducing the population density of such organisms as PTM, Colorado potato beetle, aphids and mites that may invade the crop (Baidoo *et al.* 2012).

(ii) Effects of onion on other crop pests

Baidoo *et al*., (2012) reported that mixed cropping of carrots with onions reduced attacks by carrot fly. Intercropping of mustard (*Brassica raous*. var. Bari Sarisha-7) with onion and garlic was shown to reduce numbers of the aphid *Lipaphis erysimi* Kalternbach significantly. It was observed that aphid numbers in onion and garlic-intercropped blocks were significantly low as compared to non-intercropped blocks (Singh *et al*., 1996). Baidoo *et al*., (2012) also reported that significantly fewer whitefly and cabbage webworm infested brassica plants intercropped with onion than the sole crop.

(iii) Other benefits of onion to farmers

The onion plant has been used as an ingredient in various dishes for thousands of years by many cultures around the world. Onion is effective against many bacteria including *Bacillus subtilis, Salmonella*, and *Escherichia coli*. Onion is not as potent as garlic since the sulphur compounds in onion are only about one-quarter the level found in garlic. Onions have a variety of medicinal effects. In Chinese medicine, onions have been used to treat angina, coughs, bacterial infections, and breathing problems (Singh *et al.,* 1996). Besides the medical benefits, onion has no side effects as a potato intercrop because it does not compete for nutrients, sunlight and water.

(b) Marigold (*Tagetes.* spp)

(i) Effects of marigold on PTM

Marigold is commonly cultivated in gardens from where it often escapes to the wild, and is native to the western Mediterranean. It is an erect annual herb, branching above, growing up to 90cm high, and rooting at the lower nodes (Stoll, 2000). The flower heads are deep orange to dark red, solitary and arranged on erect stalks. They have a slightly bitter, salty flavour and contain mainly volatile oil, sapiens, a bitter principle called calendar, carotenoids, flavonoids, phytoncides, vitamin C, fats, resins, salicylic acid and other substances (Barbouche *et al*., 2001). The marigold plant parts with pest-controlling properties are flowers, leaves and roots. The compounds in the plant organs are repellent, insect-controlling, fungicidal and nematicidal to most insect pests and larvae of Lepidoptera (Stoll, 2000). The volatile oils are usually liquid mixtures of volatile, often aromatic substances that influence the secretion of urine. The PTM adults and larvae are thought to be affected by these volatile oils through dehydration and eventually death (Stoll, 2000). Phytoncides are substances with varied chemical composition. They limit the development of or kill some organisms. Phytoncides may prevent the growth of larvae and at times kill it. Saponins are heterosid molecules well known for their role in plant defence mechanisms (Barbouche *et al*., 2001). The ability of the exudates to inhibit the hatching of PTM eggs, poison their larvae and have repulsive properties could probably explain the interference of saponins with membrane cholesterol, causing the formation of a saponins/cholesterol complex, which generates a phenomenon of formation of pores and cellular loss of integrity (Barbouche *et al*., 2001). Saponins possess insecticidal properties; they send a strong rapid-working action against a broad range of pest insects. Most of the observed effects are increased mortality, lowered food intake, weight reduction, retardation in development and decreased reproduction. Saponins have a repellent or deterrent activity, and they provoke insect moulting defects or cause cellular toxicity effects (Barbouche *et al*., 2001).

Bitter principle is an amalgam of natural substances with a complex chemical composition and a bitter taste. The compounds in the marigold plant affect microorganisms including insect pests by inducing salivation, urinary secretion (dehydration), starvation, and decreasing reproduction. These factors keep a constant check on the pest population in a field with marigold. It can be grown around crops or intercropped to deter or repel insect pests (Barbouche *et al*., 2001).

(c) Garlic (*Allium sativum*)

(i) Effects of garlic on PTM

Garlic is a cosmopolitan plant which grows in temperate zones as well as in the tropics and subtropics. It can be cultivated on a wide range of soils. Garlic contains volatile oils, which have insecticidal, repellent, anti-feedant, bactericidal, fungicidal and nematicidal effects on insect pests. Recent studies conducted at the Bhabha Atomic Research Centre in Mumbai, India on differential toxicity of garlic oil on housefly and khapra beetle indicated that adults as well as larvae respond to the vapours of garlic oil by exhibiting hyper-excitability, ataxia, salivation and excretion-the usual signs of poisoning when treated similarly with insecticides (Ross *et al*., 2001). The larvicidal principles of garlic have been isolated and identified as ‘daily1 disulphide’ and ‘daily1 trisulphide’. Garlic vapours reduce pest population density by influencing salivation and excretion from the adults and larvae. This could be the mode of control on the Potato Tuber Moth (Ross *et al*., 2001).

(ii)Effects of garlic on other crop pests

Garlic in mixed cropping effectively repels harmful pests while retaining beneficial ones. If tomatoes are grown, planting some garlic prevents red spider mites from attacking the tomato crop (Patterson, 2008). Planting garlic around apples or peach trees repels fruit borers and intercropping garlic with cabbages reduces infestation by diamond-back moth. Exposure of dipteran pests, cabbage root fly and housefly to different concentrations of garlic juice revealed variability in insecticidal effect across life stages (Prowse *et al*., 2005). Garlic is effective against a wide range of diseases and insects at different stages of their life-cycle (i.e. egg, larva, adult). Affected insects include ants, aphids, armyworms, caterpillars, Colorado beetle, diamond-back moth, pulse beetle and whitefly (HDRA, 2012).

(iii) Other benefits of garlic to the farmer

Besides insect pest-controlling properties, garlic has other benefits to the farmer. It has a number of amazing medicinal uses and economic benefits. Studies have shown that consuming garlic generally has several physical effects to human health. Garlic lowers blood pressure by 9% to 15 % with one or two medium cloves per day. It is also known to lower cholesterol by 9% to 15 % with one or two medium cloves per day. Garlic helps reduce atherosclerotic build up (plaque) within the arterial system. Allicin is the "magic bullet" in garlic from which its many benefits are derived but being unstable, it reacts with many things and breaks down into other compounds (Russo, 2011).

