Small holder farmers' perceptions, host plant suitability and natural enemies of the groundnut leafminer, *Aproaerema modicella* (Lepidoptera: Gelechiidae) in South Africa.

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Abstract

The groundnut leafminer (GLM), *Aproaerema modicella* (Lepidoptera: Gelechiidae), is a well known pest of groundnut and soybean in Asia. It has been reported in Southern Africa on groundnut since 2000. The groundnut leafminer causes a reduction in crop yield by tunneling in the leaves and thereby reducing the leaf area for photosynthesis. Larvae tunnel into the leaves where they feed between the upper and lower epidermis causing defoliation of groundnut crops. Last-instar larvae web two leaves together and pupate in between these leaves. Since GLM is a new pest in South Africa, no integrated management program for control of this insect exists. A survey was conducted among the small holder farmers at the Tshiombo irrigation scheme where GLM is an important pest in groundnut fields. Results showed that the majority of residents involved in farming activities were females aged between 41 and 60 years. It was also observed that groundnut is important as part of the daily diet and a cash crop in the surrounding villages and Thohoyandou, the nearest town. Farmers were familiar with the damage symptoms caused by GLM larvae, but they did not know the agent causing the damage to their groundnut fields. They regarded chemical control as the only pest control strategy capable of reducing crop losses caused by GLM. Since chemical control of GLM is not a sustainable strategy there is a need to carry out investigations likely to generate reliable GLM management strategies and this requires using live insects of known age and sex. One of the constraints encountered when conducting experimental studies on GLM moths was the fact that these moths are small, very agile and the sex of live moths cannot be easily identified. Male and female moths lack easily identifiable distinguishing characteristics. Another area of investigation was directed towards identifying cultivated and wild host plants that serve as either off-season or alternative hosts of GLM. When such plants are identified they can serve as trap crops in strategies designed to manipulate the groundnut crop environment in order to reduce crop damage due to GLM. With this objective in mind behavioral bioassays designed to compare the preferences of GLM for groundnut, soybean, lucern and cowpea were carried out. A Y-tube olfactometer bioassay was used to examine moth orientation to test plant odors. No-choice tests bioassays were used to examine moth oviposition responses, plant damage and GLM development on the test plants. Although moths oriented positively to cowpea plants in the Y-tube bioassays, GLM larvae did not infest cowpea plants in the larval development bioassays. This may be due to lack of feeding stimulants for GLM in the cowpea plants. Comparatively speaking GLM larvae caused more damage on soybean than on groundnut. The mean number of lesions on soybean plants was higher than on groundnut. Results from these experiments also showed that the rate of larval development was much better on groundnut than on soybean and lucern. Within the groundnut fields nine wild host plant species of GLM were identified and the geographical distribution of those plants was established. In addition to these observations, ten species of natural enemies were reared from GLM larvae and pupae. High levels of larval (54.2%) and pupal (43.7%) parasitism were recorded. The impact of those natural enemies on GLM populations in the study area remains to be investigated in detail. The potential of using wild host plants to minimize GLM attacks on groundnuts also requires further investigations. This study shows that there are components that can be used to develop IPM strategies for managing GLM in South Africa but this will require a concerted effort of carrying out the necessary research and working closely with the farmers.

Key words: *Aproaerema modicella*, GLM, small holder farmers, host plants, IPM, natural enemies.

Opsomming

Titel: Kleinboerpersepsies, die geskiktheid van gasheerplante en natuurlike vyande van die grondboonbladmyner, *Aproaerema modicella* (Deventer) (Lepidoptera) in Suid-Africa.

Die grondboonbladmyner (GBM), *Aproaerema modicella* (Lepidoptera: Gelechiidae), is 'n bekende plaag van grondbone en sojabone in Asië. Die voorkoms van GBM op grondbone is vanaf 2000 in suider Afrika opgemerk. GBM veroorsaak 'n afname in die opbrengs van die gewas deurdat die larwes tussen die twee epiteellae van die blare tonnel en vreet, en sodoende die oppervlak vir fotosintese verlaag. Hierdie skade lei tot ontblaring van grondboonplante. Die laaste-instar larwes spin twee blare aanmekaar waarbinne papievorming plaasvind en die lewensiklus van GBM voltooi word. Aangesien GBM 'n nuwe plaag in Suid-Afrika is, bestaan daar tans geen geintegreerde plaagbeheerstrategie om die insek te beheer nie. 'n Opname is gedoen by die Tshiombo besproeiingsskema deur middel van vraelyste wat met kleinboere bespreek is. GBM is 'n belangrike plaag van grondbone in die omgewing. Die meerderheid boere wat voltyds met die boerdery praktyk besig is, bestaan uit vrouens tussen die ouderdomsgroep van 41 en 60 jaar. Grondbone is 'n belangrike bron van inkomste en kos vir hierdie boere. Die boere verkoop 'n gedeelte van hul grondboon-opbrengste in die omliggende gemeenskappe en ook in die naaste dorp, Thohoyandou. Die skadesimptome wat deur GLM-larwes veroorsaak word, was aan meeste van die boere bekend, al kon hul nie die oorsaak van hierdie simptome identifiseer nie. Die boere beskou chemiese beheer as 'n belangrike deel van 'n beheerstrategie vir GBM. Een van die beperkende eienskappe van eksperimentele studies met GBM is die feit dat daar nie maklik tussen lewende mannetjie- en wyfie-motte onderskei kan word nie. Dit is as gevolg van gebrek aan onderskeidende eienskappe en omdat motte baie klein en aktief is. Dit was belangrik om wilde gasheerplante en ander moontlike gasheerplante anders dan grondbone te identifiseer wat verantwoordelik mag wees vir die oorlewing van GBM in tye wanneer grondbone nie aanwesig is nie. Dit kon moontlik ook lei tot die identifisering van vanggewasse. Die voorkeur van GBM-motte vir grondbone is vergelyk met twee ander moontlike gasheer plante, sojabone en lusern, sowel as met akkerbone wat 'n nie-gasheerplant is. n Y-buisolfaktometer en 'n geenkeuse-toetseksperiment met motte uit 'n teelkolonie is gebruik om die voorkeur van GBM vir die verskillende plantspesies te bepaal. 'n Hoër persentasie motte het positief reageer ten opsigte van die grondbone in al die moontlike kombinasies met ander gewasse. Die gemiddelde aantal GBM-letsels per plant was hoër op sojabone as grondbone. Elf moontlike wilde gasheerplantspesies met GBM skadesimptome is gevind in grondboonlande en verspreidingskaarte van hierdie spesies is voorsien. Tien spesies natuurlike vyande is geteel uit GBM-larwes en -papies. Om die impak van hierdie natuurlike vyande as biologiese beheeragente op GBM te bepaal, word verdere studies benodig. Parasitismevlakke van GBM-larwes (54.2%) en -papies (43.7%) was hoog en moet in ag geneem word as moontlike biologiese beheeragente. Gedurende die studie is verskeie komponente wat 'n bydrae kan lewer to die onwikkeling van 'n geintegreerde plaagbeheerstrategie vir die beheer van GBM in Suid-Afrika geidentifiseer. Om so 'n geintegreerde stategie te implimenteer en suksesvol te onderhou, moet boere deurlopend toegang hê tot bystand en hulpverlening soos nodig.

Kern woorde: *Aproaerema modicella*, GBM, kleinboere, gasheerplante, GPM, natuurlike vyande.

Table of contents

Chapter 1

1.1 Introduction

Groundnut (*Arachis hypogaea* L.) is a source of food for many small holder farmers and is widely cultivated in semi-arid countries (Wheatley *et al.*, 1989). This crop is grown in tropical and sub-tropical regions, up to 40°N and S of the equator and India is one of the main countries where groundnut is grown (Hill, 1987). According to Annecke & Moran (1982), groundnut probably originated in South America. In South Africa this crop is currently grown in the Northern Cape, northwest Free State, North-West province and on smaller scale in the Limpopo Province and Kwa-Zulu Natal-midlands (Annecke & Moran, 1982).

The oil of groundnut is used for various purposes from cooking to manufacturing of margarine, soap, massage cream, paints and dye and the pods can be used for fuel (charcoal) (Annecke & Moran, 1982). Wheatley *et al.* (1989) reported that groundnut is the major source of edible oil in India and forms an important component of the diet of many subsistence farmers in Africa, South-East Asia and China. Groundnut is known to enrich the soil with nitrogen and is thus valuable in crop rotation systems and for soil improvement (Giller *et al.*, 1987). This crop is often intercropped with a wide range of short-duration crops such as sorghum and millet (Muthiah & Kareem, 2002).

Groundnut production is constrained by a number of factors such as pests, diseases and environmental conditions, especially drought (Wheatley *et al.*, 1989). Damage caused by insects are very important on young groundnut plants while diseases and nematodes are important throughout the production period (Annecke & Moran, 1982). The economically important pests of groundnut in the world are listed in table 1.1 (Hill, 1987). One of the most important insect pests is the groundnut leafminer (GLM), *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) (du Plessis, 2003). GLM can reduce the yield of the crop by feeding on leaves and thereby reducing the leaf area for photosynthesis (Shanower *et al.*, 1993).

1.1.1 Distribution and yield loss

GLM occurs throughout South-East Asia (Wheatley *et al.*, 1989; Muthiah & Kareem, 2002; Shanower *et al.*, 1993; Senguttuvan & Sujatha, 2000; Ranga Rao & Reddy, 1997). GLM is a pest on groundnut (*Arachis hypogaea* L.), soybean (*Glycine max* (L.) Merr.) and pigeon pea (*Cajanus cajan* (L.) Millsp.) (Shanower *et al.*, 1995; Shanower *et al.*, 1993; Senguttuvan, 1999; du Plessis, 2003; Sahayaraj & Paulraj, 1998). The bulk of research on *A. modicella* was done in India where it is an important sporadic pest of groundnut. Even in India, the pest is very sporadic with large population fluctuations between generations and seasons (Kenis & Cugala, 2006; Senguttuvan, 1999; Shanower *et al.*, 1995).

The first report of GLM in Africa was in Uganda during 1998 and later in Malawi in 2000 (Page *et al.*, 2000; Subrahmanyam *et al.*, 2000). During 2000 GLM was also reported in South Africa, first at the Vaalharts Irrigation scheme (27°50; S 24°50E) in the Northern Cape Province. During 2001 it was found causing damage to groundnut crops over the entire groundnut production area in the Free State, Northern Cape, North-West and Mpumalanga provinces (du Plessis, 2003). *A. modicella* was also observed on soybean in Mpumalanga and lucern in the Northern Cape province in 2001 (du Plessis, 2003)

Damaged leaves become brownish, rolled and desiccated. When high infestation levels and large scale defoliation occur on young plants this may affect growth and yield of plants (Fig. 1.1) (Kenis & Cugala, 2006). Pod yield loss caused by GLM infestation of plants was reported to be > 30 % in India (Shanower *et al.*, 1992). Another study in India reported GLM damage to range between 11 and 90.1 % in major groundnut-growing districts of Tamil Nadu (Muthiah & Kareem, 2000). Raja Reddy & Divakar, (2003) reported crop losses to the extent of 49 – 60% in India. In comparison to India, where insecticide applications are recommended when five to 10 larvae per plant are found, an average of 45-56 mines and 29-38 larvae per plant were recorded in Southern Mozambique (Kenis & Cugala, 2006). Prior to this study, no research has been done on

A. modicella in South Africa. In Africa publications on this pest are largely limited to first reports.

1.1.2 Biology

GLM moths are brownish gray with a 10 mm wing span (Fig. 1.2) (Ranga Rao & Reddy, 1997). Subrahmanyam *et al.* (2000) reported adult moths to be grayish and small (7-9 mm long). They lay their eggs on the undersides of leaflets and on stems and petioles. Eggs are small (<1.0 mm) and oval shaped, with longitudinal pits on the surface (Fig. 1.3) (Shanower *et al.*, 1993). Egg production is temperature dependant with significantly fewer eggs produced at 15 °C and 35 °C than at 30 °C (Shanower *et al.*, 1993).

Shanower *et al.* (1993) reported that first instar larvae feed through the epidermis in order to reach the leaf mesophyll in which they create short serpentine mines between the upper and lower epidermis. This damage by larvae leads to defoliation. Shanower (1989), cited by Shanower *et al.* (1993) determined that the consumption of an individual larva was 179.3 mm^2 of leaf area. There are five larval instars (Shanower *et al.*, 1993; Kenis & Cugala, 2006). Final-instar larvae (Fig. 1.4) are approximately 6.0 mm long and very active (Shanower *et al.*, 1993; Subrahmanyam *et al.*, 2000). These final instar larvae emerge from the mine, web two or more leaflets together and pupate between the leaflets (Fig. 1.5) (Shanower *et al.*, 1993).

It is not possible to distinguish between males and female moths with the naked eye or even under a microscope. It is however, possible to distinguish between the sexes during the larval stages when distinctive pink testes of the male are visible through the cuticle (Shanower *et al.*, 1993). However, since larvae are small and difficult to handle during experiments, the need exists to identify characteristics that could also be used to identify males and females during the pupal stages when handling is easier. This would facilitate experiments with known numbers of male and female moths.

Figure 1.1. Browning of leaves resulting from GLM infestation.

Figure 1.2. Groundnut leafminer, *Aproaerema modicella* moth.

Figure 1.3. Egg of *Aproaerema modicella* on a leaf petiole.

Figure 1.4. Larva of *Aproaerema modicella.*

Figure 1.5. Pupa of *Aproaerema modicella.*

The lifecycle of GLM from egg to adult may be completed in 15-28 days in southern India, but takes between 37-45 days in northern India, where mean temperatures range between 14 and 22 °C (Shanower *et al.*, 1993). Eggs generally hatch within three to four days under warm conditions and six to eight days at lower temperatures. Larval development lasts nine to 28 days under field conditions (Shanower *et al.*, 1993) and development to the adult stage requires approximately 325 degree-days above a threshold temperature of 11.3 °C (Shanower *et al.*, 1989 cited in Shanower *et al.*, 1993). The pupal stage lasts between three and 10 days (Kenis & Cugala, 2006; Shanower *et al.*, 1993). Wheatley *et al.* (1989) recorded three to four generations of GLM per groundnut-growing season. The number of generations per crop may vary from two to seven depending on climatical conditions (Kenis & Cugala, 2006). Jagtap *et al.* (1985) cited by Shanower *et al.* (1993) also reported that GLM may survive the extremely hot, dry Indian summer in pupal diapause or aestivation.

1.1.3 Ecology

A series of studies were done concerning environmental influences on GLM survival (Muthiah & Kareem, 2002; Senguttuvan, 1999; Shanower *et al.*, 1993; Shanower *et al.*, 1992; Wheatley *et al.*, 1989). Wheatley *et al.* (1989) indicated that GLM numbers can increase up to 20 % per generation in the absence of natural mortality factors and this can result in high population densities present during the pod-filling stage. The time of infestation can partly determine the impact of GLM on groundnut growth and yield (Shanower *et al.*, 1993). For example, an infestation of five larvae per plant 10 days after emergence has a much greater impact than 20 larvae per plant at 75 days after emergence (Shanower *et al.*, 1993).

In India, GLM numbers were reported to be higher on the most drought stressed plants and where the leaf surface temperatures were highest through genotypic variation (Wheatley *et al.*, 1989). When plants suffer from heat stress, some biochemical changes occur in the plant that results in a more favorable food medium for these insects (Wheatley *et al.*, 1989). The fact that *A. modicella* densities were observed to be highest where leaf surface temperatures exceeded 35 °C can be related to the observation that GLM can survive temperatures that would normally result in the death of other insects (Wheatley *et al.*, 1989). The survival of GLM at high temperatures can be ascribed to the lower temperature inside the larval refuge (the mine or webbed leaflets) together with the tolerance of larvae to temperatures in the 35 – 45 °C range (Wheatley *et al.*, 1989). It has also been reported by Wheatley *et al.* (1989) that heat stress influenced a number of GLM parasitoids, but it was not mentioned which parasitoid species.

A study done by Senguttuvan (1999) showed significant positive correlations of damage and larval populations with temperature. Shanower *et al.* (1992) found that even though GLM abundance may be greater under low-rainfall conditions, rainfall does not directly influence the mortality of GLM eggs and larvae. Rainfall may have an indirect influence on GLM populations, for example, heavy and persistent rainfall may interfere with GLM oviposition or even fungal pathogens and parasitoids (Shanower *et al.*, 1995). Amin

(1987) reported that heavy rainfall reduced leafminer populations (Muthiah & Kareem, 2002). This observation was based on the negative effect that rainfall had on numbers of moths caught in light – and pheromone traps (Muthiah & Kareem, 2002). The latter study concluded that high rainfall may have a more subtle negative influence on GLM population dynamics by increasing the humidity and favoring fungal pathogens (Muthiah & Kareem, 2002).

1.1.4 Integrated pest management (IPM)

Integrated pest management is a system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest population at levels below those causing economic injury (Kogan, 1998). Further more it is important to have ecological information about pests and their crop environments before a pest control program can be conducted (Kogan, 1998).

The strategies that can be combined in an IPM program include cultural-, biological- and chemical control as well as host plant resistance. In Asia, GLM is mainly controlled by insecticide applications, but recent studies suggested more integrated approaches involving other control methods such as intercropping, manipulation of planting dates, utilization of less susceptible crop genotypes, trap crops, botanical pesticides and *Bacillus thuringiensis* Berliner (Kenis & Cugala, 2006).

An example of an integrated approach to management of GLM is that described by Muthiah (2003), using trap crops, a botanical pesticide, biological control agent, (*Bacillus thuringiensis*) and reduced doses of insecticides. Based on GLM pheromone trapping data, Muthiah (2003) achieved successful timing of control with the application of insecticide mixtures consisting of low dosages of phosphamidon (0.02 %) and endosulfan (0.04%) together with neem oil (2%).

Early detection of the pest is often the key to its effective management (Muthiah *et al.*, 2002). However, there are still great problems concerning pests and how to control them. Especially small-scale farmers are in need of control methods other than chemical control, for example pest resistant varieties (Page *et al.*, 2000).

1.1.4.1 Cultural control

This strategy to manage pests was used before the invention of pesticides (Van Emden, 1983). Cultural control of insect pests is affected by the manipulation of the environment in such a way as to render it unfavorable for the pest (Dent, 2000). Many of these methods interfere with the pests' ability to colonize a crop and reproduce or survive (Dent, 2000). Some cultural control techniques include intercropping, crop rotation and manipulation of the planting date.

By using crop rotation, the soil fertility could be maintained and better average yields could be achieved (Dent, 2000). Crop rotation with non-host crops can also result in suppression of pest numbers since host plants will be absent during the season following the main host crop (Dent, 2000). Intercropping includes planting different crops on the same field, either in different rows or as a mixture as is often done by small holder farmers. Logiswaran and Mohanasundaram (1985), cited by Shanower *et al.* (1993) reported lower GLM larval densities when groundnut was intercropped with sorghum, millet or cowpea, than in monoculture groundnut. Intercropping of groundnut with black gram, pigeon pea, green gram and pearl millet was also reported to reduce GLM infestation levels in a study done at the Oilseeds Research Station in Tindivanam, India (Muthiah, 2000).

In the study done by Muthiah (2003) trap crops were used as part of an integrated approach to manage GLM. These trap crops, included soybean (*Glycine max* (L.) Merr.), pearl millet (*Pennisetum glaucum* (L.) R.Br.) and castor (*Ricinus communis* L.). One row of soybean was grown after every four rows of groundnut. Three rows of pearl millet were grown around the groundnut plots (Muthiah, 2003). In the end, the pod yield at harvest and the income for the groundnut and the trap crops were recorded. The lower incidence of pests in intercropping systems was ascribed to crop diversity, physical barriers, shade, production of adverse chemical stimuli and presence of natural enemies as a result of intercropping (Muthiah, 2003). Results showed that intercropping resulted in increased parasitism and could be used together with other components of pest control to reduce leafminer damage (Muthiah, 2003).

The use of trap crops has gained popularity over the past decade (Hokkanen, 1991). Hokkanen (1991) reported an example in soybeans where 70-85 % of the stink bug population can be attracted to a trap crop that covers only 1-10 % of the total crop area. For these reasons it is important to determine the suitability of other cultivated and wild host plants for survival of GLM in South Africa. *A. modicella* is polyphagous and many host plant species have been documented in India (Table 1.2).