2.5. Basis for alternative non-chemical PTM management strategies

PTM is usually controlled extensively by the use of insecticides in Zimbabwe's semi-arid regions of Matabeleland provinces. Insecticides such as monocrotophs, dichlorvos, carbofuran, chlorpyrifos and carbaryl are used on potatoes on fixed schedule, without regard to actual pest pressure. A number of considerations and problems associated with an excessive dependency on insecticide include, among others:

1. the development of resistance in both target and non-target organisms towards the pesticide;

2. disturbance in equilibrium existing between insect pests and their parasitoids and predators. This leads to changes in the abundance of species and diversity of ecosystems;

3. increase in disease susceptibility in hosts; and

4. residues of inorganic pesticides in tubers. Whilst the level of residue of insecticides in potato tubers is not yet established, there is justifiable concern to human health.

The resource-limited small-scale farmers cannot afford the cost of insecticides, and those that can afford pesticides, do not have adequate protective clothing and application equipment, thus exposing themselves to poisoning risks and food contamination. It is generally agreed that there is need for alternative strategies in management of potato tuber moth (Stoll, 2000).

The PTM larvae that make tunnels into the plant tissues as they feed cause the damage on the potato foliage and tubers. The intercropping pest management strategies are based on the resource concentration and natural enemy hypotheses. The chemical compounds in onion, garlic and marigold have pest-controlling effects and the farmer stands to benefit from these intercrops as they have medicinal uses to humans. The intercrops also have economic benefit as onion and garlic have a ready market in many communities which use them as herbals. Marigold commands a strong appeal as a herb for treating several ailments. Farmers need not view it as a weed, but a necessity in pest control management and human health remedy.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The study was conducted at Solusi Farm, Solusi University, Zimbabwe (18.583^{0}S 32.757^{0}E, 1200 m altitude). It is located in Natural Farming Region IV of Matabeleland South Province which is characterized by mean annual rainfall of 450 mm and mean temperature of 23.7 ˚C with Kalahari sandy soils. Solusi Farm soils are loamy with good organic matter levels and a pH of about 5.0.

3.2. Land preparation

The marked plots were prepared using a garden digger to a depth of 600 mm and a fine tilth created using a rake.

3.3. Treatments and experimental design

A Randomised Complete Block Design was used. The study had five treatments, namely; onion, garlic, marigold intercrops, sole crop (without insecticides) and sole crop with fixed schedule insecticide treatment with Nuvacron (a.i. monocrotophos). There were three replicates for each of the five treatments for each planting season. Nuvacron insecticide was applied at a rate of 0.75 a.i/ha. The treatments were randomly allocated to blocks. Each plot measured 6 m x 5 m. The rows of the experimental units were perpendicular to the direction of the irrigation pipes. All plots were given the same amount of water, nutrients and weeding or other cultivation practices.

3.4. Sprouting of potatoes

Potato seeds were bought from Inyanga Experiment Station in 30 kg pockets containing potatoes of sizes ranging from 25 mm to 48 mm in diameter with an average of 380 tubers in a pocket, and already treated with copper oxychloride fungicide. Some 60 kg of seed tubers were immersed in a 50 litre mixture of water and gibberrellic acid (prepared in a ratio of 100 ml of water to 16 ml of gibberellic acid in accordance with the manufacturer's specifications) to stimulate sprouting. The gibberellic acid-treated tubers were then covered in black polythene plastic in moderate sunshine to quicken sprouting.

3.5. Fertilization

A basal application of compound S (Nitrogen: Phosphate: Potash at 7:21:7 respectively) at a rate of 1500 kg/ha was applied in all plots during the three trial seasons. The basal dressing was done after land preparation before planting the sprouted seed potatoes. Top dressing with ammonium nitrate (AN) at rate of 290 kg/ha was done at three weeks after emergence. Sulphate of Potash was applied twice as a top dressing at a rate of 400-500 kg/ha, first at flowering and the other equal part at two weeks after flowering.

3.6. Planting of potatoes in the plots

The potato crop was planted over two seasons in a year. The first trial crop was planted on the 23rd of February 2011 (during the February-June 2011season) so that it matures before the frost period. The second trial crop was planted on the 3th of September 2011 (during the August-

December 2011 season), after the risk of frost has passed. The third trial crop was planted on the 26th of February 2012 (during the February-June 2012 season). During each trial season, the pest was studied in two cropping systems of intercropping and monocropping. The potato variety Mont-Claire was used for each planting season. The newly sprouted seeds were manually placed in rows, 30 cm apart, with a row-to-row spacing of 90 cm. The tubers were planted 10 cm deep and were covered by a thin film of soil before the first irrigation was applied.

3.7. Chemical application schedules

The chemically-treated potatoes were administered with Nuvacron 40 WSC on a rigid schedule regardless of the status of pest presence and density. When the chemical application operations were undertaken, the targeted plots were always secluded from the adjacent plots under different treatments by erecting polythene material around them to prevent chemical drifting to non-target crops. The Nuvacron insecticide was applied using the knapsack sprayer at a rate of 0.75 a.i/ha.

3.8. Earthing up

The earthing up of potatoes is an important agronomic process as more tubers form from buried stems. The operation involves drawing mounds of soil up around the plant to prevent new tubers from being exposed and turning green and becoming poisonous. This practice also helps to prevent tuber moth infestation and blight infection. The first earthing was done after top dressing with AN, at 4 weeks after emergence. This also served as a weed control operation. The second ridging was done during the flowering stage.

3.9. Monitoring PTM larval density and foliage-feeding pests

Every seven days from plant emergence to pre-harvest defoliation, three plants were randomly selected from the plots following a zig-zag pattern. The stems and leaves were inspected with magnifying glasses for presence of PTM larvae and their developmental stages, aphids and leafhoppers. Mean PTM larval population density data per plot were square root transformed ($p = \sqrt{(x + 1)}$) to normalise the data. These data were then subjected to ANOVA using the GLM procedure of GenStat Release 14.1 software. The treatment means were separated using Fisher's least significance difference (LSD) procedure.

3.10. Sweep net sampling for flying insects

Collection of flying insects was done using a sweep net. The nets were made of mesh collecting bags with a diameter of 38 cm. Five sweeps were done on each treatment plot once a week. Collected specimens were sorted, identified and classified using an insect identification key developed by Saleti *et al*., (2000).

3.11. Determining PTM canopy infestation preferences

The focus of infestation preference study was to determine the site of severe foliage damage by the larvae in accordance with their developmental stages. The sampling procedure of plants was as described in section 3.9 above. Sampling was done on three plant positions: the leaf canopy, the upper stem and the bottom stem. The numbers of larvae and their developmental stages in each plant position were determined. The data on the number of larvae per plot were transformed using the formula; $p = \sqrt{(x + 1)}$) and analysed as described in section 3.9.

3.12. Assessing PTM tuber infestation

The degree of tuber infestation by larvae was determined at harvest. Samples of 10 plants were collected from each plot and classified into different categories. The first category was of infested tubers with any visible tunnelling damage regardless of the presence or absence of larvae. The second category was the green tubers. The tubers were regarded green even if only slight change of colour was detected and the infested tubers were separated from non-infested ones. Tubers in each category were counted and weighed and percent infestation was calculated. The data on the number of healthy and infested tubers per plot was transformed using $\sqrt{(x + 1)}$ and analysed as described in section 3.9.

3.13. Assessment of PTM parasitism

Every 6-7 days from plant emergence to pre-harvest defoliation, three stems were randomly selected from each plot during the 2011-2012 seasons. The stems and leaves were inspected with magnifying glasses for presence of larvae and their developmental stages. The sampled leaves and stems were each kept in plastic containers with cloth lids until adult moths or parasitoids emerged. The samples were incubated at 18^0C and 18:6 light: dark photoperiod. The emerging parasitic wasps were counted for each location. Adult parasitoids were preserved in 85% ethanol and kept for identification at Africa University. Mean population of adult parasitoids were square root transformed ($p = \sqrt{(x + 1)}$). Percentage parasitism was calculated using the formula:

$$\frac{Mean\,number\,of\,adult\,\,parasitoids\,that\,emerged}{Total\,number\,of\,PTM\,larvae\,sampled} \text{ x } 100 = \text{ \% parasitism}$$

Parasitoids were identified using wing morphology. Forewings were detached, mounted on slides and viewed under a compound microscope. A motic image camera was mounted on the compound microscope eye piece and connected to a laptop computer. Images were taken and the wing venation was used to for identification using keys developed by Marsh (1979). The images are shown in Plates 4.1 and 4.2.

CHAPTER 4

RESULTS

4.1. PTM larval density and foliage-feeding pests

There were significant differences (P¿0.01) in the small larval density on foliage between sole potato plots, all the intercrop combinations and the Nuvacron-treated potatoes during the February-June 2011 season trial (Table 4.1). There were no significant differences (P¿0.01) in the large larval density among the garlic, marigold intercrops and the Nuvacron-treated potatoes (Table 4.1). No significant differences (P¿0.01) were noted in pupating larval density between onion and garlic intercrops (Table 4.1). There was no significant difference (P¿0.01) in density of Aphids between the marigold intercrop and the Nuvacron-treated potatoes. Leafhoppers were significantly different (P¿0.01) between the onion, garlic intercrops and the Nuvacron-treated potatoes (Table 4.1).

Table 4.1. PTM larval density and foliage-feeding pests during the February-June 2011 season trial.

	Number of PTM larvae ±SE			Foliage-feeding insects ±SE	
Treatment	Small	Large	Pupating	Aphids	Leafhoppers
Sole potato	2.51±0.24[a]	2.38± 0.24[a]	1.79±0.42[a]	1.05±0.53[a]	1.09±0.31[a]
Onion	2.10±0.63[a]	1.71±0.30[b]	1.41±0.00[a]	1.32±0.25[a]	1.23±0.18[a]
Garlic	1.96±0.48[a]	1.52±0.18[bc]	1.270±.24[ab]	1.38±0.19[a]	1.23±0.18[a]
Marigold	1.99±0.26[a]	1.140±.24[c]	1.140±.24[b]	1.90±0.33[b]	1.96±0.56[b]
Nuvacron	1.14±0.24[b]	1.14±0.24[c]	1.00±0.00[b]	2.21±0.64[b]	1.52±0.11[b]
Significance	**	**	**	**	**
LSD	0.730	0.4377	0.4361	0.5299	0.4730
CV%	20.7	15.3	18.1	18.5	18.5

Means within columns followed by different letters are significantly different (P¿0.01).
**, denotes significance at P< 0.01.

During the August-December 2011 season trial, there were no significant differences (P¿0.01) in the small larval density on foliage between garlic and marigold intercrops (Table 4.2). A significant difference (P¿0.01) was noted between the Nuvacron-treated potatoes and the sole potato ((Table 4.2). No significant differences (P¿0.01) were noted in the large larval density on foliage among onion, garlic and marigold intercrops (Table 4.2). Differences (P¿0.01) in the pupating larval density on foliage between garlic intercrop and marigold intercrop were also not significant. No significant differences (P¿0.01) were realized in the density of aphids among the garlic, marigold intercrops and the Nuvacron-treated potatoes. A significant difference (P¿0.01) was noted between onion intercrop and the marigold intercrop in the leafhopper density (Table 4.2).

Table 4.2 PTM larval density and foliage-feeding pests during the August-December 2011 season trial

	Number of PTM larvae ±SE			Foliage-feeding insects ±SE	
Treatment	Small	Large	Pupating	Aphids	Leafhoppers
Sole potato	2.94±0.19[a]	2.70±0.22[a]	1.88±0.43[a]	1.18±0.23[a]	1.05±0.23[a]
Onion	2.55±0.48[ab]	2.16±0.14[b]	1.41±0.00[ab]	1.36±0.37[ab]	1.36±0.50[a]
Garlic	1.86±0.53[b]	1.80±0.34[bc]	1.27±0.24[ab]	1.90±0.50[bc]	1.69±0.16[ab]
Marigold	2.06±0.36[b]	1.91±0.16[b]	1.27±0.24[ab]	2.24±0.37[c]	1.79±0.24[b]
Nuvacron	1.14±0.24[c]	1.41±0.00[c]	1.00±0.00[b]	2.03±0.00[c]	1.82±0.00[b]
Significance	**	**	**	**	**
LSD Value	0.6989	0.3441	0.3973	0.849	0.715
CV%	18.2	9.6	15.7	26.7	25.5

Means within columns followed by different letters are significantly different (P¿0.01).
**, denotes significance at P<0.01.