1.1.4.2 Biological control

Biological control is the action of living organisms as pest control agents. For insects, these control agents or natural enemies include predators, parasitoids, parasites and pathogens (Thomas & Waage, 1996). These natural enemies could cause a reduction in pest numbers to such an extent that it will remain below the economic injury level. The term parasitoids are used to describe a group of insects that develop as larvae on the tissues of other arthropods, which they ultimately kill. Most of the known parasitoids derive from families of Diptera and Hymenoptera (Waage & Hassell, 1982). Different types of parasitoids are known according to the parasitoid's host preference. Primary parasitoids attack non-parasitoid hosts while hyper-parasitoids attack other parasitoids, including secondary and tertiary parasitoids. Solitary parasitoids develop singly in or on a host while gregarious parasitoids develop in groups from eggs laid during one or more ovipositions. Idiophytic parasitoids parasitise non-growing stages of the host, for instance the eggs or pupae, while koinophytic parasitoids manipulate host growth by developing as larvae within a growing host.

According to Begon *et al.* (1996), there are four types of biological control: introduction, inoculation, augmentation and inundation. The four types can vary as follows; 1) the introduction of a natural enemy from another geographical area so that the control agent should persist and maintain the pest population in the long term below its economic threshold; 2) inoculation requires the periodic release of control agents where it is unable to persist throughout the year, with the aim of providing control for only one or perhaps a few generations; 3) augmentation is the release of an indigenous natural enemy in order to supplement an existing population, and is also therefore carried out repeatedly; and 4) inundation is the release of large numbers of a natural enemy, to kill those pests present at the time, but with no expectation of long term goals.

Parasitoids differ from parasites in that they kill their host as soon as their development is at such a stage that they do not need it anymore, where usually parasites are depended on a host for its entire life. They differ from predators because each parasitoid only needs one prey in order to complete development. Biological control occurs naturally, but some major factors limit the effectiveness of this control method. Some of the factors that influence biological control include chemical control that eliminates the natural enemies and environmental conditions that are unsuitable for natural enemies (Thomas & Waage, 1996). Amongst the various control options, natural control agents play a significant role in the population suppression of GLM (Rang Rao & Reddy, 1997).

Natural enemies are very important in IPM systems and biological control is realized as one of the most important strategies in pest management. Although some predators that attack GLM have been identified in India their impact on GLM numbers has not yet been quantified (Shanower *et al.*, 1993).

Three primary parasitoids, *Temelucha* sp., *Avga choapes* Nixon and *Sympiesis dolichogaster* Ashmead, and four secondary parasitoids, *Pteromalus* sp., *Oomyzus* sp., *Elasmus anticles* Walker and *Aphanogmus fijiensis* (Ferriere) were reared for the first time from GLM larvae at ICRISAT (Shanower *et al.*, 1992). Mohammad (1981), cited by Shanower *et al.* (1992) stated that the food web which includes GLM and its primary and secondary parasitoids is much more complex than previously thought. One braconid species previously thought to be a single species, were determined to be three species in different genera: *Apanteles* sp., *Avga choapes* and *Bracon* sp. (Shanower *et al.*, 1992). These three species are larval ectoparasitoids that paralyze the host before oviposition (Shanower *et al.*, 1992).

Muthiah and Kareem (2000) reported that GLM larvae were parasitized by 11 species of hymenopterous parasitoids in Tamil al Nadu, India (Table 1.3) and when larval numbers of the leafminer increased, the percentage parasitism also increased (Muthiah & Kareem, 2000). One nematode species and two disease agents (viruses and fungi) are also known to infect GLM larvae in India (Shanower *et al.*, 1993). The symptoms caused by fungal infections include black "mushy-bodied" GLM larvae (characteristic of virus infection) and fungal hyphae growing out of the bodies (Shanower *et al.*, 1992).

Amongst the various control options, natural control agents such as fungi also play a significant role in population suppression of *A. modicella* (Ranga Rao & Reddy, 1997). Ranga Rao & Reddy (1997) found that the fungus *Metarhizium anisopliae* (Metsch.) recorded from GLM larvae cause up to 30% larval mortality. Considering its effectiveness over a short period, and its easy multiplication under artificial conditions, this fungus can be used as an effective natural control component in future groundnut IPM programs (Ranga Rao & Reddy, 1997).

There is a need to identify parasitoids of GLM in South Africa as well as the levels of parasitism. This will provide information for use in IPM programs and will also indicate whether the parasitoids that occur in South Africa are indigenous or whether the parasitoid complex accompanied the pests into Africa, from its area of origin.

Classical biological control is the importation of natural enemies for introduced pests that, after invading a new area, have escaped from the regulating action of their natural enemies in their native environments (Ruberson, 1999). It is also known as "importation" and the success of it depends on careful planning and a sequence of procedures (Ruberson, 1999).

1.1.4.3 Chemical control

The use of pesticides may be necessary, but it is most effectively used when integrated with other control methods in an IPM system. Some of the disadvantages and problems associated with the use of chemical control include the development of resistance, secondary pests that emerge and possible resurgence of the primary pest (Shanower *et al.*, 1993). These chemicals are also hazardous to the environment and to human health. Also, the effectiveness of parasitoids of GLM is constrained by the use of insecticides, which result in lower parasitization rates (Shanower *et al.*, 1992). Ranga Rao & Shanower (1988), cited by Shanower *et al.* (1993), reported that pesticide applications for the control of GLM in groundnut production areas in Andhra Pradesh, India, appeared to disturb the natural control of *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae) and *Spodoptera litura* L. (Lepidoptera: Noctuidae).

The correct dosage and method of insecticide application is important when chemicals are applied. A wide variety of chemical insecticides, in all major classes except microbials, have been evaluated against GLM (Shanower *et al.*, 1993). These chemicals were applied to foliage either as a liquid spray or dust, whereas systemic insecticides have been tested as seed dressings or incorporated as granules into soil. Some of the chemicals used for GLM control in India include carbaryl, dieldrin, endrin and parathion as well as some organophosphates and carbamates (Shanower *et al.*, 1993). Some of the chemicals recommended in India include: carbaryl 50 WP 0.1 % and 0.2% monocroptophos 36 EC 0.5%, phosphamidon 85 EC 0.05%, endosulfan 35 EC 0.05% and dimethoate 30 EC, all applied in a volume of 500-700 l water ha^{-1}. No insecticides are registered for GLM control in South Africa (Nel *et al.*, 2002).

According to the study done by Sahayaraj & Paulraj, (1998) it was observed that in regions of south and southeast Asia the use of chemical pesticides for the control of

GLM, created several complications. They concluded that their method of control was safer than conventional insecticides and therefore fitted well into the pest management system for groundnut (Sahayaraj & Paulraj, 1998). Their research on the use of plant products as alternative proved to be ecologically sound and effective. The study focused on three plant products and their relative toxicity to the final instar larvae of *A. modicella.* The three plant products were neem *Azadirachta indica*, *Pongamia glabra* and *Caloptropis giganta.* Extracts from these plant leaves were prepared and used as a stock solution. Different concentrations (0.5, 1, 2, 4 and 6%) were prepared from the stock by adding distilled water (Sahayaraj & Paulraj, 1998). Groundnut leaves were dipped in the different concentrations of the various plant extracts for 15 minutes and distilled water was used as a control. Results showed that all three plant products were toxic to GLM larvae. Some of the symptoms suffered by GLM larvae included blackening of the body, breaking cuticle and oozing out of body fluid. Small-sized pupae and death during moulting were other direct effects observed (Sahayaraj & Paulraj, 1998).

For small holder farmers to use insecticides as the only control method is unpractical and too expensive. A study on GLM in Uganda by Page *et al.* (2000) showed that many subsistence farmers were unable to afford chemicals. The emergence of GLM as a pest may therefore become an important factor in the sustainability of groundnut production for farmers in that country. These farmers usually have to walk long distances to reach their fields and it is not possible to carry large volumes of water and chemicals for such distances. Storing chemicals is also a problem for small holder farmers and alternative control strategies need to be developed. Needs assessments should also be done in farming communities where GLM occurs to determine farmer's perceptions of the importance of groundnut pests and to determine current control strategies and farming practices that may affect development and adoption of pest management strategies.

1.2 Objectives of this study

Most of the literature on *A. modicella* reports on pest control strategies in Asia. Apart from chemical control options, which are not relevant to small holder farmers in Africa, no sustainable control strategy for this pest has been developed yet. The aims of this study were to determine small holder farmer perceptions of GLM, identify factors that play a role in sustaining GLM populations and to identify natural enemies of this pest in South Africa. This study focused largely on farmers and farming systems at the Tshiombo irrigation scheme in Venda in the Limpopo Province.

The specific objectives of this study were:

- To do a survey of small holder farming practices and to determine farmers' perceptions of crop pests.
- To evaluate the preference of GLM moths for groundnut and other host plants.
- To identify characteristics that would enable distinction between male and female larvae and pupae.
- To collect natural enemies of GLM and determine parasitism levels.
- To determine infestation levels of GLM.
- To identify wild host plants of GLM.
- To evaluate the suitability of other host plants for survival of GLM larvae.

These objectives are reported on in the following chapters:

- A survey of farming practices and farmer's perceptions of crop pests at the Tshiombo irrigation scheme (Chapter 2)
- Host plant preference of groundnut leafminer moths (*Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae). (Chapter 3)
- Using larval and pupal characteristics to distinguish between male and female larvae and pupae of the groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae). (Chapter 4)
- Infestation levels and parasitism of the groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) on groundnut. (Chapter 5)
- Host plant diversity and suitability of cultivated host plants for the development of the groundnut leafminer (*Aproaerema modicella*) (Lepidoptera: Gelechiidae). (Chapter 6)

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Table 1.1. A world list of groundnut (*Arachis hypogaea*) pests (Hill, 1987).

Pest	**Common name**	**Distribution**	**Damage done**
Achaea finita Gn.	Semi-looper	Africa	Larvae defoliate plants
Agrotis ipsilon (Hfn.)	Black cutworm	Cosmopolitan	Seedlings are severed
Alcidodes dentipes (Ol.)	Striped sweet potato weevil	Africa	Adult girdles stem; larvae gall stem
Amsacta moorei (Wlk.)	Tiger moth	India, Australia	Larvae defoliate plants
Anomala spp.	White grubs	South-east Asia	Larvae eat roots
Anoplocnemis phasiana (F.)	Coreid bug	Indo-China	Sap-suckers; toxic saliva
Aphis craccivora (Koch)	Groundnut aphid	Pan-tropical	Virus vector
Aproaerema modicella (Dev.)	Groundnut leafminer	India, Asia, Africa	Leaves are mined
Archips micaceana (Wlk.)	Tortrix	Indo-China	Larvae roll leaves
Bagrada spp.	Harlequin bugs	Africa, Asia	Sap-suckers; toxic saliva
Caryedon serratus (Oliv.)	Groundnut bruchid	West Africa	Infest pods in field & storage
Caliothrips indicus (Bagn.)	Thrips	Africa, India	Scarify foliage, virus vector
Cicadulina spp.	Maize leafhoppers	South America, Africa	Sap-suckers
Diabrotica undecimpunctata Mann.	Spotted cucumber beetle	USA	Defoliate plants
Diabrotica spp.	Leaf beetles	USA, South America	Defoliate plants
Diacrisia obliqua Wlk.	Tiger moth	India	Larvae defoliate plants
Dorylus orientalis Westw.	Oriental army ant	Indo-China	Damage to leaves
Dysmicoccus brevipes (Ckll)	Pineapple mealy bug	Pantropical	Virus vector
Elasmopalpus lignosellus (Zell.)	Lesser cornstalk borer	USA, South America	Larvae bore stems
Empoasca spp.	Green leafhoppers	Africa, India, USA, South America	Sap-suckers, virus vector
Epicauta albovittata (Gestro)	Striped blister beetle	East Africa, Somalia	Adults eat flowers
Epicauta sp.	Striped blister beetle	Asia, USA	Adults eat flowers
Etiella zinckenella (Triet.)	Pea pod borer	Malaysia	Larvae bore pods
Euborellia stali Dohrn.	Earwig	South India	Damage pods
Eulepida mashona Arr.	Whitegrub	Africa	Larvae eat roots
Ferrisia virgata (Ckll.)	Striped mealy bug	Africa, India	Scarify foliage, virus vector
Frankliniella fusca Hinds.	Tobacco thrips	USA	Scarify foliage, virus vector
Frankliniella schultzei (Trydom)	Cotton flower thrips	East Africa, Sudan	Scarify foliage, virus vector
Gonocephalum spp.	Dusty brown beetles	Africa	Adults damage plant

Graphohnathus spp.	White-fringed weevils	South Africa, Australia, NZ, USA, South America	Adults eat leaves; larvae eat roots
Helicoverpa armigera (Hub.)	African bollworm	Old World tropics	Larvae damage pods and foliage
Hilda patruelis Stal	Groundnut hopper	Africa	Subterranean sap-suckers
Hodotermes mossambicus (Hag.)	Harvester termite	South & East Africa	Defoliate plants
Homona coffearia (Nietn.)	Tea tortrix	Pupua New Guinea	Larvae roll leaves
Lampides boeticus (L.)	Pea blue	Indo-China	Larvae bore pods
Latoia lepida (Cram.)	Blue-striped nettle grub	India, South-east Asia	Larvae defoliate plants
Leptoglossus australis (F.)	Leaf-footed plant bug	Africa, Asia, Australia	Sap-sucker; toxic saliva
Leucopholis spp.	White grubs	Philippines	Larvae eat roots
Locusta migratoria spp.	Migratory locusts	Africa, Asia	Defoliate plants
Mylabris spp.	Banded blister beetles	Pantropical	Adults eat flowers
Maruca testulalis (Geyer)	Mung both	Cosmopolitan	Larvae bore pods
Nezara viridula (L.)	Green stink bug	Cosmopolitan	Sap-sucker; toxic saliva
Odontotermes spp.	Termites	Africa, India	Damage roots & foliage
Ootheca mutabilis (Salhb.)	Brown leaf beetle	East Africa, Nigeria	Defoliate plants
Parasa vivida (Wlk.)	Stinging caterpillar	East & West Africa	Larvae defoliate plants
Pseudococcus spp.	Mealy bugs	Africa, Australia Central & South America	Scarify foliage, virus vector
Rhopaea magmicornis Blkb.	Pasture white grub	Australia	Larvae eat roots
Schizonycha spp.	Chafer grubs	Africa	Larvae eat roots
Spodoptera exigua Hub.	Lesser armyworm	Europe, Africa, India, Japan, USA	Larvae defoliate plants
Spodoptera frugiperda (J.E. Smith)	Black armyworm	USA, Central & South America	Larvae are cutworms
Spodoptera littoralis (Boisd.)	Cotton leafworm	Africa	Larvae defoliate plants
Spodoptera litura (F.)	Rice armyworm	India, South-east Asia	Larvae defoliate plants
Stegasta basqueella (Chambers)	Red-necked peanutworm	USA, Brazil	Larvae bore buds
Stegasta variana (Meyr.)	Peanutworm	Malaysia	Larvae bore buds
Strigoderma arboricola F.	White grub	Southern USA	Larvae eat roots
Systates spp.	Systates weevils	Africa	Adults eat leaves
Taeniothrips sjostedti (Trydom)	Bean flower thrips	Africa	Scarify foliage, virus vector
Tetranychus spp.	Red spider mites	Cosmopolitan	Scarify foliage
Zygrita diva Thoms.	Lucern crown borer	Australia	Larvae bore stems

Table 1.2. Host plants of *Aproaerema modicella* in India (from a review by Shanower *et al.* (1993)).

Scientific name	**Common name**
Arachis hypogaea L.	Groundnut
Boreria hispida K. Sch.	-
Cajanus cajan (L.) Millsp.	Pigeonpea
Glycine max (L.) Merr.	Soybean
Glycine soja Sieb. & Zucc.	Wild soybean
Indigofera hirsuta L.	Roughhairy indigo
Lablab purpureus L.	Hyacinthbean
Medicago sativa L.	Alfalfa, Lucerne
Psoralea corylifolia L.	Bu Gu Zhi
Rhynchosia minima Dc.	Least snoutbean
Teramnus labiolis (L.) Spreng	Blue wiss, rabbit vine, kattuzhunninveru
Trifolium alaxandrium L.	Berseem/Egyptian Clover
Vigna radiata (L.) Wilzcek (= *Phaseolus aureaus*)	Mung bean
Vigna umbellata (Thunb.) Ohwi and Ohashi	Japanese rice bean, climbing mountain bean, mambi bean, oriental bean, red bean, rice bean

Table 1.3. Natural enemies of *Aproaerema modicella* and their relative importance in groundnut-growing regions of Tamil Nadu, India (Muthiah & Kareem, 2000).

Family	**Parasitoid species**	**Parasitism (%)**
Braconidae	*Chelonus* sp.	26.0
	Avga chaospes Nixon	1.3
	Apanteles sp.	1.3
Eulophidae	*Stenomesius japonicus* Ashmead	4.0
	Tetrastichus sp.	2.7
Ichneumonidae	*Temelucha* sp.	3.7
Eurytomidae	*Eurytoma* sp.	5.3
Pteromalidae	*Pteromalus* sp.	4.3
Eupelmidae	*Eupelmus* sp.	1.3
Bethylidae	*Goniozus indicus* Ashmead	16.7
Chalcididae	*Brachymeria wittei* Schmitz	20.0
Trichogrammatidae	*Trichogramma* sp.	10.3

Chapter 2

A survey of farming practices and farmer's perceptions of crop pests at the Tshiombo irrigation scheme

2.1 Introduction

The Tshiombo irrigation scheme in Venda (Limpopo Province) is home to small scale farmers that largely depend on this land for income and survival. This area is situated in the north-eastern corner of the Limpopo Province of South Africa, between latitudes 22.15 and 25.24 south and longitudes 29.50 and 20.31 east. The single most important crop, in terms of area planted, is maize, the staple food in the area, which accounts for 40-50% of total cultivated area (Lahiff, 1997). Other important crops grown in this area include groundnut, spinach, *muxe* (a local variety of marogo), tomatoes, sweet potatoes and cabbage (Lahiff, 1997).

The groundnut leafminer (GLM), *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) has only recently been reported in South Africa (Du Plessis, 2003). In some areas such as at the Tshiombo irrigation scheme, extension personnel reported it to cause economically important losses in quality and yield of groundnut (Personal communication). Several important pests of groundnut have been reported in Africa. Anneke and Moran (1982) reported bollworms (*Helicoverpa armigera* (Hübner) (Noctuidae)), ground weevils (*Protostrophus* spp., aphids (*Aphis craccivora* Koch (Aphididae)) and the red tea bug (*Hilda patruelis* (Stål) (Tettigometridae)) as groundnut pests in South Africa.

In order to develop a sound management program for GLM, one needs to take cogniscence of farmer's knowledge of this insect as well as general socio-economic factors and farming practices. Farmers play a key role in any research regarding pests and their control in the world of small scale farming (Dicko, 1998). Management programs cannot be implemented and farmers cannot be advised effectively to manage crop production constraints without their involvement. It is per sé the farmers that need to implement the management program, making it part of their daily practices.

The objective of this chapter was to conduct surveys to collect information on socio-economic aspects, general farming practices and farmer's perceptions of the groundnut leafminer at the Tshiombo irrigation scheme in Venda.

2.2 Material and methods

Two surveys were conducted amongst farmers in several villages at the Tshiombo irrigation scheme situated at the western end of the Tshiombo valley, on the upper reaches of the Mutale River (Lahiff, 1997). The total area of about 1200 hectares consists of 930 plots, each approximately 1.2 hectares in size. The plot-holders reside in six villages situated alongside the scheme (Lahiff, 1997). The first survey was done during 2003 and the second during 2005. The first survey was conducted by a Venda-speaking employee of North-West University assisted by an extension officer known to farmers in the village. Only a particular part of the first survey will be used in this study. The second survey was conducted by this masters student, assisted by a Venda-speaking employee of the North-West University.

General information of farmers at the Tshiombo irrigation scheme was obtained from the 2003 survey done in four villages in order to understand the background of these farmers. To understand the needs of these farmers, it is important to know more about their every day living and their physical and home environment.

In the second survey conducted during 2005 data were gathered on groundnut farming practices and farmer's perceptions of pests, especially of the groundnut leafminer. The questionnaire is provided in Appendix A. Nine groundnut farmers all from the Mbahela village were consulted during this survey. This village is situated in the area of the irrigation scheme where most groundnut is cultivated. The questionnaire started with basic questions on groundnut farming and the importance of groundnut as a crop in their farming systems. These questions also considered the problems that farmers face in growing groundnut and their solutions to it. The questions addressed leaf pests of groundnut and photographs showing damage done by the groundnut leafminer were shown to the farmers. This questionnaire aimed to discuss farmers' awareness of this pest and their knowledge on what to do about this pest. The farmers that did not respond to a particular question were excluded from the calculation of percentage values for that question. When a farmer selected more than one answer or gave more than one method to a question, percentages were calculated for each group of similar answers.