During the February-June 2012 season trial, there were no significant differences (P¿0.01) in the small larval density on foliage between sole potato and the onion intercrop (Table 4.3). No significant differences (P¿0.01) were noted in the large larval density on foliage between the sole potato and the onion intercrop. No significant differences (P¿0.01) were noted in the pupating larvae among the garlic, marigold intercrops and Nuvacron-treated potatoes (Table 4.3). There were no significant differences (P¿0.01) in the density of aphids among the sole potato, onion intercrop, garlic intercrop and the Nuvacron-treated potatoes (Table 4.3). During the same season trial, there was significant difference (P¿0.01) in the leafhopper density between the sole potato, onion intercrop and the marigold intercrop (Table 4.3).

Table4.3. PTM larval density and foliage-feeding pests during the February-June 2012 season trial.

	Number of PTM larvae ±SE			Foliage-feeding insects ±SE	
Treatment	Small	Large	Pupating	Aphids	Leafhoppers
Sole potato	2.88±0.26[a]	2.45±0.21[a]	1.90±0.30[a]	1.05±0.49[a]	1.00±0.46[a]
Onion	2.58±0.12[a]	2.23±0.23[a]	1.62±0.18[a]	1.75±0.21[ab]	1.41±0.05[a]
Garlic	1.71±0.30[b]	1.38±0.37[b]	1.00±0.00[b]	1.55±0.01[ab]	1.51±0.04[ab]
Marigold	2.08±0.14[ab]	1.24±0.42[b]	1.00±0.00[b]	2.03±0.49[b]	1.90±0.44[b]
Nuvacron	1.14±0.24[c]	1.14±0.24[b]	1.00±0.00[b]	1.32±0.22[ab]	1.51±0.05[ab]
Significance	**	**	**	**	**
LSD Value	0.4008	0.755	0.2828	0.785	0.769
CV%	10.6	24.5	11.9	28.0	28.9

Means within columns followed by different letters are significantly different (P¿0.01).
**, denotes significance at P<0.01.

4.2. Larval infestation preferences

During the February-June 2011 season trial, there was no significant difference (P¿0.05) in the small larval density within the leafy canopy part of the potato plant in all the treatments (Table

4.4). There was however, a significant difference (P¿0.05) in the large larval density within the leafy canopy between the sole potato and all the other treatments. No significant difference (P ¿ 0.05) was registered in the pupating larval density on the leafy regions in all the treatments (Table 4.4).

Within the upper stem regions of the potato plant, there were no significant differences (P¿0.05) in the small larval density within the upper stem regions of crop, in all the treatments (Table 4.4). The differences (P¿0.05) in the large larval density within the upper stem regions of the potato plant among onion, garlic, marigold intercrops and Nuvacron-treated potatoes were also not significant. The pupating larval density within upper stem plant region showed no significant difference (P¿0.05) in all the treatments (Table 4.4).

No significant difference (P¿0.05) was noted in the small larval density within the bottom stem regions of the potato plant between onion intercrop and marigold intercrop (Table 4.4). There were no significant differences (P¿0.05) in the large larval density within the bottom stem regions of the potato plant among onion, garlic, marigold intercrops and Nuvacron-treated potatoes. The pupating larval density within bottom stem plant region showed a significant difference (P¿0.05) between sole potato and the other treatments (Table 4.4).

Table 4.4 Larval infestation preferences (mean number of larvae) during the February-June 2011 season trial

Treatment	Leaf canopy ±SE			Upper stem ±SE			Bottom stem ±SE		
	small	large	pupating	small	large	pupating	small	large	pupating
Sole potato	2.34±0.52	1.27±0.24[a]	1.00±0.09	1.27±0.24	1.99±0.26[a]	1.14±0.00	1.14±0.24	1.41±0.00[a]	1.58±0.52[a]
Onion	1.80±0.34	1.00±0.00[b]	1.00±0.00	1.38±0.37	1.52±0.18[ab]	1.41±0.00	1.24±0.42	1.27±0.[24ab]	1.00±0.00[b]
Garlic	1.52±0.18	1.00±0.00[b]	1.14±0.24	1.24±0.42	1.14±0.24[b]	1.14±0.24	1.00±0.00	1.27±0.[24ab]	1.00±0.00[b]
Marigold	1.79±0.42	1.00±0.00[b]	1.00±0.00	1.14±0.24	1.14±0.24[b]	1.14±0.24	1.24±0.42	1.14±0.24[b]	1.00±0.00[b]
Nuvacron	1.38±0.37	1.00±0.00 [b]	1.00±0.00	1.00±0.00	1.14±0.24[b]	1.00±0.00	1.00±0.00	1.00±0.00[b]	1.00±0.00[b]
Significance	NS	*	NS	NS	*	NS	NS	*	*
LSD	0.5711	0.1926	1.00	0.5295	0.4207	0.2724	0.5218	0.3336	0 .4209
CV%	18.1	10.0	0.0	24.1	16.7	12.3	25.5	15.0	20.7

Means within columns followed by different letters are significantly different (P¿0.05).

*, denotes significance at P<0.05. NS= No significant difference

During the August-December 2011 season trial, there was no significant difference (P¿0.01) in the small larval density within the leafy canopy part of the potato plant between the, garlic, marigold intercrops and the Nuvacron-treated potatoes (Table 4.5). There was also no significant difference (P¿0.01) in the large larval density within the leafy canopy in all the treatments. There was also no significant difference (P¿0.01) in the pupating larvae on the leafy regions in all the treatments (Table 4.5).

Within the upper stem regions of the potato plant, there were no significant differences (P¿0.01) in the small larval density within the upper stem regions of crop, in all the treatments (Table 4.5). There were no significant differences (P¿0.01) in the large larval density within the upper stem regions of the potato plant among onion, garlic, marigold intercrops and Nuvacron-treated potatoes. The pupating larval density within upper stem plant region showed no significant difference (P¿0.01) in all the treatments (Table 4.5).