2.3 Results and discussion

2.3.1 2003 Survey

2.3.1.1 Household information

The majority of the farmers responsible for daily farming activities were female (Table 2.1), even though the majority of households were male headed. Only a small percentage of farmers working the land were male. In only a few of the households the husband and wife work the land together. Apart from the 51% of farmers depending on pension for their main income, 28% depended only on their farming activities and 13% on a combination of farming and pension as income. A small group of farmers were also employed outside of agriculture. Most of the farmers at Tshiombo (67%) were aged between 40 and 60 years while 29% were older than 60 years. Only 4% were younger than 40 years of age.

The distances these farmers travel each day from their home to their fields ranged between 500 m to 3 km. This could have an effect on the IPM system farmers would be able to use in order to control GLM infestations, since it is important that they do not have easy methods of moving heavy objects from and to their fields.

Table 2.1. Data regarding the household information of farmers that participated in the survey at Tshiombo (2003 survey).

Number of participants		**79**
Male: Female		**53:26**
Gender involvement in farming activities		**%**
	Female	53.0
	Male	25.0
	Male & female	22.0
Age of farmers		
	<30	1.0
	31-40	3.0
	41-50	36.0
	51-60	31.0
	>60	29.0
Main source of income for households		
	Pension	51.0
	Farming	28.0
	Farming and pension	13.0
	Farming and employment	4.0
	Non-agricultural employment	4.0
Distance between homesteads and farmers'		
	>500m	4.0
	500m-1km	64.0
	1-2km	27.0
	2-3km	5.0

2.3.2 2005 Survey

The majority of farmers used tractors or draught power (donkeys) to cultivate groundnut fields. One farmer indicated that he used oxen to plough his fields. The reason for the higher incidence of draught power use indicated by groundnut farmers compared to farmers that would usually rather use tractors, is most likely due to the sandy soils and the fact that groundnut is not planted on ridges as other crops but on a flat seed-bed. Animal draught power and animal drawn ploughs were used since ridges, which are easily formed by high-powered tractor-mounted ploughs, were not needed in this case.

The majority of farmers buy seed from the co-operative stores but also plant seed saved from the previous harvest. The cultivars planted by the farmers include a white seeded and a red seeded variety. The red seeded variety is better known as Kangwane Red. The majority of farmers prefer to plant both cultivars.

Table 2.2. Groundnut farming practices at the Mbahela village at the Tshiombo irrigation scheme during 2005.

Number of participants		**9**
Male: Female		**3:6**
Cultivation techniques	**% farmers**	
	Tractor	44.4
	Donkey	44.4
	Ox-plough	11.2
Source of seed		
	Keep from last harvest	55.5
	Buy new and keep from harvest	44.5
	Buy only new seed	0
Groundnut cultivars planted		
	White	22.2
	Kangoane Red	11.1
	White and Kangoane red	44.5
	Unknown	22.2
Market for selling groundnut		
	Thohoyandou (nearest big town)	66.7
	Surrounding villages	22.2
	Both	11.1
Other uses for groundnut		
	Household consumption	44.5
	Selling as cash crop	44.4
	Making peanut butter	11.1
Uses of groundnut residues after harvest		
	Leave on field	30.0
	Feed to animals	70.0
Farmers perceptions of severity of GLM damage		
	High	44.5
	Average	11.1
	Low	44.4
Farmers evaluation of pod size of their crop		
	Very large	11.1
	Large	11.1
	Average	55.6
	Very small	22.2

Maize is the dominating crop in the Mbahela village and all farmers' plant maize. Other crops include vegetables and other non–tuber crops such as tomatoes and cabbage. After harvesting groundnut, most farmers plant maize, beans or other vegetables on the same field. Farmers are of opinion that no onions or potatoes should be planted after groundnut.

Planting dates range between July and October, but most farmers plant during July and August. Harvesting takes place from December to January. The time it takes the farmer to harvest a plot of groundnut (120 m x 10 m) and shell the groundnuts varies from a week to a month, depending on the assistance the farmer has in terms of extra labour or family members. Some of the farmers even let the customers do the harvesting themselves.

All farmers indicated that they sold a portion of the groundnut they produced. Groundnut is sold for between R250 and R300 per 80 kg bag. The estimated number of bags per plot that each farmer harvested ranged between three and nine (80 kg) bags. Three bags were indicated to be the average number of bags harvested per plot. The average yield per plot was therefore calculated to be between 2.0 – 6.0 t/ha. The majority of farmers sell their groundnut in Thohoyandou, the nearest town, while others prefer to sell it to the people living in surrounding villages.

Other uses for groundnut include using it as food, saving it as seed for the next season or even producing peanut butter. Groundnut crop residues can be of economic value. The majority of farmers realize the value of feeding groundnut residues to their animals but a small group of farmers (30%) leave it on the field after harvest.

Management of groundnut residue could be an important factor in the management of GLM in future. Dry groundnut leaves and plants left on fields after harvest is a source of moths that infest younger plantings not yet harvested. During the off-season, GLM is able to survive on wild host plants (Chapter 6) and as diapause pupae (Shanower *et al.*, 1993). Since the pupae are enclosed in or between leaves, it can easily survive to the next season.

2.3.2.1 Groundnut production constraints

Some production constraints indicated by farmers included seedlings that die, plants that become "sticky" and plants that remain small. It was subsequently determined that the "stickiness" referred to leaves that was spun together by GLM larvae. Some farmers explained that they tried to avoid planting late if it is possible because if they planted late, they observed moths in groundnut fields. According to the farmers some other factors like sun scorching, water shortage, diseases, ants and fertilizer shortage also reduces yields.

2.3.2.2 Insect pests and damage

The most important pests on groundnut according to the farmers were ants, "mosquito like" insects and moths (Table 2.9). The damage done by these pests, according to the farmers, include the yellowing of leaves, pods that are eaten, sticky leaves caused by little "worms" and the leaves that dry pre-maturely (also a symptom of GLM damage).

Table 2.3. Percentage farmers indicating different insect pests as problems on groundnut and the damage symptoms of insect infestation.

Insect pest	Farmers (%)	Damage symptoms
Ants	55.5	Yellowing of leaves, damage to pods
"Mosquito" *	11.1	Damage to leaves
Moths	33.3	Sticky leaves, leaves become dry

* Later determined to be GLM, after visiting fields with some of the farmers

2.3.2.3 Groundnut leafminer

All the farmers indicated that they commonly observe insects that damage groundnut leaves. The symptoms they described included browning of leaves, especially when planting is done late and leaves that stick together. They also observed moths flying around and most farmers ascribed damage to leaves together with pods that are empty to GLM.

Most of the farmers agreed that the symptoms associated with GLM started appearing at the irrigation scheme after the severe storms and floods that ravaged the Limpopo Province and Mozambique during 2000. This was also the time when GLM were first noticed in South Africa. Du Plessis (2003) reported that GLM infestations occurred in Malawi, Mozambique and South Africa during 2000, two years after it was reported in Uganda (Page *et al.*, 2000). This confirms the observations of the farmers on the time of appearance of GLM. It could therefore be that the rapid spread of GLM in southern Africa could have resulted form the raging whether systems at that time. Based on farmers' perceptions of the severity of GLM damage to their crops and the small pod size observed during harvest, it can be concluded that farmers are of the opinion that GLM is a serious pest.

2.3.2.4 Pest control

All the farmers indicated that chemical control would be the solution to their pest problems but few of the farmers used chemicals. The chemicals they use include mercaptothion, cypermethrin, monocrotophos and endosulfan. They also used these chemicals on vegetable crops that are planted either next to groundnut or the crop that preceded or followed groundnut.

After showing the farmers photos of damage caused by GLM they were asked what the solution to this pest problem would be. Crop rotation and irrigation were some of the methods that farmers indicated as limiting to GLM damage. Chemical control was still the dominating answer, even though they find it very expensive.

2.4 Conclusions

It can be concluded that farmers are aware of pests on all their crops but that they do not actively employ any pest management strategies, except for the use of insecticides in some instances. Farmers at this irrigation scheme adopted new technologies such as the use of hybrids, purchasing of seed and mechanical cultivation. All groundnut farmers were aware of GLM as a "new" invasive pest and were of the opinion that infestation resulted in economic losses.

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Appendix A

GROUNDNUT SURVEY ON LEAF MINERS 2005

ANCHEN VAN DER WALT

Village: ______________________ Name of Enumerator: ______________________

Date: ________________

Land characteristics

1. What is your total land size in ha? __________________________

2. How do you cultivate your land during land preparation?

   Tractor / draught power / hand howing / other ________________________

3. What crops do you plant on the same field before groundnut?

Crops grown	**Acreage (ha?) or (e.g. 20 x 30m)**	**Average yield season (kg? Or bags of grain)**	**How much used at home**	**How much sold**	**At what price**

4. What crops do you plant on the same field after groundnut?

Crops grown	Acreage (ha?) or (e.g. 20 x 30m)	Average yield season (kg? Or bags of grain)	How much used at home	How much sold	At what price

5. What months of the year do you plant groundnut? (There can be several planting dates per farmer, e.g. plant in March – harvest in October)___________

____

5.1 What month do you harvest ___________________________

5.2 Where do you get groundnut seed from? **Buy / Keep from previous harvest**

6. What is the cultivar name? ___________________________

7. What do you do with the groundnut harvest?

7.1 Sell: **Yes / No**

If yes, where do you sell it? ___________________________.

At what price do you sell it? (per bag) ________________. How big is the bag? (Kg) ________________.

7.2 Eat: **Yes / No**

If yes, how much is consumed by the household? (Bag / kg)______________

7.3 Other:___________________________________

8. How many bags of shelled groundnut (clean seeds) do you estimate you harvest from your fields per year? (How big is the field planted to groundnut?) ___________

____

9. How long does it take you to harvest the area with the groundnut on?

____

9.1 How big is the area? ___________________________

10. How long does it take to shell that harvest? ______________________________

____

11. What do you do with groundnut plant residues after harvest and shelling?

11.1 Leave on field: ______________________________

11.2 Feed to animals: ______________________________

11.3 Other: ____

12. What problems do you face in growing groundnut? How do you deal with the problems?

Problem	**Solution**

13. Which pests attack your groundnut crop?

Name of Pest	**The kind of damage caused by the pest**

14. How do you deal with the pests

Name of pest	**How farmer deals with pest**

15. Have you had problems with leaf pests on your groundnut crops? (Show pictures)

Yes / No / I do not know

15.1 If yes, what are the symptoms? ____

____

____

16. Since when have you observed these symptoms? (e.g. 1999, 2002)

____

17. How do you rate the infestation of leaf miners in your groundnut field?

a) Very high____ b) high____ c) low____ d) Very low____

18. How do you rate the quality of the groundnut pods of your crop?

a) Very big____ b) big____ c) small____ d) very small___

19. What do you do about the leaf miner problem? __________________________

____

____

____

____

20. Any other comments____

____

____

____

____

Thank you.

Chapter 3

Host plant preference of groundnut leafminer moths (*Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae).

3.1 Introduction

Host plant preference of pests can be exploited to manipulate pests in order to limit damage to crops. Insects use chemical information from their environment at all stages of development, to locate food, oviposition and hibernation sites, to come together with conspecifics and sexual partners, and to avoid dangerous situations or unsuitable habitats and hosts (Agelopoulos *et al.*, 1999). Norris and Kogan (2000) reported that most interactions between plants and arthropods are mediated through chemicals produced by the plant. Schoonhoven *et al.* (1998) cited by Norris and Kogan (2000) reported that most oligophagous arthropods would concentrate on the few species that they accept as hosts because they find the majority of sympatric plants either lacking necessary feeding excitants or possessing the right feeding deterrents. This preference that pests have for a certain plant species are the key to cultural control methods for example the use of trap crops.

Trap crops are plant stands that are grown to attract insects away from the main crop in order to protect target crops from pest attack (Hokkanen, 1991). Protection may be achieved either by preventing the pests form reaching the crop or by concentrating them in a certain part of the field where they can economically be destroyed (Hokkanen, 1991). It is important that the trap crop is more attractive to the pest than the main crop, at least at some critical time, but preferably over long periods (Hokkanen, 1991). If the trap crop is highly attractive for the pest and also result in very low or no survival of the pest offspring, it may be termed a "dead-end" trap crop (Shelton & Badenes-Perez, 2006). Another advantage of trap crops apart from the potential it has to improve the environmental soundness and overall performance of conventional agriculture, is that it may have special importance to subsistence farming systems in developing countries (Hokkanen, 1991).

The study of semiochemicals, and the interactions they mediate, is part of chemical ecology and contributes to an understanding of the behavior, development and evolution of organisms (Agelopoulos *et al.*, 1999). However, from a practical point of view, such research also provides the basis for successful use of semiochemicals for pest control as an alternative to exclusive use of broad-spectrum toxicants (Agelopoulos *et al.*, 1999). Semiochemicals that have the ability to attract or repel insects, or that enhance (synergise) or inhibit the action of other chemicals, have the potential to be used in direct control of pests by mass trapping or mating disruption, or in deterring pests from food and oviposition sites (Agelopoulos *et al.*, 1999). Secmiochemicals, being involved in multitrophic interactions, can also be used to influence the behavior of pests and natural enemies of pests (Agelopoulos *et al.*, 1999). Some or all of these activities can be utilized as components of integrated pest control strategies (Agelopoulos *et al.*, 1999).

Since the groundnut leafminer (*Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae)), which is a new invasive pest in South Africa, has also been recorded on other host plants in the country, the need exists to identify its preference for these plants in order to identify possible trap plant species and to gather basic information that may play a role in its pest status. Du Plessis (2002) reported that GLM was also recorded on soybean (*Glycine max* (L.) Merr.) in the Mpumalanga province and on lucern (*Medicago sativa* L.) in the Northern Cape province during 2001. If these plants are highly attractive to GLM moths, they could have potential to be used as trap crops.

The aim of this chapter was to evaluate the preference of GLM moths for its main host plant (groundnut) in comparison with other cultivated species that could possibly be used as trap crops in an IPM program.

3.2 Material and Methods

A laboratory experiment was conducted to evaluate moth preference for cultivated host plants of GLM. This study included three host plants, i.e., groundnut (*Arachis hypogaea* L.), soybean (*Glycine max* (L.) Merr.) and lucern (*Medicago sativa* L.) and one non-host plant, cowpea (*Vigna unguiculata* (L.) Walp.). Plants were grown in pots and these potted plants were used in laboratory bioassays. Each plant species was evaluated in four combinations i.e. groundnut compared with soybean, lucern, cowpea and a control treatment. The control treatment consisted of a similar sized plant pot containing the same type of potting soil as other treatments (Table 3.1).

Table 3.1. Treatment combinations used in the Y-tube olfactometer experiment.

Treatments	Plant 1	Plant 2
Combination 1	Groundnut	Control
Combination 2	Groundnut	Soybean
Combination 3	Groundnut	Cowpea
Combination 4	Groundnut	Lucern
Combination 5	Soybean	Cowpea
Combination 6	Soybean	Lucern
Combination7	Soybean	Control
Combination 8	Cowpea	Lucern
Combination 9	Cowpea	Control
Combination 10	Lucern	Control

A Y-tube olfactometer was used to evaluate moth preference for the different plant species. The experiment was set up as illustrated in figures 3.1 and 3.2. Each pot was covered in a bell-jar with an outlet feeding into each of the treatment arms of the Y-tube. The treatment arms of the olfactometer were 20 cm long while the main arm was 25 cm long. The main arm of the olfactometer was connected to an air suction pump with an airflow rate of 500 ml/min. The volume of air entering the other two arms was therefore calculated at 250 ml/min/arm. For each replication a moth was released at the base of the main arm as shown on figure 3.1. All replications were done at temperatures between 23 ± 2°C.

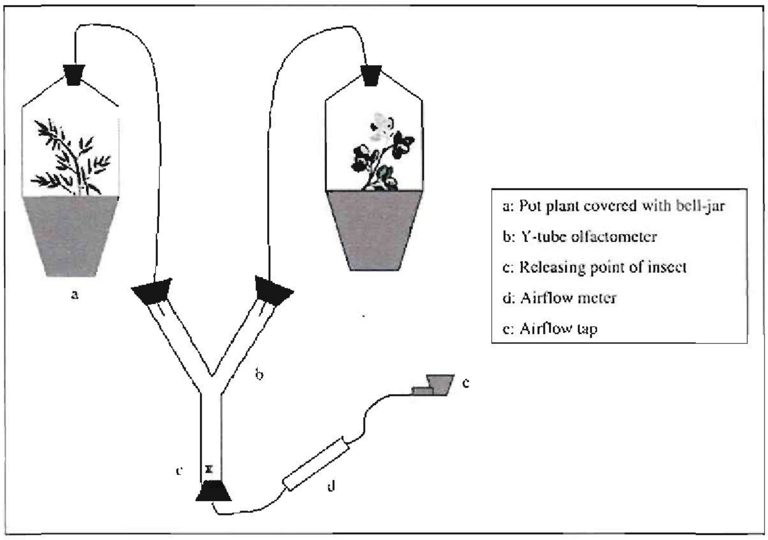

Figure 3.1. Diagram of the Y-tube olfactometer setup, showing important components.

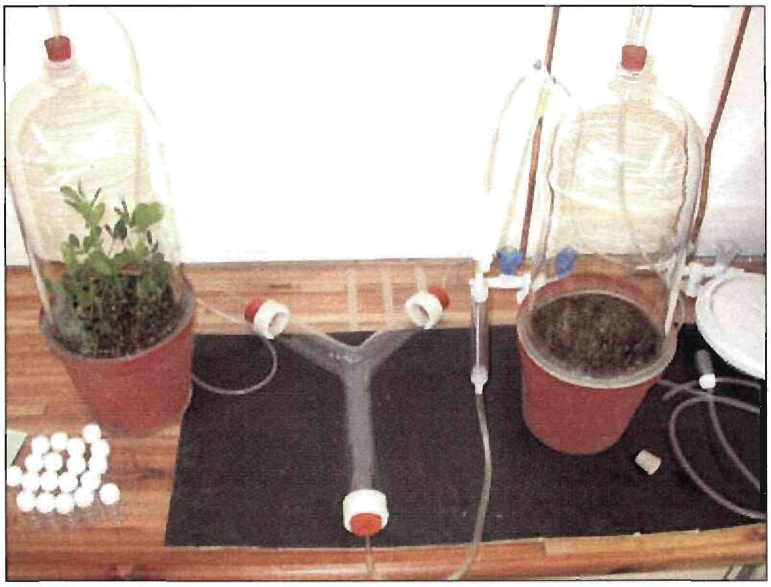

Figure 3.2. A photograph of the Y-tube olfactometer setup used in the experiment with a groundnut plant on the left hand side and the control treatment on the right hand side.

Each moth was left for three minutes to choose between the two treatment arms. A successful choice was recorded when the moth moved further than one centimeter into one of the treatment arms. The first choice as well as subsequent choices made by the moth during the 3-minute period was recorded.

Data was recorded on a computer using the OLFA-program. The computer program then calculated the number of times the moth entered each arm of the Y-tube olfactometer, as well as the total time spend in each arm. New plants were used after every three replications.

3.3 Results and discussion

The percentage moths that responded to either one of the two choices in each combination as the first choice, are summarized in figure 3.3.

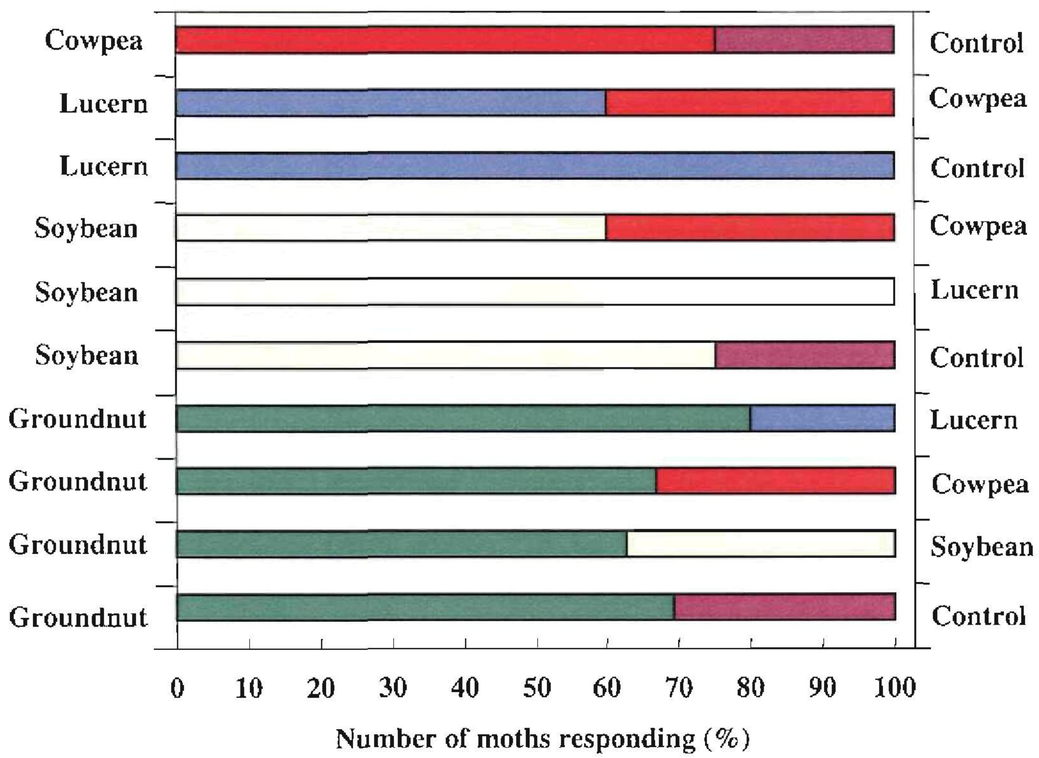

Figure 3.3. Proportional response of GLM moths to different host plant combinations.