There was a significant difference (P¿0.05) in the small larval density within the bottom stem regions of the potato plant between sole potato and the other treatments (Table 4.5). There were no significant differences (P¿0.01) in the large larval density within the bottom stem regions of the potato plant between the garlic intercrop and Nuvacron-treated potatoes. The pupating larval density within bottom stem plant region showed a significant difference (P¿0.01) between sole potato and the other treatments (Table 4.5).

Table 4.5 Larval infestation preferences (mean number of larvae) during the August-December 2011season trial

Treatment	Leaf canopy ±SE			Upper stem ±SE			Bottom stem ±SE		
	small	large	pupating	small	large	pupating	small	large	pupating
Sole potato	2.31± 0.12[a]	1.47±0.50	1.14±0.24	1.66±0.62	1.91±0.16[a]	1.14±0.24	1.80±1.06	1.79±0.42 [a]	1.79±0.42[a]
Onion	2.03±0.55[a]	1.24±0.42	1.00±0.00	1.71±0.30	1.38±0.37[b]	1.14±0.24	1.14±0.24	1.71±0.30[a]	1.14±0.24[b]
Garlic	1.79±0.42[ab]	1.00±0.00	1.00±0.00	1.14±0.24	1.24±0.42[b]	1.00±0.00	1.00±0.00	1.52±0.18[ab]	1.00±0.00[b]
Marigold	1.82±0.56[ab]	1.00±0.00	1.00±0.00	1.38±0.37	1.14±0.24[b]	1.00±0.00	1.00±0.00	1.80±0.34[a]	1.27±0.24[b]
Nuvacron	1.14±0.24[b]	1.00±0.00	1.00±0.00	1.14±0.24	1.00±0.00[b]	1.00±0.00	1.00±0.00	1.14±0.24[b]	1.14±0.24[b]
Significance	**	NS	NS	NS	**	NS	NS	**	**
LSD	0.6157	0.5337	0.0000	0.6911	0.5093	0.2724	0.4521	0.5570	0.4767
CV%	18.6	25.7	0.0	27.0	21.0	14.2	22.2	19.2	20.7

Means within columns followed by different letters are significantly different (P¿0.01).
**, denotes significance at P<0.01.   NS= No significant difference

During the February-June 2012 season trial, there was no significant difference (P¿0.01) in the small larval density within the leafy canopy part of the potato plant between the, garlic, marigold intercrops and the Nuvacron-treated potatoes (Table 4.6). There was also no significant difference (P¿0.01) in the large larval density within the leafy canopy in all the treatments. There was also no significant difference (P¿0.01) in the pupating larval density on the leafy regions in all the treatments (Table 4.6).

Within the upper stem regions of the potato plant, there were no significant differences (P¿0.01) in the small larval density within the upper stem regions of crop, in all the treatments (Table 4.6). There were no significant differences (P¿0.01) in the large larval density within the upper stem regions of the potato plant among onion, garlic, marigold intercrops and Nuvacron-treated potatoes. The pupating larval density within upper stem plant region showed no significant difference (P¿0.01) in all the treatments (Table 4.6).

There was a significant difference (P¿0.01) in the small larval density within the bottom stem regions of the potato plant between sole potato and the other treatments (Table 4.6). There were no significant differences (P¿0.01) in the large larval density within the bottom stem regions of the potato plant among onion, garlic and marigold intercrops and Nuvacron-treated potatoes. The pupating larval density within bottom stem plant region showed a significant difference (P¿0.01) between sole potato and the other treatments (Table 4.6).

Table 4.6 Larval infestation preferences (mean number of larvae) during the February-June 2012 season trial

Treatment	Leaf canopy ±SE			Upper stem ±SE			Bottom stem ±SE		
	small	large	pupating	small	large	pupating	small	large	pupating
Sole potato	2.34±0.74[a]	1.27±0.24	1.27±0.00	1.71±0.30[a]	1.80±0.34[a]	1.41±0.00[a]	1.27±0.24[a]	1.88±0.43[a]	1.61±0.34[a]
Onion	2.23±0.23a	1.24±0.42	1.00±0.00	1.14±0.23[b]	1.24±0.18[b]	1.00±0.00[b]	1.00±0.00[b]	1.00±0.00[b]	1.14±0.24[b]
Garlic	1.61±0.34[ab]	1.14±0.24	1.00±0.00	1.14±0.23[b]	1.27±0.24[b]	1.00±0.00[b]	1.00±0.00[b]	1.14±0.24[b]	1.00±0.00[b]
Marigold	1.61±0.34[ab]	1.00±0.00	1.14±0.24	1.41±0.00[b]	1.24±0.42[b]	1.00±0.00[b]	1.14±0.24[b]	1.00±0.00[b]	1.00±0.00[b]
Nuvacron	1.14±0.24[b]	1.00±0.00	1.00±0.00	1.00±0.00[b]	1.14±0.24[b]	1.00±0.00[b]	1.00±0.00[b]	1.00±0.00[b]	1.00±0.00[b]
Significance	**	NS	NS	**	**	NS	**	**	**
LSD	0.6564	1.000	1.000	0.3632	0.5396	1.000	0.2724	0.3475	0.3375
CV%	20.2	21.3	0.0	15.6	21.3	0.0	13.8	15.2	16.1

Means within columns followed by different letters are significantly different (P¿0.01).

**, denotes significance at P<0.01.   NS= No significant difference

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4.3. Tuber infestation

During the February-June 2011 season trial, there were no significant differences (P>0.01) in the intensity of green tuber infestation between onion and sole potato (Table 4.7). There was significant difference (p<0.01) in the green tuber infestation intensity between the three intercrops and the Nuvacron-treated potatoes. The white tubers showed no significant difference (P>0.01) in the infestation intensity between garlic intercrop and the Nuvacron-treated potatoes (Table 4.7).

Table 4.7. Tuber infestation during the February-June 2011 season trial

	Mean Number of tubers/ 10 plants / 50m^2				
	Green tubers ±SE		White tubers ±SE		% reduction of
Treatment	Healthy	Infested	Healthy	Infested	tuber infestation over sole potato
Sole potato	8.33±3.79	14.67±3.51^a	60.33±1.16^a	10.67±2.52^a	
Onion	5.67±3.22	10.33±2.08^{ab}	74.00±5.29^b	6.00±3.61^{ab}	35.33
Garlic	9.00±2.65	7.33±2.52^{bc}	76.67±2.52^b	2.33±1.16^b	61.84
Marigold	3.33±3.22	9.00±3.61^{ab}	64.33±2.52^a	5.67±2.52^{ab}	42.11
Nuvacron	10.33±3.22	1.33±1.53^c	79.67±2.08^b	1.33±0.58-^{b}	89.47
Significance	NS	**	**	**	
LSD	9.30	4.279	4.530	3.186	
CV%	46.2	23.8	3.3	27.9	

Means within columns followed by different letters are significantly different (P<0.01).
**, denotes significance at p<0.01. NS= No significant difference

There were significant differences (p¿0.01) infestation intensity of green tubers between the marigold intercrop and the Nuvacron-treated potatoes during the August-December 2011 season trial (Table 4.8).There were no significant differences (p¿0.01) in the intensity of green tuber infestation between garlic intercrop and marigold intercrop (Table 4.8). There were no significant differences (p¿0.01) in the infestation intensity of white tubers between the sole potato and onion intercrop (Table 4.8).

Table 4.8 Tuber infestation during the August-December 2011 season trial

	Mean Number of tubers/ 10 plants / 50m^2				
	Green tubers ±SE		White tubers ±SE		%reduction of tuber infestation over sole potato
Treatment	Healthy	Infested	Healthy	Infested	
Sole potato	13.67±4.04	17.33±1.53^{a}	64.67±3.22^{a}	12.33±1.16^{a}	
Onion	7.00±3.00	14.33±1.53^{a}	74.67±2.08^{b}	10.33±2.08^{a}	20.43
Garlic	15.00±2.00	6.67±2.52^{b}	80.67±2.52^{c}	4.33±1.33^{b}	64.52
Marigold	9.00±6.00	8.67±4.04^{b}	61.00±2.00^{a}	4.00±2.65^{b}	59.14
Nuvacron	10.67±8.08	2.33±0.58^{c}	95.33±3.06^{d}	0.33±0.58^{c}	91.40
Significant	NS	**	**	**	
LSD	9.30	4.279	4.530	3.186	
CV%	46.2	23.8	3.3	27.9	

Means within columns followed by different letters are significantly different (p¿0.01).
**, denotes significance at $p<0.01$. NS= No significant difference

During the February-June 2012 season trial, there were significant differences ($p<0.01$) in the tuber infestation intensity between the onion intercrop and the Nuvacron-treated potatoes (Table 4.9).White tuber infestation intensity during the February-June 2012 season trial was not significantly different ($p>0.01$) between the garlic intercrop and the Nuvacron-treated potatoes (Table 4.9).

Table 4.9 Tuber infestation during the February-June 2012 season trial

	Mean Number of tubers/ 10 plants / 50m^2				
	Green tubers ±SE		White tubers ±SE		
Treatment	Healthy	Infested	Healthy	Infested	%reduction of tuber infestation over sole potato
Sole potato	4.33±1.53	6.33±0.53^{a}	80.00±2.00^{a}	8.33±2.52^{a}	
Onion	4.33±1.53	4.67±2.08^{a}	77.00±2.65^{ab}	6.67±2.52^{a}	22.73
Garlic	5.33±1.53	3.33±3.79^{ac}	84.33±3.79^{ac}	1.00±1.00^{b}	70.45
Marigold	6.33±0.58	3.00±1.00^{ab}	69.33±4.16^{b}	3.00±1.00^{ab}	59.09
Nuvacron	6.00±2.00	0.33±0.58^{b}	90.33±2.8^{ac}	1.00±1.00^{b}	90.91
Significance	NS	**	**	**	
LSD Value	NS	2.530	5.810	3.220	
CV%	28.6	40.9	4.0	44.3	

Means within columns followed by different letters are significantly different ($P<0.01$).
**, denotes significance at $P<0.01$. NS= No significant difference

4.4.Assessment of PTM parasitism

Parasitic wasps which emerged from larvae of *P. operculella* collected from Solusi farm were identified as *Apanteles* spp. (Plate 4.1) and *Copidosoma* spp. (Plate 4.2).

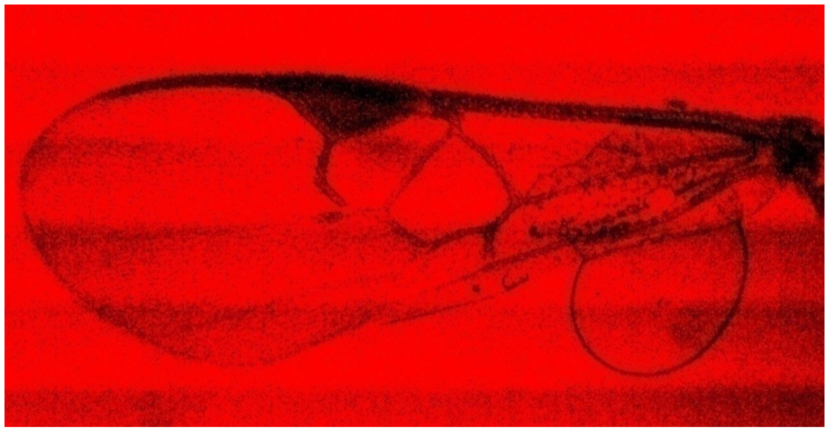

Plate 4.1 *Apanteles* sp. parasitoid forewing veins (Image taken using a Motic image camera at magnification of X40)