More moths were attracted to groundnut when this crop was evaluated in combinations with the other plant species and the control treatment. Soybean was highly preferred compared to lucern while lucern was slightly preferred to cowpea. The host preference of moths in terms of 1st-choice can therefore be concluded to be groundnut > soybean > lucern > cowpea.

Moths spent more time in the groundnut-baited arms in three of the four treatment combinations (Fig. 3.4). In the combination of groundnut and cowpea, moths spend more time in the cowpea arm than in the groundnut arm, even though more moths chose groundnut as first choice.

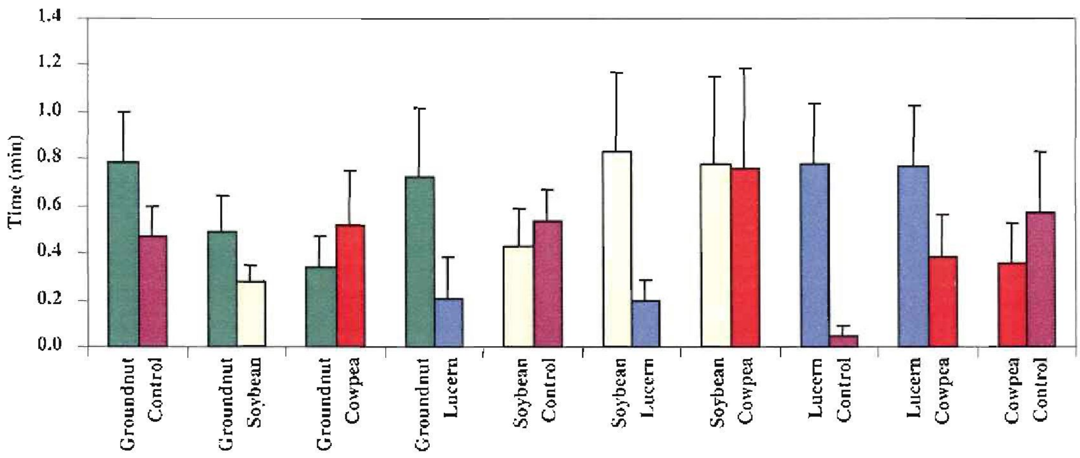

Figure 3.4. Time spend by groundnut leafminer moths in treatment arms of the Y-tube olfactometer provided with olfactory cues form different plant species.

Soybean was the more favored first choice by most moths in the combinations of soybean with the control treatment, cowpea and lucern. Even though most moths responded to soybean as first choice compared to the control, moths spend more time in the control arm. In the lucern/soybean combination, all moths responded to soybean, even though a little time was spend in the lucern arm.

Since cowpea is not a known host, it was expected that moths would choose soybean predominantly over cowpea. However 40 % of the moths chose cowpea over soybean. Almost the same amount of time was recorded in both the soybean and the cowpea arm. This cannot be explained, since no GLM damage was recorded on cowpea (Chapter 6).

Higher numbers of moths preferred lucern than cowpea when these two crops were evaluated in combination. Moths did not once choose soil over lucern as 1st-choice in the lucern-soil combination. Moths spent more time in the lucern treatment arm of the Y-tube olfactometer when evaluated in combination with the control and cowpea plants. In each combination with the control, moths responded in higher percentages to the host plants.

3.4 Conclusion

Groundnut compared to the other possible hosts, was the most preferred by groundnut leafminer moths. Soybean was also a highly preferred host for GLM moths. These results therefore show that moths do have preferences for certain cultivated host plant species that may also be planted in groundnut farming systems. This study therefore provide a basis for future development of trap cropping as a pest management tool for GLM. However, more experiments, for example those described in chapter 6 needs to be conducted using female moths in bioassays. In the Y-tube olfactometer experiment the moths selected a plant on the basis of plant volatiles, while the survival of GLM on these plants were recorded in chapter 6.

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Chapter 4

Using larval and pupal characteristics to distinguish between male and female larvae and pupae of the groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae).

4.1 Introduction

The groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) was reported in East Africa during 1998 after which it rapidly spread throughout East and southern Africa (du Plessis, 2003). This pest damages the leaves of groundnut and may cause significant yield loss. Larval tunnelling into leaves and feeding between the upper and lower epidermis result in formation of mines in the leaf. The final-instar larva spins a web between two or more leaflets thereby creating an enclosure in which pupation takes place (du Plessis, 2003).

The adult is a small brownish-grey moth (4-6 mm) (Fig. 4.1) and it is impossible to distinguish between the different sexes even under a stereomicroscope. Research on oviposition behaviour and host plant preference of this pest is hampered by the fact that male and female moths cannot easily be distinguished. Shanower *et al.* (1993) reported that males and females can be distinguished during the larval stage by the presence of pink gonads of the male which are visible through the cuticle but did not provide more detail.

To facilitate insect behavior studies on this pest, the aim of this chapter was to identify and document distinguishing characteristics of male and female larvae and pupae that are visible with the naked eye or under a stereomicroscope.

4.2 Materials and methods

Aproaerema modicella larvae were obtained from groundnut fields and allowed to complete their life cycles on groundnut plants inside cages.

Larvae were observed using a light microscope to determine differences between males and females. Male and female larvae were identified based on the characteristics indicated by Shanower *et al.* (1993) and photographed under a stereomicroscope using a CoolPIX 995 digital camera with a MD C2 Relay Lens.

Male and female larvae were then reared individually on groundnut leaves until they reached the pupal stage. Photographs were taken under a stereomicroscope.

A scanning electron microscope (SEM) (SEI ESEM Quanta 200) was used to make a detailed study of the morphological characteristics that could possibly be used to distinguish between male and female pupae. Basic preparation techniques for the SEM were followed. The pupae were fixed in 70% ethanol for 2 – 8 hours, after which the ethanol was exchanged with 70 % acetone for 15 min. The material was then dehydrated in an acetone series (80%, 90% and 2 x 100% for 15 min each. During this process, the samples were not exposed to air. The samples were then critical point dried (CPD) after which the samples were mounted by means of double-sided carbon tape on SEM stubs. The pupae were coated with a 25 nm layer of gold/palladium in a sputter coater before photographing was done using a FEI Quanta 200 ESEM with Oxford Inca 200 EDS System.

4.3 Results and discussion

4.3.1 Larvae

The differences observed between male and female larvae confirmed observations by Shanower *et al.* (1993) that the presence of pink-colored gonads in the region of the sixth and seventh abdominal segments was a distinguishing characteristic of male larvae. The gonads are easily visible through the cuticle even with the naked eye (Fig. 4.2).

4.3.2 Pupae

The position of the male genital aperture (Fig. 4.3) is a useful distinguishing characteristic present in male pupae. It is also indicated in line drawings (Fig. 4.4). The male genital aperture is further away from the proximal side of the last abdominal segment, compared to the aperture of the oviduct and bursa copulatrix of the female. The genital aperture of the male pupa is approximately in the middle third of the last abdominal segment while the genital aperture is in the upper third of the last abdominal segment, closer to the proximal side of the segment. This creates the impression that a male pupa has an additional segment before the segment on which the genital aperture and the anus occur (Fig. 4.4).

The SEM results verified the findings of the light microscope for the differences between the male and female pupa (Fig. 4.5).

4.3.3 Moths

Male and female moths could not be distinguished using a stereomicroscope since the whole body is covered with many feather-like scales. This, along with the small size of moths and their high mobility prevents distinguishing between live males and females for use in experiments.

4.4 References

DU PLESSIS, H. 2003. First report of groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) on groundnut, soybean and lucern in South Africa. *South African Journal of Plant Soil* 20, 48.

SHANOWER, T.G., WIGHTMAN, J.A. & GUTIERREZ, A.P. 1993. Biology and control of the groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae). *Crop Protection* 12, 3-10.

Figure 4.1. Groundnut leafminer moth.

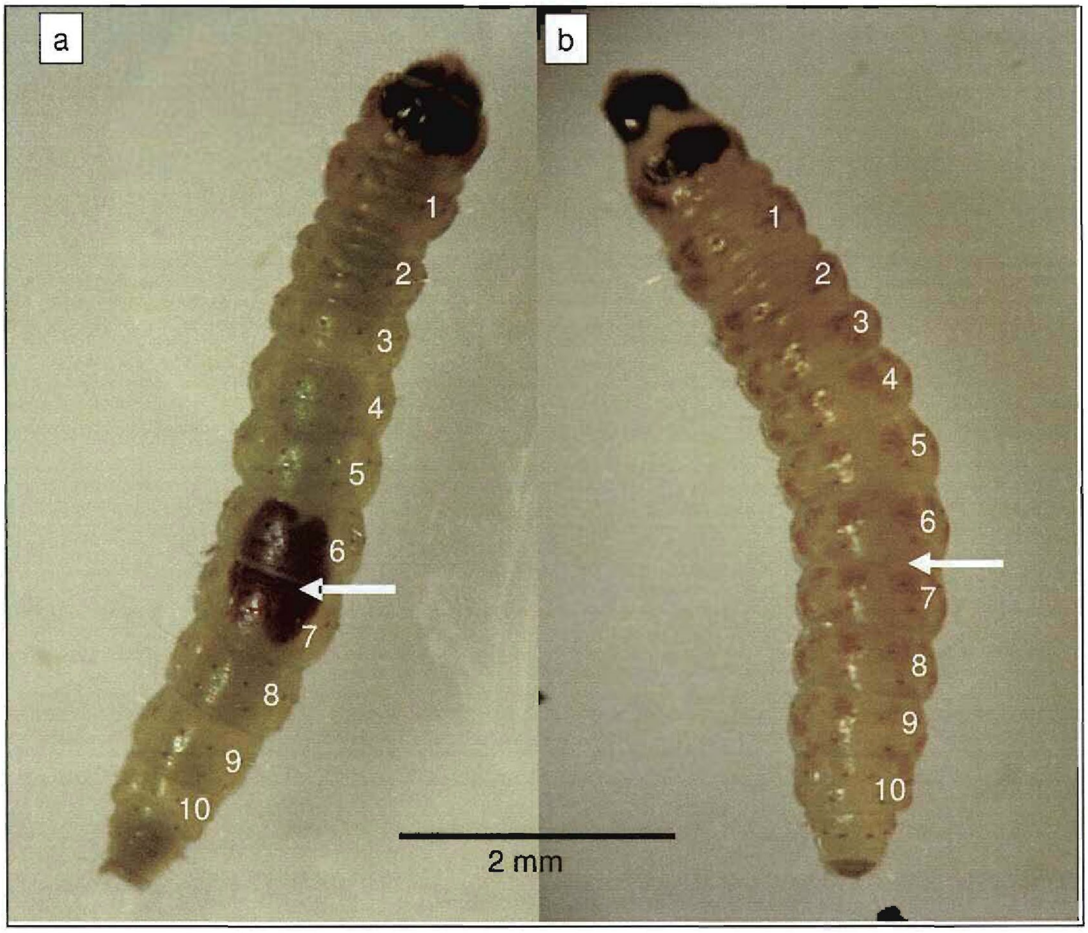

Figure 4.2. Distinguishing characteristics of male and female groundnut leafminer larvae under the light microscope. a) The male larva has gonads that are visible through the cuticle of the sixth and seventh segment, b) female larva with no gonads.

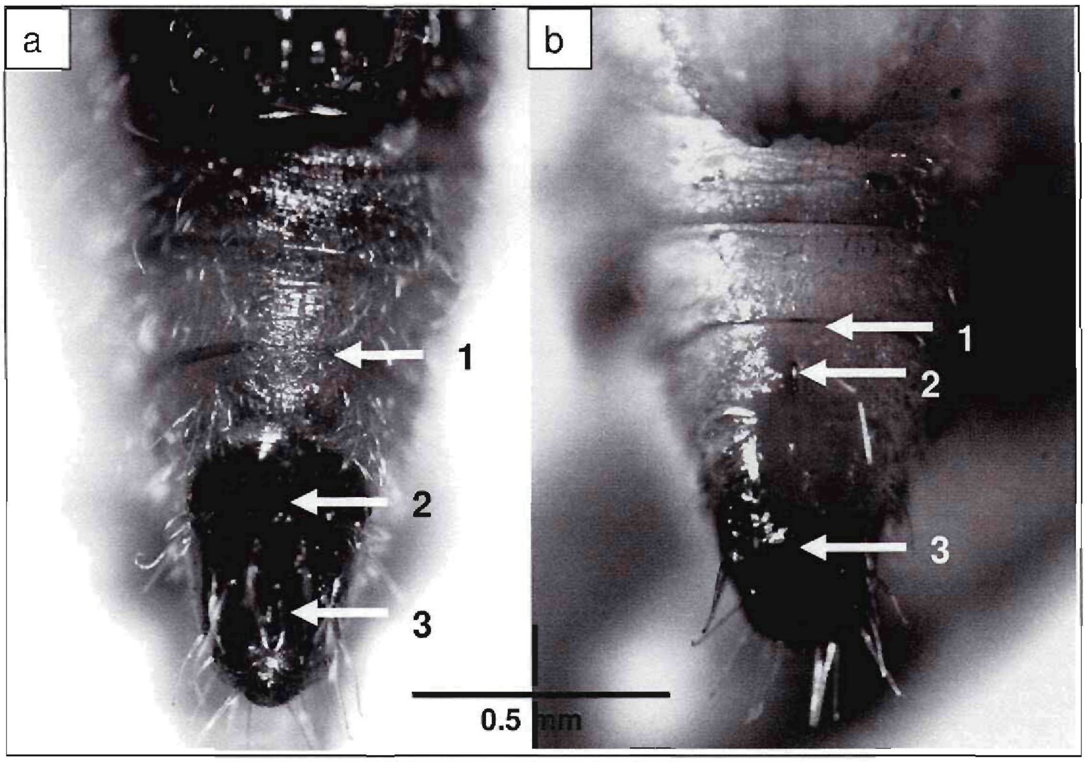

Figure 4.3. Light microscope photographs of a male and female pupa of the groundnut leafminer, *Aproaerema modicella*. a) male pupa, with 1 - beginning of the last abdominal segment, 2 - male genital aperture and 3 - aperture of anus; b) female pupa, with 1 - beginning of the last abdominal segment, 2 - aperture of oviduct and bursa copulatrix and 3 - aperture of anus.

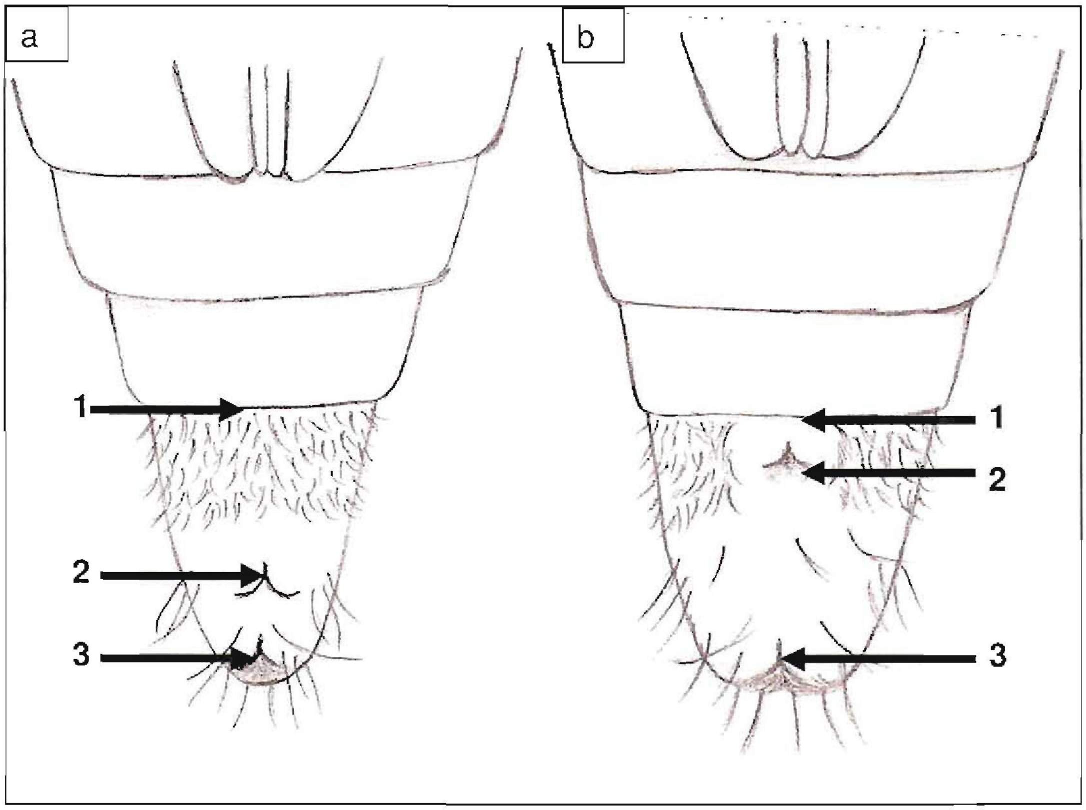

Figure 4.4. Line drawing illustrating the differences between male and female pupae of the groundnut leafminer, *Aproaerema modicella*. a) male pupa, with 1 - beginning of the last abdominal segment, 2 - male genital aperture and 3 - aperture of anus. b) female pupa, with 1 - beginning of the last abdominal segment, 2 - aperture of oviduct and bursa copulatrix and 3 - aperture of anus.

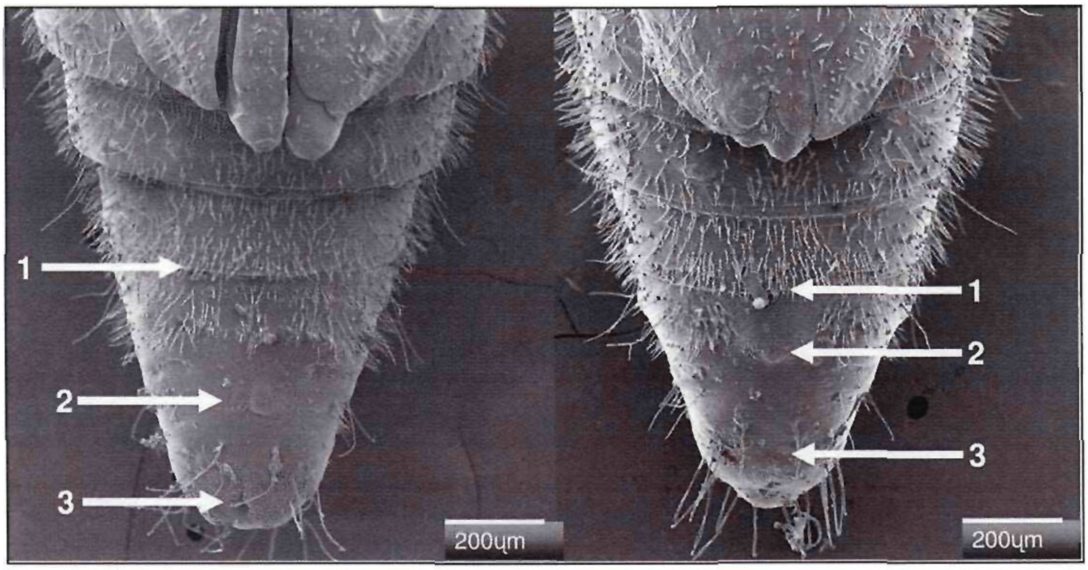

Figure 4.5. SEM photographs of male and female pupa of the groundnut leafminer, *Aproaerema modicella*. a) male pupa, with 1 - beginning of the last abdominal segment, 2 - male genital aperture and 3 - aperture of anus; b) female pupa, with 1 - beginning of the last abdominal segment, 2 - aperture of oviduct and bursa copulatrix and 3 - aperture of anus.

Chapter 5

Infestation levels and parasitism of the groundnut leafminer, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) on groundnut.