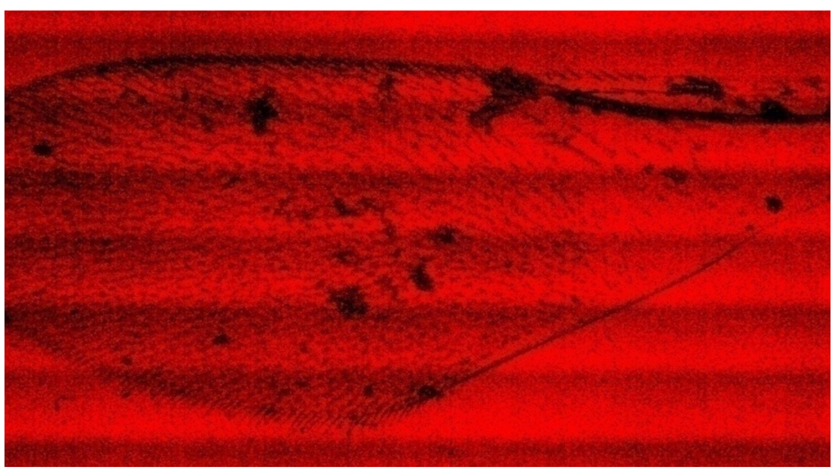

Plate 4.2 *Copidosoma* sp. parasitoid forewing veins (Image taken using a Motic image camera at magnification of X40)

During the February-June 2011 season trial, there were no significant differences (p>0.05) in the emerging adult *Apanteles* parasitoid in all the treatments (Table 4.10). There was also no significant difference (p>0.05) in the emerging adult *Copidosoma* parasitoid in all the treatments. The combined percentage parasitism of *Apanteles* and *Copidosoma* ranged from 52.66% to 80.60% (Table 4.10).

Table 4.10 PTM parasitism during the February-June 2011season trial

Treatment	Number of PTM larvae collected ±SE	Number of *Apanteles* ±SE	% *Apanteles* Parasitism ±SE	Number of *Copidosoma*	% *Copidosoma* Parasitism	Combined% Parasitism
Sole potato	4.33±1.53	1.71±0.05	39.49	1.62±0.03	37.41	76.90
Onion	4.33±1.53	1.67±0.09	38.57	1.82±0.22	42.03	80.60
Garlic	5.33±1.53	1.94±0.18	36.40	1.51±0.09	28.33	64.73
Marigold	6.33±0.58	1.67±0.09	26.38	1.69±0.09	26.70	53.08
Nuvacron	6.00±2.00	1.82±0.00	30.33	1.34±0.26	22.33	52.66
Significance	NS	NS		NS		
LSD	2.73	91.2		1.049		
CV%	28.6	37.9		36.2		

NS= No significant difference

During the August-December 2011 season trial, there were significant differences (p<0.05) in the emerging adult *Apanteles* parasitoid among sole potato, the onion intercrop and the garlic, marigold intercrops and the Nuvacron-treated potatoes (Table 4.11). There was also significant difference (p<0.05) in the emerging adult *Copidosoma p*arasitoid between the sole potato and the marigold intercrop. The combined percentage parasitism of *Apanteles* and *Copidosoma* was 100% in the garlic and marigold intercrops (Table 4.11).

Table 4.11 PTM parasitism during the August-December 2011season trial

Treatment	Number of PTM larvae collected ±SE	Number of *Apanteles* ±SE	% *Apanteles* Parasitism	Number of *Copidosoma* ±SE	% *Copidosoma* Parasitism	Combined% Parasitism
Sole potato	6.33±0.53^{a}	1.69±0.52^{ab}	26.70	1.86±0.23^{a}	29.38	56.08
Onion	4.67±2.08^{ab}	1.27±0.43^{a}	27.19	1.49±0.37^{b}	31.91	59.10
Garlic	3.33±3.79^{b}	1.64±0.18^{b}	49.25	1.69±0.34^{ab}	50.75	100
Marigold	3.33±3.79^{b}	1.94±0.24^{b}	58.00	1.43±0.37^{b}	42.00	100
Nuvacron	4.33±1.00^{ab}	1.94±0.00^{b}	44.80	1.47±0.24^{b}	33.95	78.75
Significance	**	*		*		
LSD	2.530	1.048		0.743		
CV%	40.9	34.0		25.7		

Means within columns followed by different letters are significantly different (P<0.05).
*, **, denote significance at P<0.05 and 0.01 respectively. NS= No significant difference

During the February-June 2012 season trial, there were no significant differences (p>0.05) in the emerging adult *Apanteles* parasitoid in all the treatments (Table 4.12). There was also no significant difference (p>0.05) in the emerging adult *Copidosoma* parasitoid in all the treatments. The combined percentage parasitism of *Apanteles* and *Copidosoma* ranged from 46.44% to 78.37% (Table 4.12).

Table 4.12 PTM parasitism during the February-June 2012 season trial

Treatment	Number of PTM larvae collected ±SE	Number of *Apanteles* ±SE	% *Apanteles* Parasitism ±SE	Number of *Copidosoma*	% *Copidosoma* Parasitism	Combined% Parasitism
Sole potato	6.33±0.53[a]	1.51±0.50	23.85	1.43±0.09	22.59	46.44
Onion	4.33±1.53[ab]	1.38±0.15	31.87	1.47±0.03	33.95	65.82
Garlic	3.33±3.79[b]	1.32±0.21	39.64	1.27±0.25	38.14	77.78
Marigold	4.67±2.08[ab]	1.87±0.35	40.04	1.79±0.27	38.33	78.37
Nuvacron	4.67±2.08[ab]	1.55±0.02	33.19	1.64±0.12	35.12	68.31
Significance	**	NS		NS		
LSD Value	2.530	0.950		0.6361		
CV%	40.9	4.2		23.0		

Means within columns followed by different letters are significantly different (P<0.01).
**, denotes significance at P<0.01. NS= No significant difference

5.0 DISCUSSION

5.1 PTM larval density and foliage-feeding pests

One mechanism that may account for low PTM larval density and foliage-feeding pests in garlic plots, could be mortality in the eggs, thus preventing larval eclosion. Garlic compounds may toughen the structure of the egg, preventing hatching in a way similar to that in which dehydration can act, with embryos apparently developing normally but hatching inhibited (Neveu *et al.,* 1997).

This study did not deal directly with the underlying mechanisms of garlic toxicity; however, previous studies have implicated enzyme inhibition by the compounds in the garlic oil vapour as a potential mode of action (Neveu *et al.,* 1997). Acetyl cholinesterase is one enzyme that has been shown to be inhibited by garlic compounds, notably a mixture of diallyl disulphide and diallyl trisulphide [$C_6H_{10}S_2$] and [$C_6H_{10}S_3$],respectively and allicin [$C_6H_{10}OS_2$] (Singh and Singh, 1996). The most abundant garlic compound found in garlic oil vapour is diallyl trisulphide, followed by diallyl disulphide at half the concentration. When acetyl choline esterase enzyme is inhibited, the insect nervous system is disrupted, thus affecting insect survival.

The low pest density in the marigold intercrop could be attributed to the strong insect-repellent properties in the plant (Fusire, 2008). Mexican marigolds are said to offend a host of destructive insects and wild rabbits as well (Smith, 2003). Marigold contains saponins which possess insecticidal properties; they have a strong rapid-working action against a broad range of pest insects. Most of the observed effects of marigolds are increased mortality, lowered food intake, weight reduction, retardation in development and decreased reproduction (Barbouche *et al*., 2001). Saponins have a repellent or deterrent activity, and they provoke insect moulting defects or cause cellular toxicity effects. The density of PTM, aphids and leafhoppers could have been reduced because of the effects of saponins.

5.2 PTM larval infestation preferences

The general preference of the leafy canopy and the upper stem regions of the plant by the PTM larvae could be attributed to the pest's laying preference. Palacios *et al*. (1998) reported the same trend in Peru, attributing it to the moth's preference to laying its eggs on the upper stem part of the plant. The distribution of the small and large larvae in the leafy canopy and upper stem regions of the plant could also be attributed to the plant's developmental stage, when the plant has very tender tissues where there is meristematic growth for easy feeding by the larvae.

5.3 PTM tuber infestation

The green tubers in all plots were more vulnerable to PTM infestation as the larvae could access these easily. The sandy soils in Solusi farm provide easy entry of the larvae into the soil to damage the tubers. This trend is in agreement with findings of Palacios *et al.* (1998) where they found that larvae penetrated the soil to a depth of 5 cm. In the present study, there was less tuber damage from white tubers (tubers at deeper levels) probably because of the moth's limited penetration ability and its low infestation density in the lower part of the plant. Results of the present study are generally in conformity with those reported by Raymundo and Alcazar (1983).

Raymundo and Alcazar (1983) observed that potato plants grown in association with onion had significantly less tuber damage from *P. Operculella* than for potato alone.

Tubers from marigold intercrop were generally small than those from other treatments. This trend could have obtained as a result of potato crop failing to get adequate nutrients and water because of competition with the marigold plant. The marigold plant has a dense rooting system and the fertilizer applied did not carter for the marigold plant.

5.4 Assessment of PTM parasitism

The general low insect pest population densities in all the intercrops indicate the strength of the repellent properties in garlic, marigold and onion plants. Marigolds are relatively pest free and many people interplant them in their vegetable gardens to deter insect pests (Schalau, 2004).
Garlic is a broad-spectrum insecticide that will kill beneficial insects as well as pests (Fusire, 2008). This pattern points to how sole potato encourages biological management of potato tuber moth. The present study on the parasitism, intercropped potatoes is in agreement with other studies. Mohammad (2011) outlined the effects of intercropping in relation to the species diversity of population level of natural enemies that may be influenced by the complex environment of intercrop. In a similar study, *Copidosoma koehleri* and *Apanteles subandinus* were the most common tuber moth parasitoids (Abbas *et al*. 1993). In this study, *Apanteles* parasitoids appear to suppress the population of the tuber moth larvae in potatoes. Intercrops seem to serve as a source of habitat for establishment of parasitoids at Solusi farm. The level of parasitism observed in the Nuvacron-treated potatoes, compared to intercrops, seem to reflect the density that the parasitoids populations are capable of attaining under conditions of chemical pest

control. It is also possible that parasitoids display a numerical response to the pest, in which case the higher rate of parasitism on intercrop combinations corresponds to the higher density of the pest on those fields. *A.subandinus* females are more attracted to complex chemical compounds from damaged potato plant and PTM larvae. *A. Subandinus* is able to distinguish from a distance of 30cm between infested and un-infested plants with PTM larvae. Odour originating in infested plants foliage appears to be an important attractive stimulus for female *A. Subandinus* (Du *et al*. 1996). *A. subandinus* is a larval parasitoid while *C.koehleri* is an egg parasitoid. While data is lacking as to whether marigolds actually deter insect pests, they definitely attract parasitoids, this was as a result of flowers which serve as a source of nectar for the parasitoid.

During three seasons trials, in the Nuvacron-treated-potatoes, it was found that between 22.33% to 35.12% of the PTM larvae were nevertheless parasitized by *C. koehleri,* which indicated that the parasitoid could tolerate relatively severe pesticide spray regimes. This corroborated observations that insecticide applications against tuber moth have negligible effects on the maximum parasitism by its natural enemies (Whiteside, 1980). In a trial conducted in 1988 in South Africa, potato tuber moth larvae were collected from potato leaves and tubers towards the end of the season from a field sprayed weekly with various pesticides and between 71% and 82% of the potato tuber moth larvae were found parasitized by *C. koehleri* (Kfir, 1989).

CHAPTER 6

CONCLUSION

Garlic and marigold intercrops are effective insect-repellent crops that suppress the PTM larval density on foliage and reduce tuber infestation intensity and can be used to replace Nuvacron insecticides. The repellent properties of onion, garlic and marigold have no direct influence on the infestation preferences of the larvae. Whilst marigold intercrop was an effective PTM larval control, it reduced the potato yields. Garlic and marigold intercrops effectively reduced the abundance of other insect-pests on potatoes. *A. subandinus* and *C. koehleri* parasitoids are promoted by intercropping.

RECOMMENDATIONS

1. Further evaluation of these insect-repellent crops in powdery and aqueous solution in the field and store to prevent infestation of store potato seed should be carried out.
2. Further research on fertilizer application rates to cater for intercrop nutrient requirements and the optimum plant populations of the potato and intercrops with focus on agronomic practices such as earthing-up and harvesting should be conducted.
3. The intercrops can be planted well before the potato crop is planted so that by the time the pest invades the crop, the insect-repelling properties will be effective as the plant will be mature enough to fight the larvae.
4. Farmers can safely use the garlic and marigold intercrops with potato to control PTM instead of the environmentally unsafe and costly Nuvacron insecticides.

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