5.1 Introduction

The groundnut leafminer (GLM) (*Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) is an important pest of groundnut. The bulk of research on *A. modicella* was done in India where it is an important pest of groundnut. In Africa publications on this pest are largely limited to first reports. Prior to this study, no research has been done on *A. modicella* in South Africa. In India, the economic threshold level for insecticide applications is when five to ten larvae per plant are observed. These levels are low compared to the 45-56 mines and 29-38 larvae per plant recorded in Southern Mozambique (Kenis & Cugala, 2006) and indicates the high infestation levels that GLM can attain outside it's area of origin. Shanower *et al.* (1993) reported population densities that ranged between one to >320 larvae per plant in some seasons while densities of >50 larvae per plant were also recorded in other seasons (Shanower *et al.*, 1993).

Wheatley *et al.* (1989) recorded three to four generations of GLM per groundnut-growing season in India. Jagtap *et al.* (1985) cited by Shanower *et al.* (1993) also reported that GLM may survive the extremely hot, dry Indian summer in pupal diapause or aestivation. In the absence of natural mortality factors, GLM numbers can increase by up to a factor of 20 per generation so that, by the pod-filling stage, they have the potential to be present in high densities (Wheatley *et al.*, 1989). In India the number of generations per crop may vary from two to seven depending on climatical conditions (Shanower et al., 1993 cited by Kenis & Cugala, 2006). The time of infestation partly determines the impact of GLM on groundnut growth and yield. For example, an infestation level of five larvae per plant ten days after crop emergence has a much greater impact than 20 larvae per plant at 75 days after emergence (Shanower *et al.*, 1993).

Studies on the natural enemies of GLM were mostly done in Asia (Shanower *et al.*, 1993) but a number of parasitoids have also been recorded in Africa (Kennis & Cugala, 2006). That leaves us with the question, did the natural enemies of GLM migrate with it to Africa or did local natural enemies make a new association with this pest in Africa?

The most important natural enemies of GLM are parasitic Hymenoptera, which primarily attack the larval stage (Table 5.1) (Shanower *et al.*, 1992; 1993). In India, GLM larval parasitoids often parasitized more than 90% of the available hosts late in the rainy season (Shetgar & Thombre, 1984; Khan & Raodeo, 1978; Wightman, unpublished cited by Shanower *et al.*, 1992). A review on the natural enemies of *A. modicella* in Asia showed that the predators of GLM include larvae of *Chlaenius* sp. (Coleoptera: Carabidae) found inside mines of *A. modicella* in groundnut and soybean leaves (Kenis & Cugala, 2006). All the predators of GLM found in Asia are polyphagous species and thus would not be suitable for introduction into Africa (Kenis & Cugala, 2006).

Shanower *et al.* (1992) recorded three primary parasitoids, *Temelucha* sp. (Hymenoptera: Ichneumonidae), *Avga choapes* Nixon, and *Sympiesis dolichogaster* Ashmed (Eulophidae: Eulophinae), and four secondary parasitoids, *Pteromalus* sp. (Hymenoptera: Pteromalidae), *Oomyzus* sp. (Eulophidae: Tetrastichinae), *Elasmus anticles* Walker (Chalcidoidea: Eulophidae) and *Aphanogmus fijiensis* (Ferriere) (Hymenoptera: Ceraphronidae), in India.

Only four GLM parasitoid species in two families have so far been reported in Africa (Table 5.2) (Kenis & Cugala, 2006). In Mozambique, the parasitoid species belonged to the families Braconidae, Ichneumonidae, Chalcididae, Eulophidae and Bethylidae (Cugala *et al.* unpublished, cited by Kenis & Cugala, 2006).

The aims of this chapter were to determine spatial infestation patterns of GLM larvae and pupae on plants and to determine infestation levels and parasitism levels over time at the Tshiombo irrigation scheme in Venda. Parasitoids of *A. modicella* were also collected and identified. This information will be important in the development of an integrated management program for the control of GLM.

5.2 Materials and methods

In order to identify parasitoids of GLM, groundnut- and soybean plants infested with GLM were collected from Brits (North-West province). Groundnut only were sampled from the Tshiombo irrigation scheme in Venda (Limpopo province), Potchefstroom (North-West province), Vaalharts (Northern Cape province), Burgershall (Mpumalanga province) and Brits (North-West province) during the 2006 and 2007 growing seasons. Infested leaves were inspected to confirm the presence of larvae or pupae after which they were reared until moths or until parasitoids appeared.

The spatial distribution, infestation and parasitism levels of GLM were studied at the Tshiombo irrigation scheme in Venda in the Limpopo Province. Plants were sampled at monthly intervals between January and March 2006 and February and May 2007. Ten plants were randomly collected from three different groundnut fields on each of the sampling dates. Plants were inspected, larvae and pupa collected and the position of GLM on each plant was recorded. Larvae and pupae were placed separately in petri dishes and kept at 25° C (±1° C) in an incubator. Larvae were provided with fresh food as needed and monitored for moth or parasitoid emergence. The mean number of larvae and pupae as well as the total infestation level per plant was calculated for each field and sampling date.

Parasitoids reared from larvae and pupae were identified at the Biosystematics Division of the Agricultural Research Council in Pretoria. The percentage parasitism was calculated in terms of the total number of larvae and pupae recorded on each plant.

Each plant was divided into four parts *viz.* main stem, young leaves (MS-YL); main stem, mature leaves (MS-ML); side branch, young leaves (SB-YL)' side branch, mature leaves (SB-ML) (Fig. 5.1). This information was used to determine the distribution of GLM on different plant parts and parts of different ages. Each sample was then given a code for identification purposes.

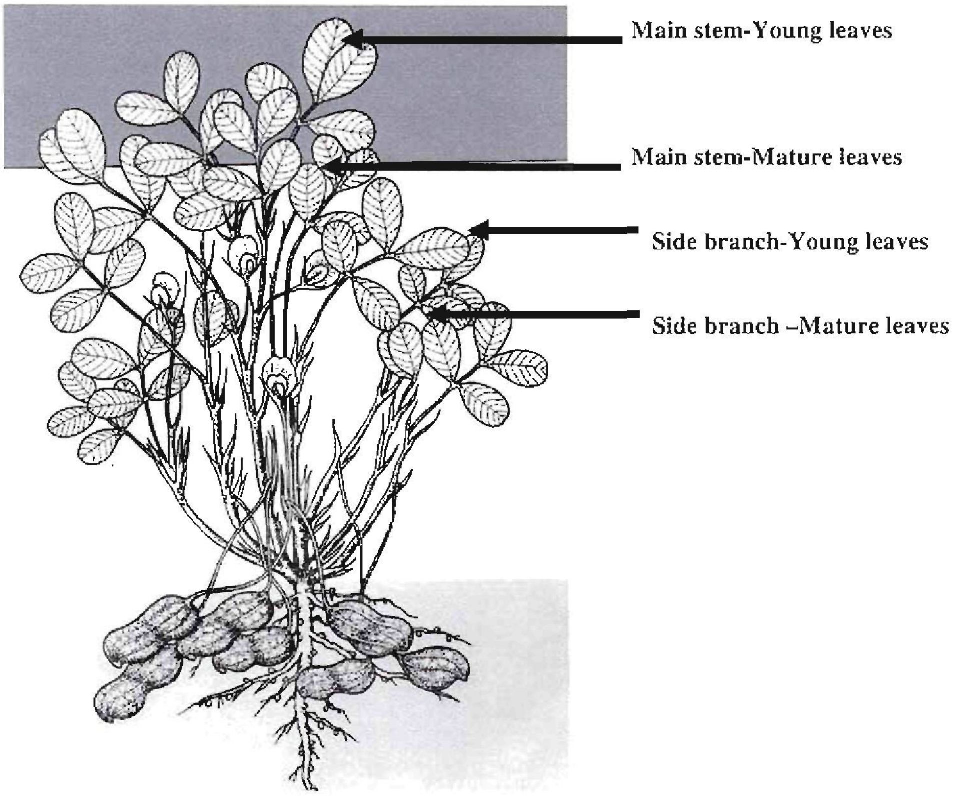

Figure 5.1. A drawing of a groundnut plant illustrating the four main parts of plants referred to in this study. The four main parts were: MS-YL (main stem, young leaves), MS-ML (main stem, mature leaves), SB-YL (side branch, young leaves), SB-ML (side branch, mature leaves).

5.3 Results and discussion

5.3.1 Infestation levels of GLM

The mean number of larvae per plant for 2006 ranged between 0.73 and 1.2 (SE= ±0.18) (fig. 5.2). During 2007 the mean number of larvae per plant ranged between 0.83 and 15.9 (SE= ±1.70) clearly higher than the previous season. The mean number of pupae per plant ranged from 0.5 and 0.7 (SE = ±0.24) for 2006 while the mean number of pupae per plant for 2007 ranged between 0.77 and 10.97 (SE= ±1.37) (fig. 5.3). Previous studies only reported on the number of larvae per plant (Muthiah & Kareem, 2000; Kenis & Cugala, 2006). In India, insecticides are applied when five to ten larvae per plant were observed. This indicates that the number of infestations per plant at Tshiombo was just above this level in 2007 where control is applied in India.

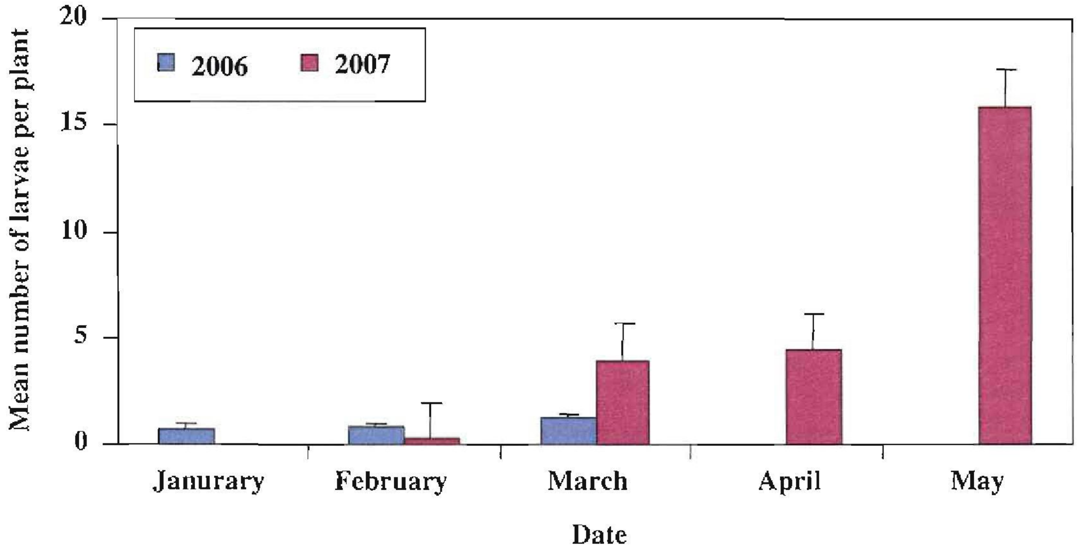

Figure 5.2. Mean number of larvae per plant at the Tshiombo irrigation scheme during 2006 and 2007.

During the 2006 season, the mean infestation levels of GLM ranged between 1.23 and 1.9 (SE = ±0.58) GLM per plant. During 2007 GLM infestation levels ranged between 1 and 26.87 (SE= ±2.75), much higher than in 2006.

The incidence of GLM on groundnut was higher in 2007, but the tendency was similar during the two seasons. The build-up of GLM infestations especially later during 2007 could be a result of overlapping generations. The differences in the mean number of GLM per plant during the two seasons were similar to observations made by Kennis and Cugala (2006), Senguttuvan (1999) and Shanower et al. (1995). They found that GLM was very sporadic with large population fluctuations between generations, seasons and years.

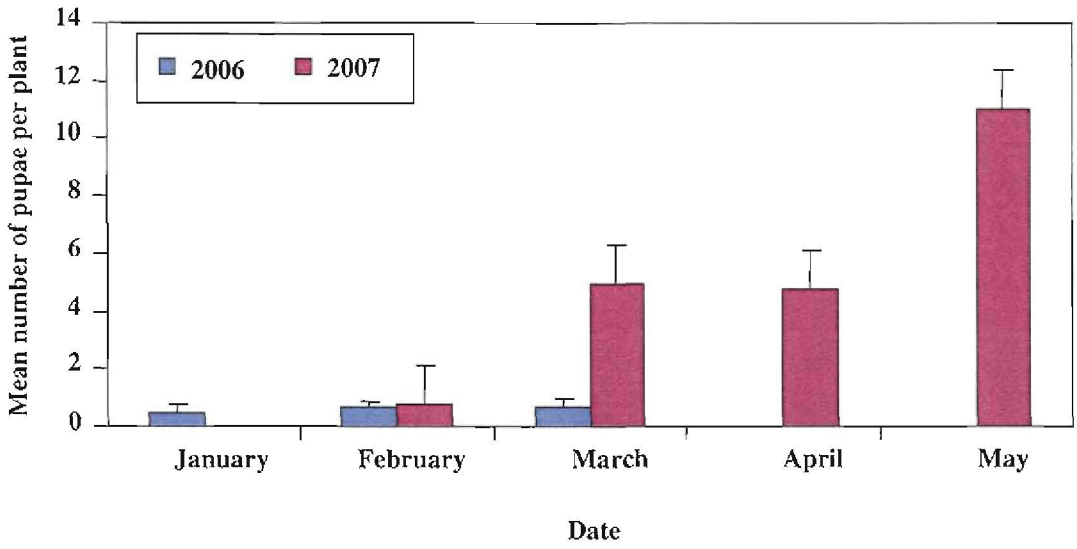

Figure 5.3. Mean number of pupae per plant at the Tshiombo irrigation scheme during 2006 and 2007.

The large population fluctuations between generations and seasons are an evident reason for a suitable and continues IPM program in order for farmers to be prepared in controlling GLM as a pest. During the survey done at Tshiombo amongst the farmers, most of the farmers were of opinion that they do not plant late, because damage to late planted groundnut were more severe. This was not practiced over the sampling period at Tshiombo, since the sampling dates run until March (2006) and May (2007). Therefore the high incidence of GLM infestations during 2007 can also be due to the fact that farmers planted late and only harvested in May 2007. Planting dates are important as part of a strategy for controlling a pest and need to be implemented successfully amongst these farmers along with other IPM methods.

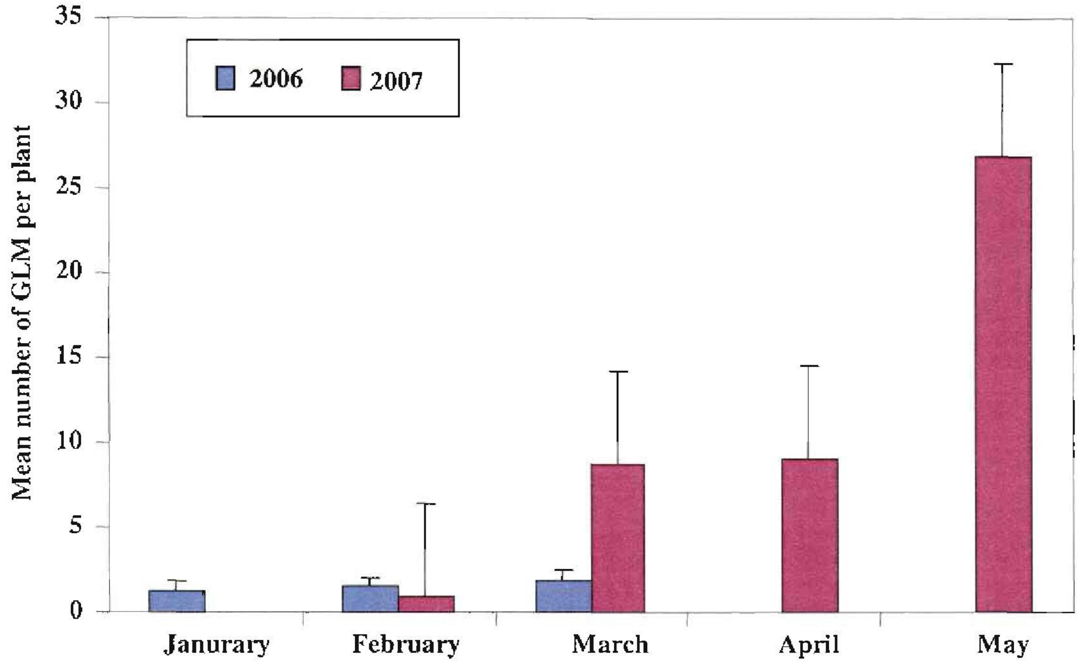

Figure 5.4. Mean number of GLM reared from groundnut plants at the Tshiombo irrigation scheme for 2006 and 2007.

5.3.2 Mortality and parasitism levels for GLM larvae and pupae

The number of larvae that died of unknown causes during 2006 ranged between 38% and 75% (SE= ±10.19) while pupal deaths ranged between 42.9% and 76.2% (SE= ±11.83) (Fig. 5.5). During 2007 this number ranged between 16.1% and 38.3% (SE= ±5.79) for larvae, which was much lower than during 2006. The incidence of pupae dying of unknown causes during 2007 was also lower than in 2006 and ranged between 8.1% and 68.1% (SE= ±6.35).

Even though the causes of these deaths were unknown, it can possibly be as a result of the techniques used. During 2006 the larvae and pupae reared from groundnut plants were placed in pertri dishes with leaves only. Even though the leaves were changed regularly, larvae would die or manage to escape from the petri dishes. Early in 2007 petri-dishes with a thin layer of agar were used with tissue paper to absorb the excessive water, resulting in a higher percentage survival. In this study no fungal and bacterial infections was observed in contrast to studies by Ranga Rao & Reddy *et al.* (1997) who reported fungal and bacterial infections that caused high levels of mortality during their studies. Shanower *et al.* (1992) reported black, "muschy-bodied" larvae and larvae with fungal hyphae growing out of the bodies.

No parasitoids emerged from larvae and pupae sampled at Vaalharts irrigation scheme and Burgershall. One *Pteromalus* sp. (Pteromalidae) was reared from a GLM larvae sampled in Brits on soybean and a *Brachymeria* sp. (Calcididae) emerged from a GLM pupa on groundnut sampled in Potchefstroom during 2006. Parasitoids reared from GLM larvae and pupae from Tshiombo irrigation scheme are summarized in Table 5.3.

Table 5.3. Parasitoids reared from groundnut leafminer larvae and pupae during the 2006 and 2007 groundnut season at the Tshiombo irrigation scheme in Venda.

Family name	**Species name**	**Reared from**
Bethylidae	*Goniozus* sp.	Pupae & larvae
Braconidae	Unidentified	Pupae
	Apanteles sp.	Larvae
	Hypomicrogaster sp.	Pupae & larvae
	Cotesia sp.	
Calcididae	*Brachymeria* sp.	Pupae
Eulophidae	*Baryscapus* sp.	Pupae
Eupelmidae	*Eupelmus* (Macroneura) sp.	Pupae
Eurytomidae	*Eurytoma* sp.	Pupae & larvae
Pteromalidae	*Pteromalus* sp.	Pupae & larvae

All the parasitoid families reared during this study in South Africa have been previously recorded in India and Africa (table 5.1 and 5.2). *Goniozus* sp., *Apanteles* sp., *Brachymeria* sp., *Eupelmus* (Macroneura) sp., *Eurytoma* sp. and *Pteromalus* sp. were previously recorded as parasitoids of GLM in India. Four of the species were not previously mentioned as parasitoids of GLM *viz.* *Hypomicrogaster* sp. and *Cotesia* sp. from the Braconidae family and *Baryscapus* sp. from the Eulophidae family. Further studies need to be conducted in order to determine the suitability of these parasitoid species as natural enemies being used in an IPM program.

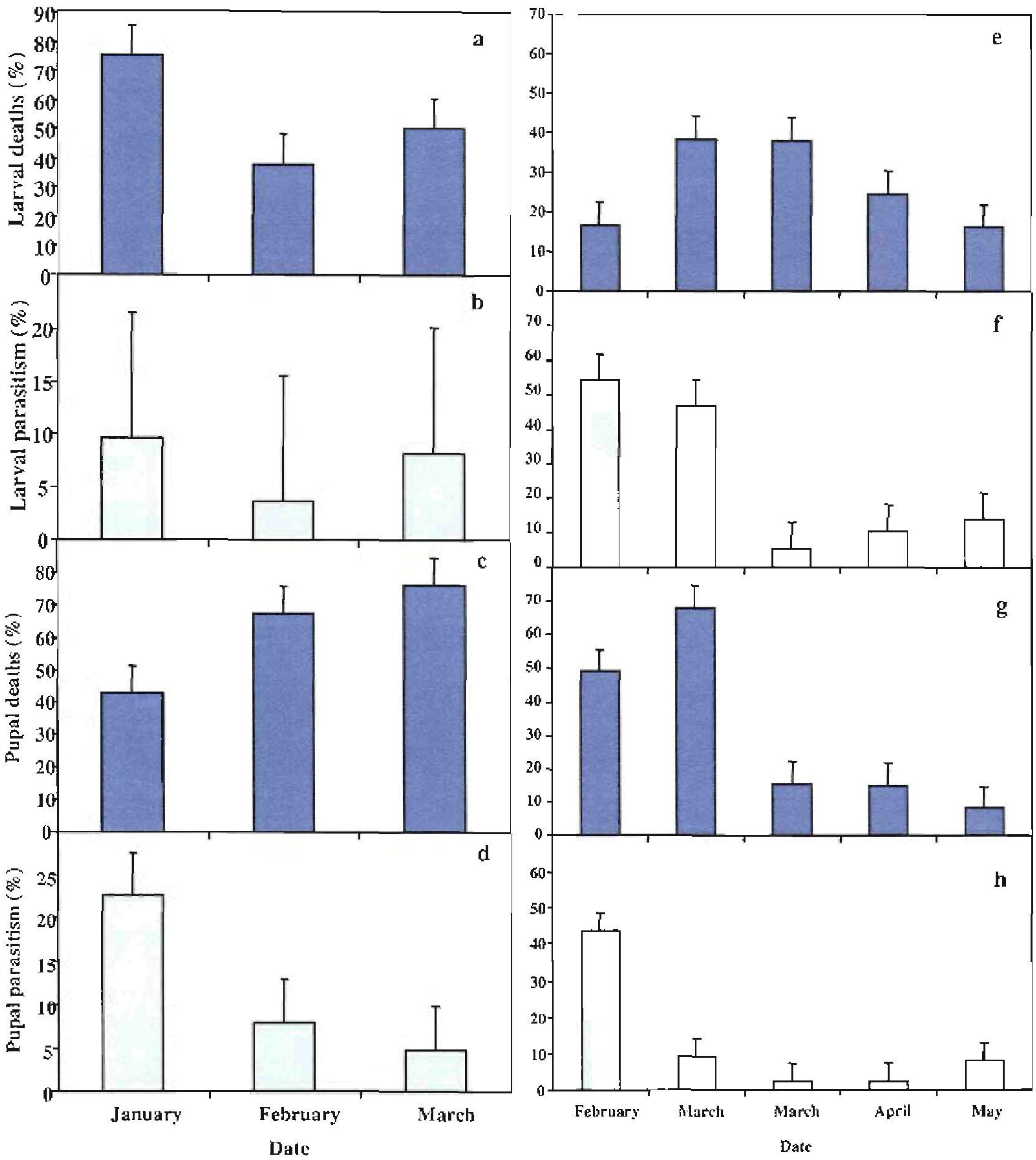

Figure 5.5. Larval (a) and pupal (c) deaths due to unidentified causes and larval (b) and pupal (d) parasitism in groundnut at the Tshiombo irrigation scheme (2006 season) as well as Larval (e) and pupal (g) deaths due to unidentified causes and larval (f) and pupal (h) parasitism in groundnut at the Tshiombo irrigation scheme (2006 season)

During 2006 the percentage larval parasitism ranged between 3.7% and 9.7% (SE= ±8.26) (Fig. 5.5). Larval parasitism during 2007 ranged between 5.3% and 54.2% (SE= ±7.61), which was much higher than during 2006. Even though the percentage of larval parasitism was higher during 2007, their were no similar tendency between the two seasons.

The percentage pupal parasitism during 2007 was between 2.3% and 43.7% (SE= ±5.01) while during 2006 it ranged between 4.8% and 22.6% (SE= ±4.98). The percentage pupal parasitism during 2007 were higher than that of 2006, and both seasons had a similar tendency of decreasing over time In Brits and Potchefstroom 20% larval parasitism and 50% pupal parasitism were recorded during this study.

Although GLM is a new pest in South Africa, high levels of parasitism occurred. Biological control will therefore play an important role in an integrated control program for GLM in South Africa. This aspect should be taken into consideration when decisions are made on the time of application and which insecticides to use for control of GLM in groundnut fields.

5.3.3 Proportional distribution of GLM

The mean distribution of GLM on groundnut plants for 2006 and 2007 are compared in figure 5.4. The distribution of GLM during 2006 illustrated that numbers are lower on young leaves than on the mature leaves.

During 2007 there are no correlation to this. Although numbers were lower on young leaves during 2006, it does not indicate that mature leaves are preferred because at the time of egg laying mature leaves could have been regarded as young leaves. GLM infestations therefore occur all over groundnut plants.

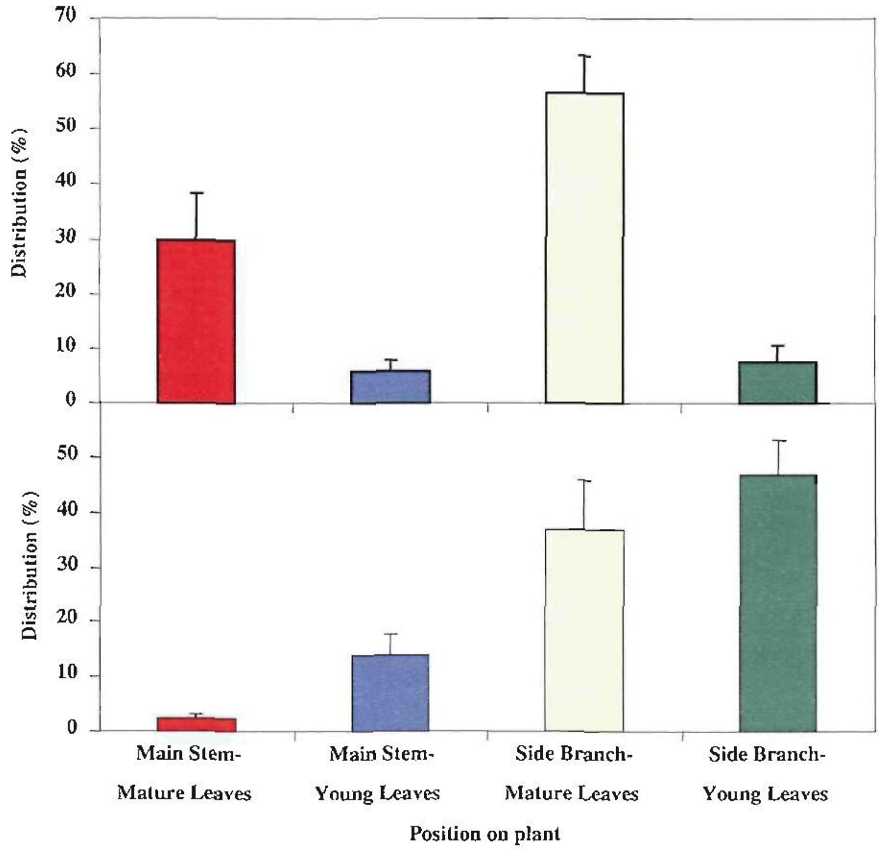

Figure 5.6. Mean percentage distribution of groundnut leafminer on groundnut during 2006 (a) and 2007 (b) at Tshiombo irrigation scheme.

5.4 Conclusion

Infestation levels of GLM larvae, pupae and total GLM were higher during 2007 with a similar tendency for both seasons. GLM infestation levels were found to differ largely between the two seasons and were confirmed by pervious studies done by Kennis and Cugala (2006), Senguttuvan (1999) and Shanower et al. (1995). Based on these results, it is important to implement a suitable and sustainable control system in order to keep GLM infestation levels to the minimum. Further studies need to be done in order to determine the suitability of the parasitoid species reared from GLM larvae and pupae. Larval and pupal parasitism levels were higher during 2007. The high levels of parasitism could contribute to biological control being used in an IPM program. Distribution of GLM were found all over the groundnut plant. The above results indicate that GLM is an important pest to farmers at the Tshiombo irrigation scheme that needs to be controlled.

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Table 5.1. Parasitoids reported from *Aproaerema modicella* on groundnut and soybean in Asia (Shanower *et al.*, 1993, Muthiah & Kareem, 2000 & Kenis & Cugala, 2006). (gn = groundnut; sb = soybean).

Family	***Parasitoid***	**Host stage**	**Host plant**
Bethylidae	*Goniozus* sp. (syn. *Perisierola* sp.)	Larva	gn, sb
	Goniozus indicus Ashmead	Larva	gn
	Goniozus. Stomopterycis Ram & Subba Rao	Larva	gn
	Perisierola sp.	Larva	
Braconidae	*Apanteles* sp. (syn. *Dolichogenidea* sp.)	Larva	gn, sb
	Apanteles javensis Rohwer	Larva	gn
	Apanteles singaporensis Szepligeti	Larva	gn
	Apanteles litae Nixon	Larva	sb
	Avga choaspes Nixon	Larva	gn
	Avga nixoni Subba Rao & Sharma	Larva	gn
	Bracon sp.	Larva	gn
	Bracon brevicornis Wesmael	Larva	gn
	Bracon gelechiae Ashmead	Larva	gn, sb
	Bracon (syn. *Microbracon) hebetor* (Say)	Larva	gn
	Chelonus (Microchelonus) sp.	Egg, larva	gn, sb
	Chelonus blacburni Cameron	Egg, larva	gn
	Chelonus curvimaculatus Cameron	Egg, larva	gn
	Protapanteles (syn. *Glyptapanteles*)	Egg, larva	gn
	africanus (Cameron)		
	Phanerotoma sp.	Egg, larva	gn
Cheraphronidae	*Aphanagmus fijiensis* (Ferrière)	Larva	gn
	Ceraphron sp.	Larva	gn
Chalcididae	*Brachymeria* sp.	Larva, pupa	gn
	Bracymeria marmonti (Girault) (syn. *wittei* Schmitz)	Larva	gn
	B. plutellophaga Girault	Larva, pupa	
	B. minuta (L.)	Larva, pupa	gn
	B. lasus (Walker)	Pupa	gn
	Brachymeria phya (Walker (syn. *Plutellophaga* (Girault))	Larva, pupa	gn
	B. wittei Schmitz	Larva	
	Kriechbaumerella sp. (syn. *Eucepsis* sp.)	Pupa	gn

	Eucepsis sp.	Larva	
Elasmidae	*Elasmus anticles* Walker	Larva	
	Elasmus brevicornis Gahan	Larva	
	E. sp. nr. *luteus* Crawford	Larva	
Encyrtidae	*Capidosoma* sp.	Larva	gn
	Homalotylus flaminius Dalman	Larva	gn
Eulophidae	*Euryscotolynx coimbatorensis* Rohwer	Larva	
	Elasmus sp.	Larva & hyper parasitoid	gn
	Elasmus anticles Walker	Hyper parasitoid	gn
	Oomyzus sp.	Larva	gn
	Pediobius sp.	Larva & hyper parasitoid	gn
	Stenomesioideus ashmeadi Subba Rao & Sharma	Larva	
	Stenomesius sp.	Larva & hyper parasitoid	gn
	Stenomesius japonicus (Ashmead)	Larva	gn,sb
	Sympiesis (*Asympiesis*) sp.	Larva	gn
	Sympiensis dolichogaster Ashmead	Larva	gn
	S. indica Girault	Larva	
	Tetrastichus sp.	Larva	gn
Eupelmidae	*Eupelmus* sp.	Larva, pupa	gn
	E. sp. nr. *anpingenisis*	Larva, pupa	
Eurytomidae	*Eurytoma* sp.	Larva	
	Plutarchia giraulti Subba Rao	Larva	gn
Ichneumonidae	*Temelucha* sp.	Larva	
Mymaridae	*Anagrus* sp.	Larva	gn
Pteromalidae	*Dibrachys* sp.	Larva	gn
	Macromesus sp.	Larva	gn
	Habrocytus sp.	Larva	
	Pteromalus (syn. *Habrocytus*) sp.	Larva	gn
Trichogrammatidae	*Trichogramma* sp.	Egg	

Table 5.2. Hymenopteran parasitoids reared from *Aproaerema modicella* on groundnut in Uganda and the Democratic Republic of Congo (Kenis & Cugala, 2006).

Family	**Parasitoid**	**Country**
Eulophidae	*Diglyphus* sp.	Uganda
	Stenomesius sp.	Uganda
	(as *Euryscotolinx* sp.	
	Asecodes sp.	Democratic Republic of Congo
	(as *Teleopterus* sp.)	
Pteromalidae	*Pteromalus* sp.	Democratic Republic of Congo

Chapter 6

Host plant diversity and suitability of cultivated host plants for the development of the groundnut leafminer (*Aproaerema modicella*) (Lepidoptera: Gelechiidae).

6.1 Introduction

Cultural control of insect pests is affected by the manipulation of the environment in such a way as to render it unfavorable for the pest (Dent, 2000). These methods interfere with the pests' ability to colonize a crop and reproduce or survive (Dent, 2000). Insect populations thrive on monoculture crops that are easily accessible, have low natural defenses and will nutritionally support one or more generations of a pest (All, 1999). Some cultural control techniques include intercropping, crop rotation, trap crops, manipulation of the planting dates and management of field margins (Dent, 2000). Shanower *et al.* (1993) reported that although several cultural methods have been recommended for control of the groundnut leafminer (GLM), only intercropping and manipulation of planting date has been evaluated under field conditions.

Intercropping includes planting different crops on the same field, either in different rows or as a mixture as is often done by subsistence farmers. Logiswaran and Mohanasundaram (1985), cited by Shanower *et al.* (1993) reported lower GLM larval densities when groundnut was intercropped with sorghum, millet or cowpea, than in monoculture groundnut. Intercropping of groundnut with black gram, pigeon pea, green gram and pearl millet was also reported to reduce GLM infestations in a study done at the Oilseeds Research Station in Tindivanam, India (Muthiah, 2000).

Lewin *et al.* (1979) cited by Shanower *et al.* (1993) observed that early planting resulted in higher infestations of GLM, whereas another study (Logiswaran *et al.*, 1982 cited by Shanower *et al.*, 1993) concluded that later plantings were more heavily attacked.

Wild host plants play an important role in the ecology of many pest species (Norris & Kogan, 2000). Available natural resources such as wild host and non-host plants can be used in management of pests, for example, grasses were used to manipulate pest behavior in order to reduce stem borer numbers in grain crops (Van den Berg *et al.*, 2001). Several wild grasses can act as a trap plants, providing natural control of stem borers (Van den Berg *et al.*, 2001). It is especially field margins where wild host plants of pests often occur, that has received attention in recent years (Norris & Kogan, 2000).

Fourteen host plant species of which nine are cultivated as crops have been reported to host GLM in India (Shanower *et al.*, 1993) (Table 1).

Table 6.1. Host plants of *Aproaerema modicella* in India (from a review by Shanower *et al.* (1993)).

Scientific name	Common name
Arachis hypogaea L.	Groundnut
Boreria hispida K. Sch.	-
Cajanus cajan (L.) Millsp.	Pigeonpea
Glycine max (L.) Merr.	Soybean
Glycine soja Sieb. & Zucc.	Wild soybean
Indigofera hirsuta L.	Roughhairy indigo
Lablab purpureus L.	Hyacinth bean
Medicago sativa L.	Alfalfa, Lucerne
Psoralea corylifolia L.	Bu Gu Zhi
Rhynchosia minima Dc.	Least snoutbean
Teramnus labiolis (L.) Spreng	Blue wiss, rabbit vine
Trifolium alaxandrium L.	Berseem/Egyptian Clover
Vigna radiata (L.) Wilzcek (= *Phaseolus aureaus*)	Mung bean
Vigna umbellata (Thunb.) Ohwi and Ohashi	Japanese rice bean, oriental bean, red bean

With the exception of *Boreria hispida* (Rubiaceae), all these are leguminous host plants (Shanower *et al.*, 1993). Du Plessis (2003) reported that GLM also occurred on soybean (*Glycine max* (L.) Merr.) in the Mpumalanga province and on lucern (*Medicago sativa* L.) in the Northern Cape province in South Africa.

An example of an integrated approach for management of GLM was described by Muthiah (2003). Trap crops, a botanical pesticide, a biological control agent (*Bacillus thuringiensis* Berliner) and reduced doses of insecticides were used in this strategy. These trap crops, included soybean (*Glycine max* (L.) Merr.), pearl millet (*Pennisetum glaucum* (L.) R. Br.) and castor (*Ricinus communis* L.). One row of soybean was grown after every four rows of groundnut while three rows of pearl millet were grown around the groundnut plots (Muthiah, 2003). The lower incidence of pests in this intercropping / trap cropping arrangement was ascribed to crop diversity, physical barriers, shade, production of adverse chemical stimuli and presence of natural enemies as a result of intercropping (Muthiah, 2003). Pearl millet extract sprayed on groundnut produced a deterrent effect on GLM (Muthiah, 2003). Results showed that intercropping resulted in increased parasitism levels by *Goniozus* sp. (Muthiah, 2003). Based on GLM pheromone trapping data, Muthiah (2003) achieved successful timing of control with the application of insecticide mixtures consisting of low dosages of phosphamidon (0.02 %) and endosulfan (0.04%) applied together with neem oil (2%).

It is unlikely that cultural control would reduce pest infestation to be below the economic damage thresholds, therefore it should be considered as the first-ditch defense around which to build other control options (Coaker (1987), cited by Dent, 2000). It is also reported that cultural control is the most relevant and economic method of pest control for farmers in Africa (Van den Berg *et al.*, 1998).

The aim of this chapter was to evaluate the suitability of selected cultivated host plants for survival of GLM larvae and to identify possible wild host plants of GLM in groundnut production areas in South Africa.

6.2 Material and methods

6.2.1 Host plant suitability for larval development

Groundnut, two cultivated host plants of GLM, soybean and lucern and a non host plant, cowpea were used in this study to determine the suitability of these plants for development of GLM larvae. Plants were grown in pots and each pot formed one of four replications. Plants were approximately the same size when they were used in the experiment. Nylon cloth cages were positioned over the pots, covering the plants (Figure 6.1). Ten moths collected from groundnut crop residues were introduced into one cage of each plant species for a 24 hour period after which the moths were removed. On each day another replication was set up in the same way and new moths were introduced.

Figure 6.1. Groundnut plant in a pot covered with a nylon cloth cage.

Immediately after removal of the cages, plants were inspected for the presence of eggs, using a 30x magnifying lens. Commencing three days after removal of cages plants were inspected for the presence of GLM larvae or damage symptoms. The number of visible damage symptoms was recorded on a daily basis until pupal development. Symptoms of damage were noted on a data sheet and marked on the plant with a fine permanent marker. Each damage symptom was taken as a larva that hatched since it was very difficult to observe eggs and first instar larvae with the magnifying glass or naked eye. The progress of these infestations on each plant was monitored until pupae were found.

Data were collected on the mean number of days until the first lesions were visible on leaves and the number of days until the first pupae was observed. The mean number of lesions per plant over time was also calculated. The survival rate of GLM on the different crops was calculated as the number of pupae in relation to the number of lesions observed on plants, and expressed as a percentage.

6.2.2 Wild host plants

Over an 18-month period several visits were made to groundnut production areas in South Africa, particularly the Tshiombo irrigation scheme. During these visits weeds inside groundnut fields and plants outside fields were inspected for the presence of GLM damage. Plants with GLM infestations were collected, photographed and numbered for identification purposes and then placed into a plant press. A field label was completed and included with each plant. The field label included information such as date collected, place of collection (including GPS reading and altitude), collectors name and number and notes on the habitat of the plant. The plant press was placed in an air drier for three days. After drying, plants were mounted onto a herbarium mounting board with wood glue. The information on the field label was transferred via the PRECIS (Pretoria Computer Information System) program onto a herbarium label that were printed out and glued next to the specimen on the mounting board. The specimens were send for identification by the South African National Biodiversity Institute (SANBI) in Pretoria. After identification, specimens were placed in the A.P. Goossens Herbarium at the North-West University (Potchefstroom Campus) as voucher specimens. Duplicate specimens were sent to SANBI (The South African National Biodiversity Institute) Pretoria. SANBI also provided a distribution map for each wild host plant species collected. The groundnut production areas in South Africa (Anonymous, 1994) were superimposed on the distribution maps of collected wild host plants, and conclusions drawn on the potential role and status of wild host plants as a reservoir for GLM during the off season.

6.3 Results and discussion

6.3.1 Host plant suitability for larval development

6.3.1.1 Mean number of days until first lesions were visible

Visible damage by GLM larvae was observed on groundnut eight (SE= ± 2.08) days after egg laying. The first damage symptoms occurred after 11.7 (SE = ±1.76) days on soybean and after 16 days (SE = ±0.58) on lucern (Fig. 6.2). The period between egg laying and first appearance of GLM damage symptoms on leaves could be considered as an indirect indication of suitability of the host plant for larval development and time that it took for first instar larvae to become large enough to bore into leaves. This result therefore indicates that the larval development rate was higher on groundnut compared to soybean and lucern. The first indications of GLM damage to leaves could be an indication of the time that it took for first instar larvae to become big enough to tunnel into leaves.

No damage was observed on cowpea. The fact that moths responded to cowpea in the Y-tube olfactometer experiment (Chapter 3) more than expected, might be explained by the presence of green leaf volatiles, however, it seemed from these results that the leaves were not suitable for oviposition or survival of larvae. Another reason contributing to the observed result indicating some degree of acceptance of cowpea is that male moths, which may respond differently to host plant odors, were also used in these bioassays. At the time of these assays, it was impossible to distinguish between male and female moths (Chapter 4). It was expected that female moths would choose host plants that would be suitable for oviposition and survival of larvae while male moths may not take these aspects into account at all.

Even though no GLM infestation was observed on cowpea in this study, cowpea may be an effective intercrop as indicated in a previous study by Logiswaran and Mohanasundaram (1985), cited by Shanower *et al.* (1993). They reported lower GLM larval densities when groundnut was intercropped with sorghum, millet or cowpea, than in monoculture groundnut. This indicates that cowpea could possibly be used as a disruptive crop when intercropped with groundnut, limiting successful host plant search by GLM moths. Further studies need to be conducted in order to identify the suitability of cowpea as an intercrop for groundnut in South Africa.

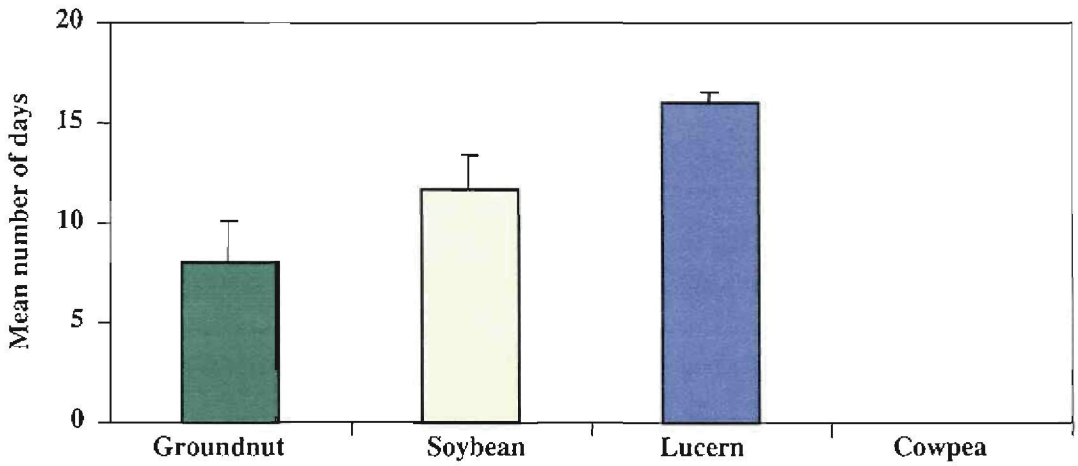

Figure 6.2. The mean number of days from egg laying until visible damage caused by GLM (*Aproaerema modicella*) larvae to leaves was observed on each plant species.

6.3.1.2 Mean number of lesions per plant

The mean number of lesions per plant was highest on soybean, reaching a mean of 19 lesions per plant, 28 days after egg laying. The mean number of lesions per plant was 12.67 on groundnut and 4.3 on lucern (Fig. 6.3). The mean number of lesions per plant reached a peak within the fifth weak after egg laying for groundnut, soybean and lucern. No lesions were observed on cowpea.

The mean number of pupae per plant was higher for soybean than groundnut and lucern (Table 6.2). The standard error for soybean was very high and can be ascribed to the fact that a very high number of pupae was reared from one of the replications.

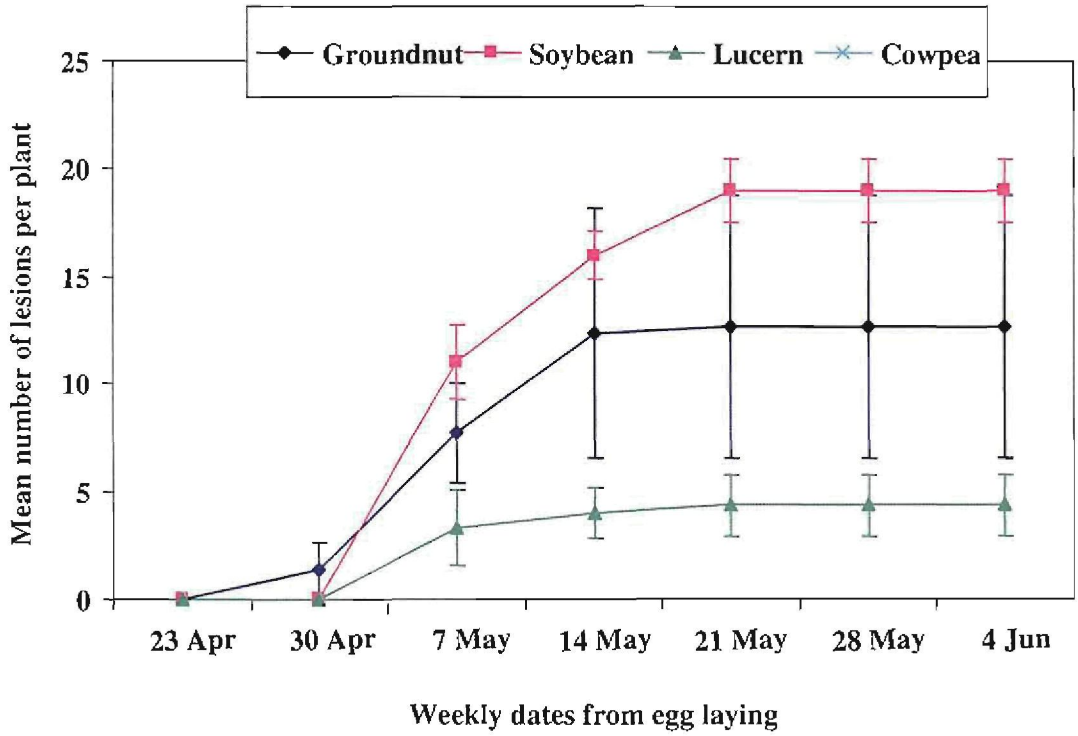

Figure 6.3. The mean number of lesions per plant for groundnut leafminer infestations over time after egg laying.

6.3.1.3 Survival rate of GLM on different crops

The number of lesions per plant was high on all crops except for cowpea where no lesions were observed or pupae recorded. The percentage survival was 92.1 %, 77.2 % and 56.5 % on groundnut, soybean and lucern respectively (Table 6.2).

The fact that no infestation levels of GLM occured on cowpea althoug GLM moths responded to cowpea in the Y-tube olfactometer experiments, does not mean that cowpea cannot be used in intercropping. Intercropping includes planting different crops on the same field, either in different rows or as a mixture as is often done by subsistence farmers. Logiswaran and Mohanasundaram (1985), cited by Shanower *et al.* (1993) reported lower GLM larval densities when groundnut was intercropped with sorghum, millet or cowpea, than in monoculture groundnut. Further studies need to be done in order to confirm these findings.

Table 6.2. Survival rate of, *Aproaerema modicella* on four different crops.

Plant	Actual # of lesions per plant	Actual # of pupae per plant	Mean # of lesions per plant (SE)	Mean number of pupae per plant (SE)	Survival rate (%)
Groundnut	38	35	12.67 (± 6.12)	11.67 (± 6.94)	92.1
Soybean	57	44	19.0 (± 10.50)	14.67 (± 12.72)	77.2
Lucern	13	11	6.5 (± 2.40)	3.67 (± 2.03)	56.5
Cowpea	0	0	-	-	n.a.

* n.a. = not applicable

Even though the mean number of lesions was higher for soybean, a much higher percentage survival rate was observed on groundnut than soybean and lucern. The fact that soybean had a much higher number of lesions per plant but a lower percentage survival rate than groundnut, illustrates an important concept of a good trap crop, in that the pest may choose the trap crop over groundnut as a host, but the survival rate will be lower than that of groundnut. It is however not the only criteria on which a trap crop are chosen and the percentage survival in this case is too high for soybean to be used as a trap crop. The results provided in chapter 3 indicated that higher numbers of moths responded to groundnut than soybean when given the choice in laboratory bioassays. Lucern had the lowest number of lesions and pupae per plant, but still a high percentage survival rate. Further experiments over a longer period of time need to be done in order to determine the value of lucern as a possible trap crop for GLM.

6.3.1.4 Mean number of days until first pupae were reared.

The mean number of days until the first pupa was observed from the different plant species was similar for groundnut and soybean (32.6 days). This figure was much higher for lucern, showing that pupae developed faster on groundnut and soybean than on lucern (Fig. 6.4).

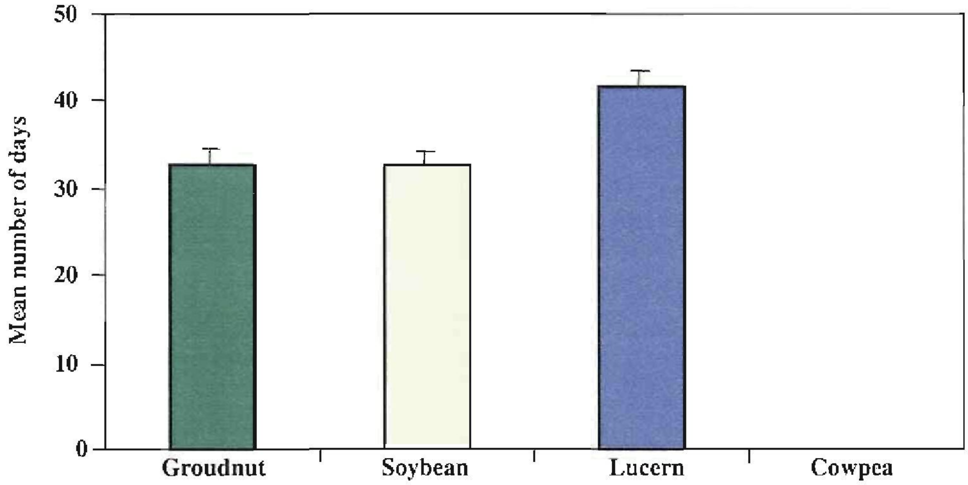

Figure 6.4. The mean number of days until groundnut leafminer pupae were observed on the different cultivated host plant species.

6.3.2 Wild host plants

During visits to the Tshiombo irrigation scheme, eleven possible wild host plant species were collected. All of the plant species were found in groundnut fields and showed symptoms of GLM infestations. Some of the possible wild host plants were found directly next to groundnut plants, with almost the same levels of infestation as the groundnut plants (Fig. 6.5). Last instar GLM larvae would sometimes use the wild host plant leaves as one side of the webbed enclosure for pupation along with a groundnut leaf. The plant species positively identified at SANBI are summarized in table 6.3.

Figure 6.5. An infested wild host plant (*Crotalaria vasculosa* Wall. ex Benth.) next to a groundnut plant in a groundnut field at the Tshiombo irrigation scheme.

Table 6.3. Plant species with groundnut leafminer infestations collected in groundnut fields at the Tshiombo irrigation scheme.

No.	Family	Plant name
1	Malvaceae	*Hibiscus schinzii* Gürke
		Hibiscus physaloides Guill. & Perr.
		Hibiscus nigricaulis Baker f.
2	Fabaceae	*Senna obtusifolia* (L.) Irwin & Barnaby
3		*Senna occidentalis* (L.) Link
4	Pedaliaceae	*Sesamum alatum* Thonn.
5	Fabaceae	*Indigofera astragalina* DC.
6		*Crotalaria vasculosa* Wall. ex Benth.
7	Convolvulaceae	*Ipomoea sinensis* (Desr.) Choisy subsp. *blepharosepala* (Hochst. ex A. Rich) Verdc ex A. Meeuse
8	Tiliaceae	*Corchorus tridens* L.
9	Capparoceae	*Cleome monophylla* L.

Photographs of each possible wild host plant were taken and are presented in figure 6.6 to 6.14 along with distribution maps provided by SANBI illustrated in figure 6.15 to 6.25. The Tshiombo irrigation scheme where the plant species were sampled are indicated in red.

Three different *Hibiscus* species were collected from the Tshiombo irrigation scheme as possible wild host plants of GLM, *viz. H. schinzii* Gürke, *H. physaloides* Guill. & Perr. and *H. nigricaulis* Baker f.. All three these species occurred throughout the Limpopo province and to a smaller extend in Kwazulu Natal. All three the *Hibiscus* species did not seem to occur in one of the other main groundnut production areas of South Africa illustrated on the distribution map. Distribution illustrated in figure 6.15 to 6.17.

Figure 6.6. A possible wild host plant (*Hibiscus* sp.) of the groundnut leafminer, found amongst groundnut plants at the Tshiombo irrigation scheme.

Figure 6.7. A possible wild host plant of the groundnut leafminer, *Senna obtusifolia* (L.) Irwin & Barnaby, found at the Tsiombo irrigation scheme next to groundnut fields.

Two *Senna* species were collected from the Tshiombo irrigation scheme, *viz. S. obtusifolia* (L.) Irwin & Barnaby and *S. occidentalis* (L.) Link. Although *S. obtusifolia* were collected at Tshiombo, it seems that this species does not occur in any of the provinces of South Africa where groundnut is produced.

S. occidentalis does occur commonly in the Limpopo province and Kwazulu Natal. It seems not to occur in the main groundnut production areas of the North-West and Free State provinces. Distribution illustrated in figure 6.18 and 6.19.

Figure 6.8. A possible wild host plant (*Senna occidentalis* (L.) Link) of the groundnut leafminer, found at the Tsiombo irrigation scheme.

Sesamum alatum Thonn. collected at the Tshiombo irrigation scheme, does occur commonly in the Limpopo province. This species has been recorded in Kwazulu Natal, but not in the groundnut production areas. This species seem not to occur in the main groundnut production areas of the North-West province or Free State. Distribution illustrated in figure 6.20.

Figure 6.9. A possible wild host plant (*Sesamum alatum* Thonn.) of the groundnut leafminer, found at the Tsiombo irrigation scheme.

Figure 6.10. A possible wild host plant (*Indigofera astragalina* DC.) of the groundnut leafminer, found at the Tshiombo irrigation scheme.

Indigofera astragalina DC. was found to be present in very high numbers in groundnut fields late in the planting season during one of the field visits. This species grows wild between groundnut plants and hundreds of GLM moths were flying off of these plants when one walked through the groundnut fields. Even though these high numbers of moths were observed on these plants, the larval infestation levels on this plant species were low. This plant species occurs in the northern part of the Limpopo province but seems not to occur in the main groundnut production areas of the North-West, Free State, Kwazulu Natal and the north western parts of the Limpopo province. Distributing illustrated in figure 6.21.

Figure 6.11. A possible wild host plant (*Crotalaria vasculosa* Wall. ex Benth.) of the groundnut leafminer, found at the Tshiombo irrigation scheme.

Crotalaria vasculosa occur only in the northern part of the Limpopo province and the north eastern part of Kwazulu Natal. It seems not to occur in the main groundnut production areas of the western part of the Limpopo province and the central part of Kwazulu natal where groundnut is produced on small scale. *C. vasculosa* do not seem to occur in the other main groundnut production areas of the North-West and Free State provinces. Distribution illustrated in figure 6.22.

Figure 6.12. A possible wild host plant (*Ipomoea sinensis* (Desr.) Choisy subsp. *blepharosepala* (Hochst. ex A. Rich) Verdc ex A. Meeuse) of the groundnut leafminer, found amongst groundnut plants at the Tshiombo irrigation scheme.

Ipomoea sinensis (Desr.) Choisy subsp. *blepharosepala* (Hochst. ex A. Rich) Verdc ex A. Meeuse occur commonly in the Limpopo and Kwazulu Natal provinces. Even though it does occur in the North-West province, it does not seem to occur in the main production areas of groundnut in the North-West or Free State province. Distribution illustrated in figure 6.23.

The distribution of *Corchorus tridens* L. is largely limited to the Limpopo province. It was also recorded n the north-eastern parts of Kwazulu Natal, but not at the groundnut production areas. *C. tridens* seems not to occur in the main production areas of the North-West and Free State province. Distribution illustrated in figure 6.24.

Figure 6.13. *Corchorus tridens* L., a possible wild host plant of the groundnut leafminer, found at the Tshiombo irrigation scheme amongst groundnut plants.

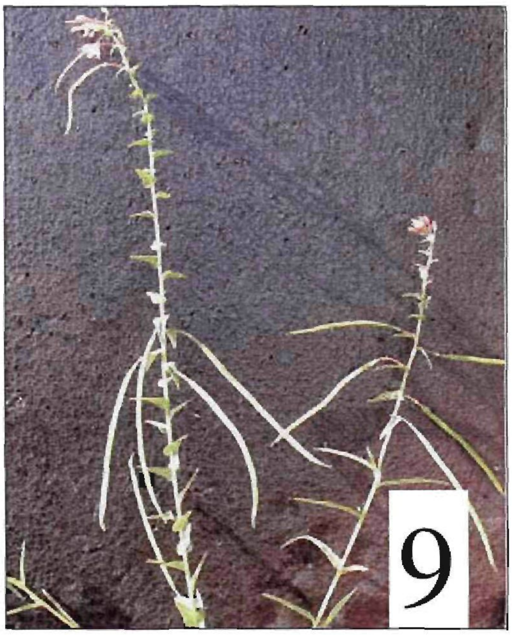

Figure 6.14. *Cleome monophylla* L., a possible wild host plant of the groundnut leafminer, found at the Tshiombo irrigation scheme.

Cleome monophylla L. was the only plant species collected at the Tshiombo irrigation scheme that occurred in all the groundnut production areas of South Africa. It is widely distributed throughout the Limpopo province. It also occurs in Kwazulu Natal, the North-West province, Free State and even the north eastern-parts of the Northern Cape province. Distribution illustrated in figure 6.25.

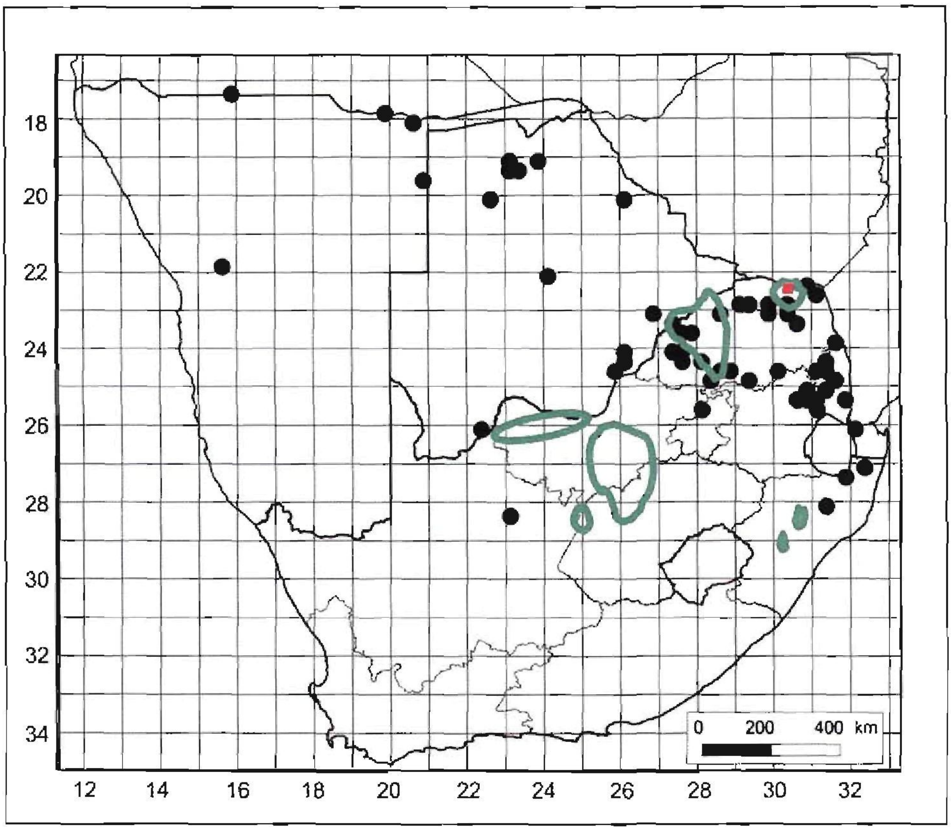

Figure 6.15. Distribution map of *Hibiscus schinzii* Gürke in southern Africa. Groundnut production areas are indicated in green.

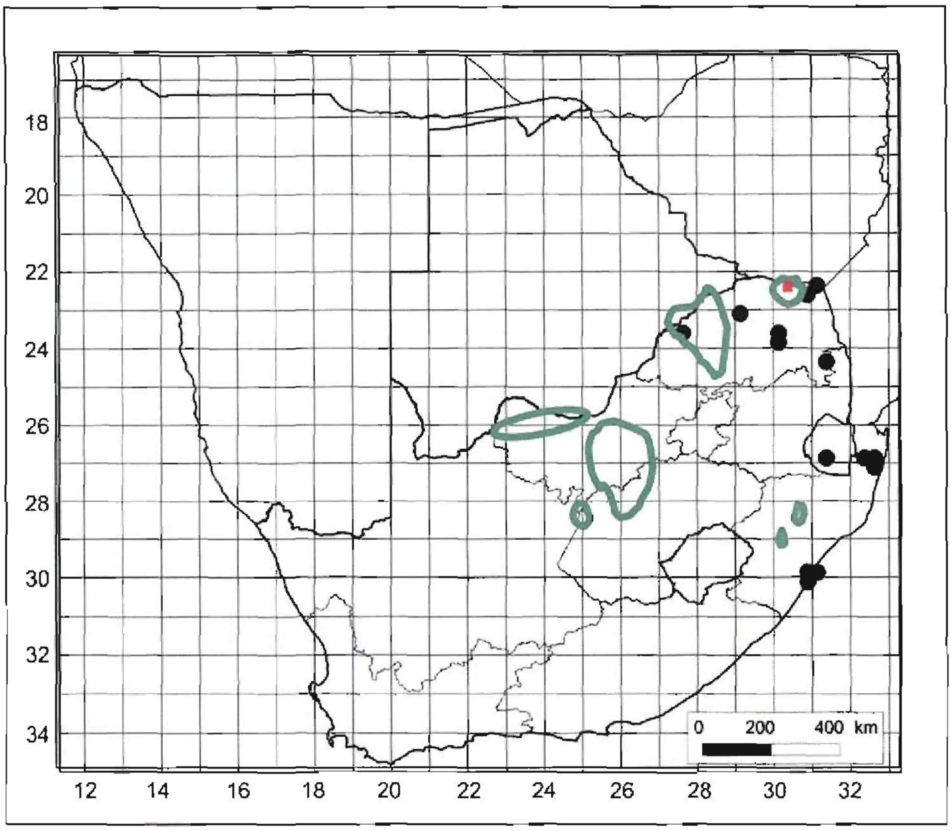

Figure 6.16. Distribution map of *Hibiscus physaloides* Guill. & Perr. in southern Africa. Groundnut production areas are indicated in green.

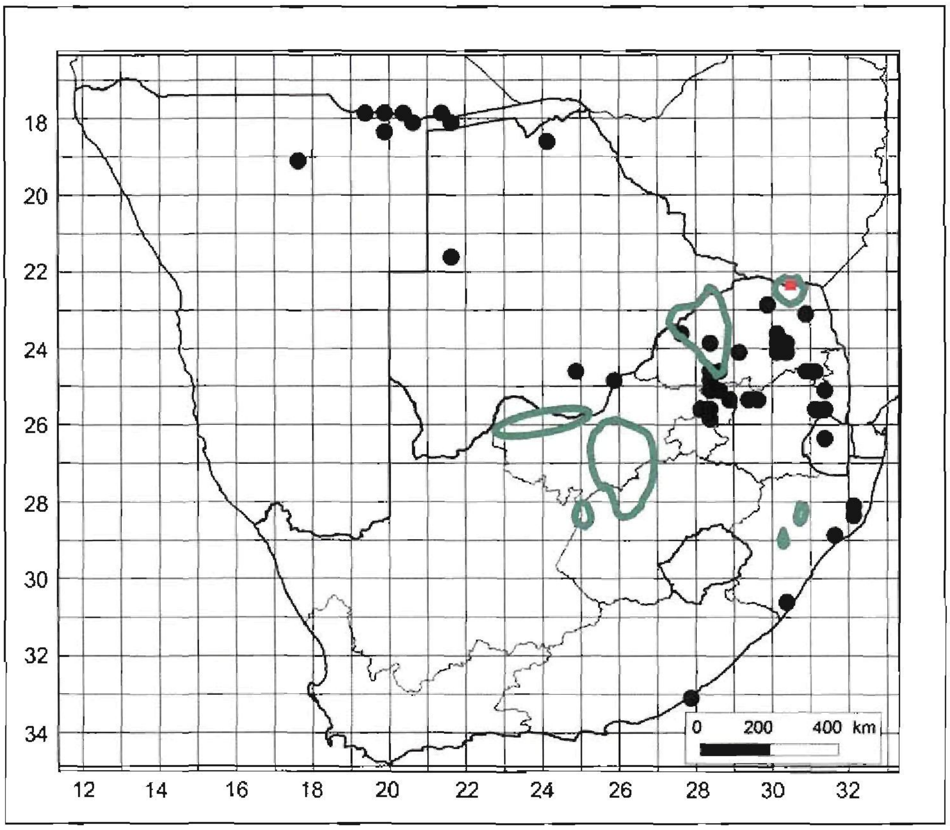

Figure 6.17. Distribution map of *Hibiscus nigricaulis* Baker f. in southern Africa. Groundnut production areas are indicated in green.

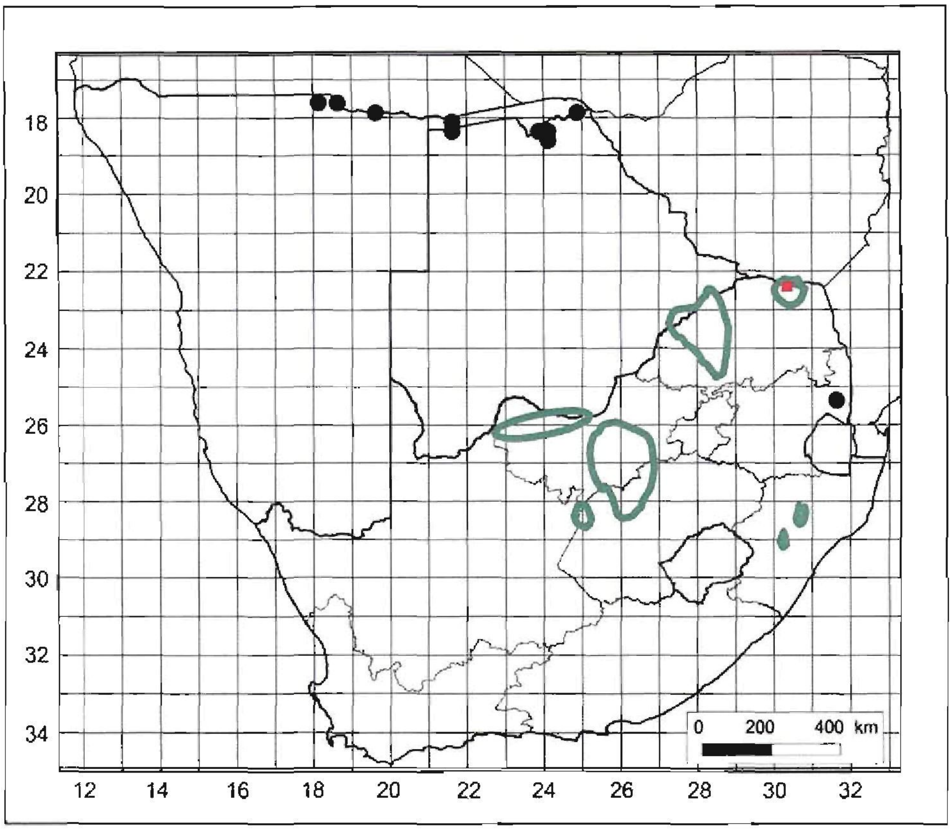

Figure 6.18. Distribution map of *Senna obtusifolia* (L.) Irwin & Barnaby in southern Africa. Groundnut production areas are indicated in green.

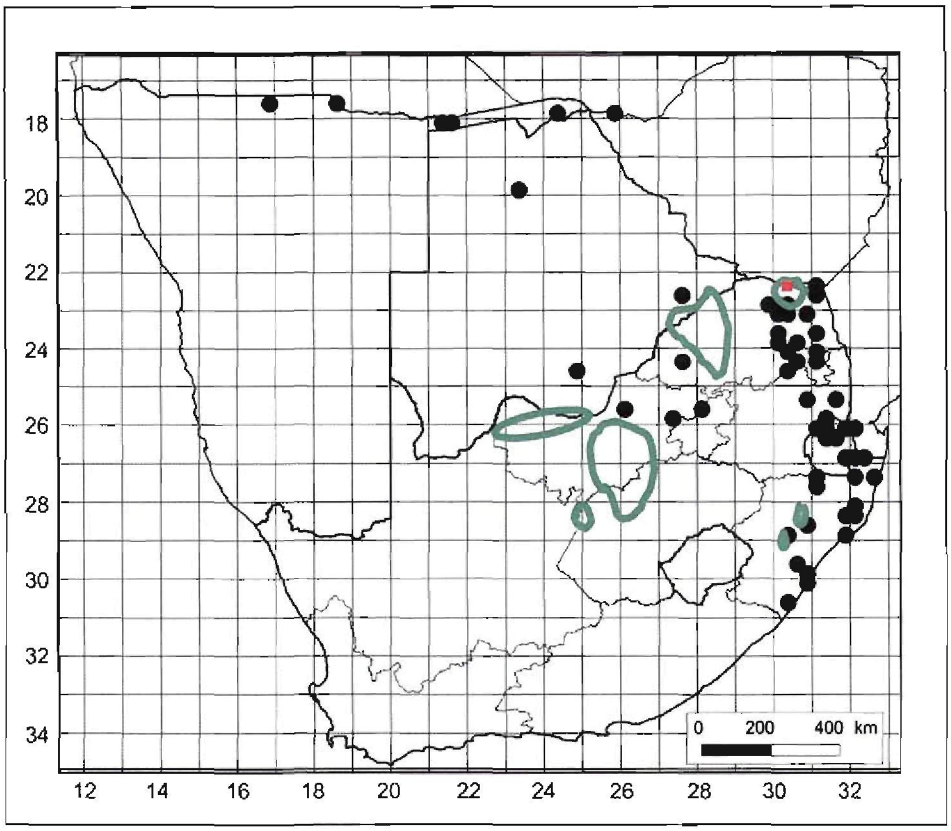

Figure 6.19. Distribution map for *Senna occidentalis* (L.) Link in southern Africa. Groundnut production areas are indicated in green.

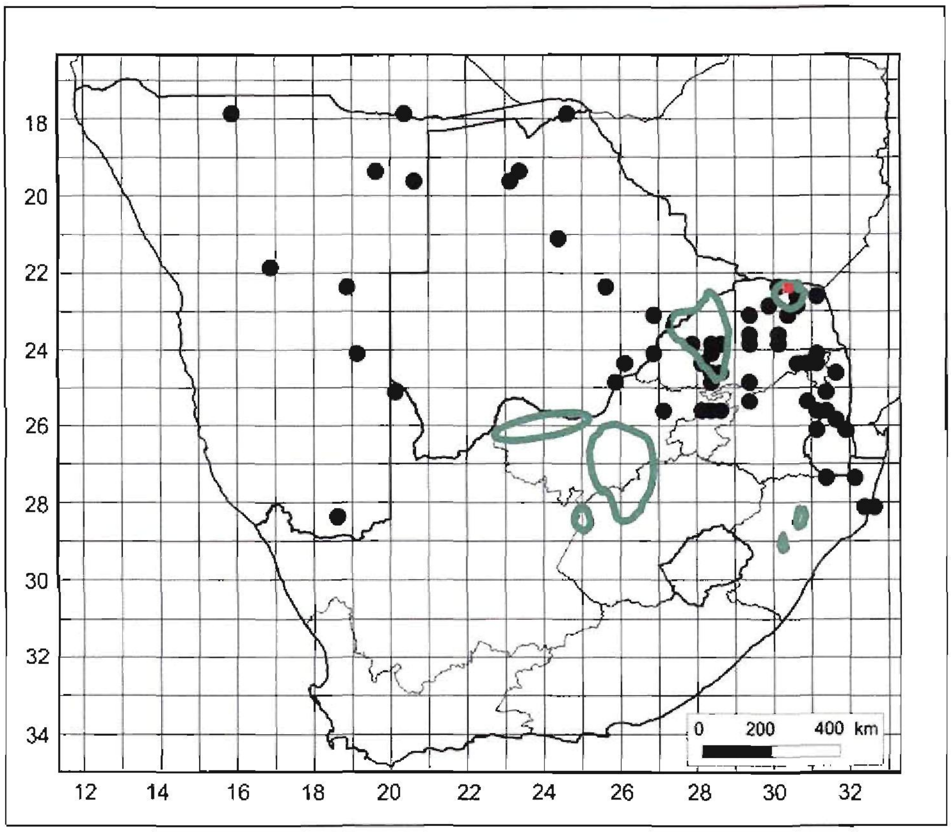

Figure 6.20. Distribution map for *Sesamum alatum* Thonn. in southern Africa. Groundnut production areas are indicated in green.

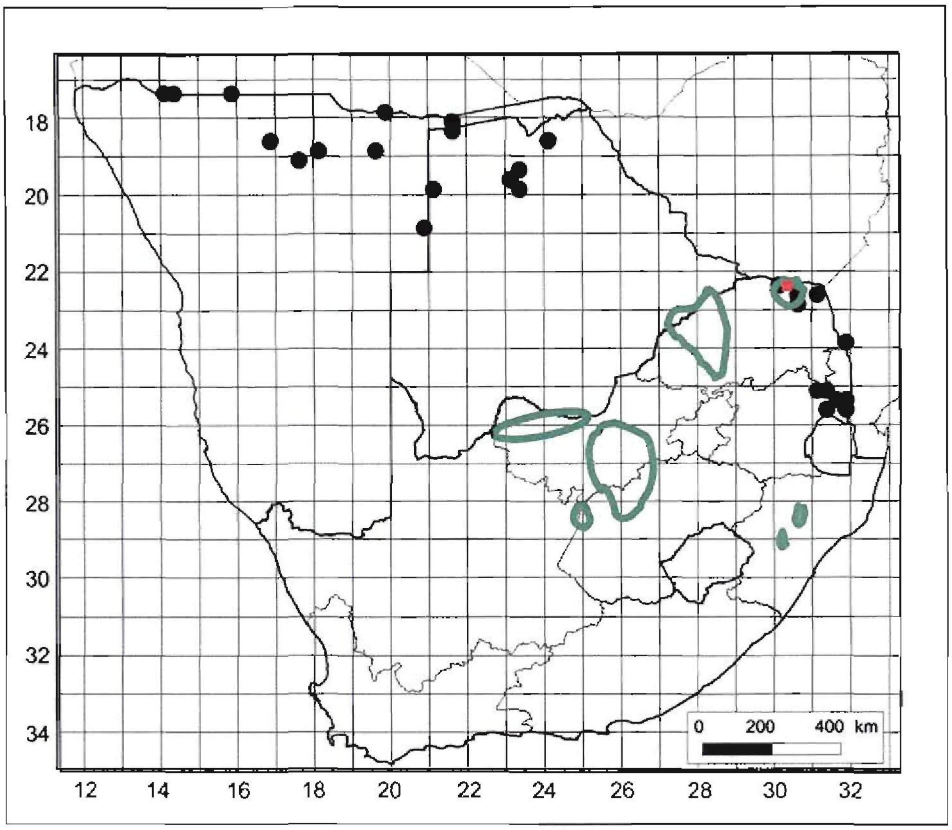

Figure 6.21. Distribution map of *Indigofera astragalina* DC. in southern Africa. Groundnut production areas are indicated in green.

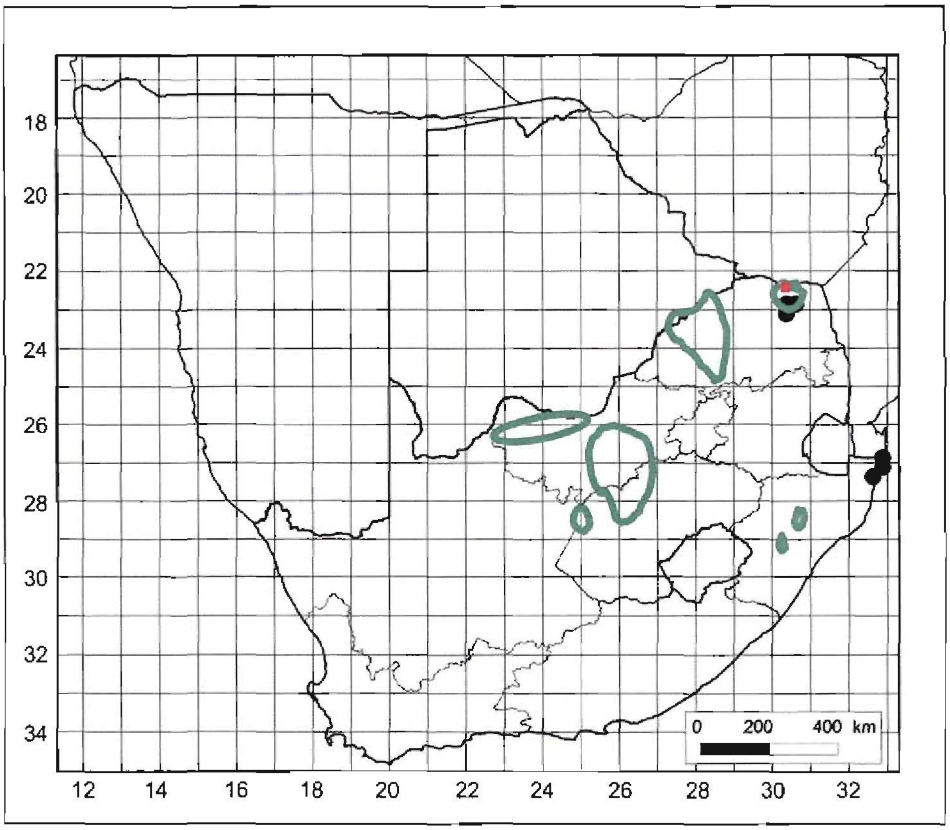

Figure 6.22. Distribution map of *Crotalaria vasculosa* Wall. ex Benth in southern Africa. Groundnut production areas are indicated in green.

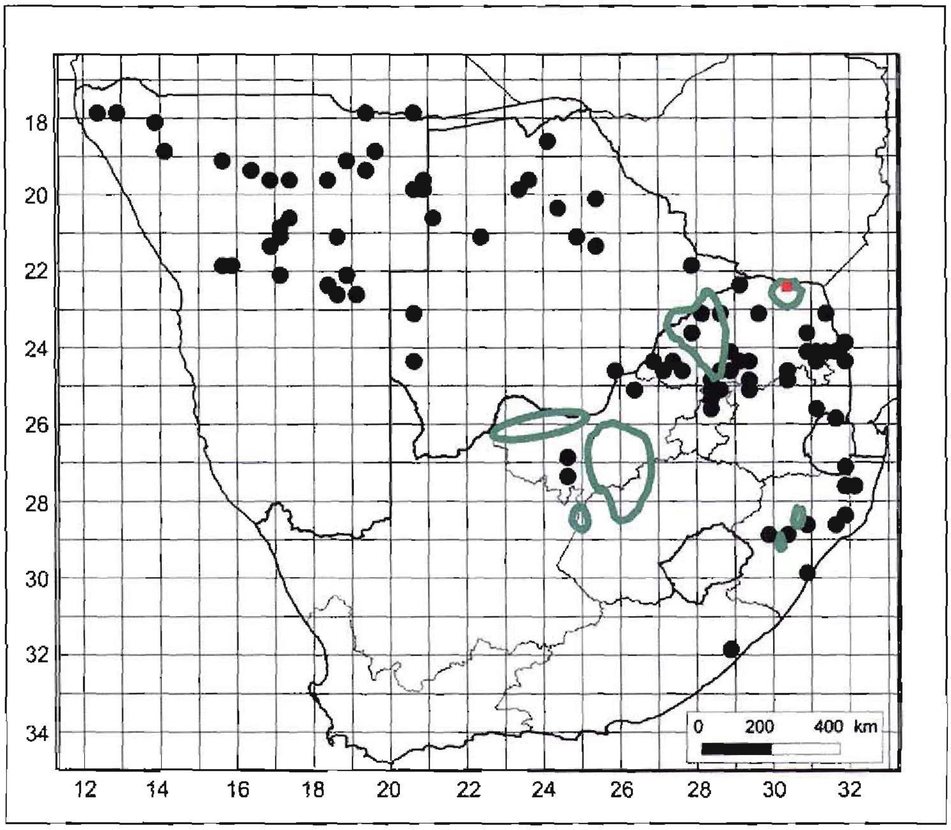

Figure 6.23. Distribution map of *Ipomoea sinensis* (Desr.) Choisy subsp. *blepharosepala* (Hochst. ex A. Rich) Verdc ex A. Meeuse in southern Africa. Groundnut production areas are indicated in green.

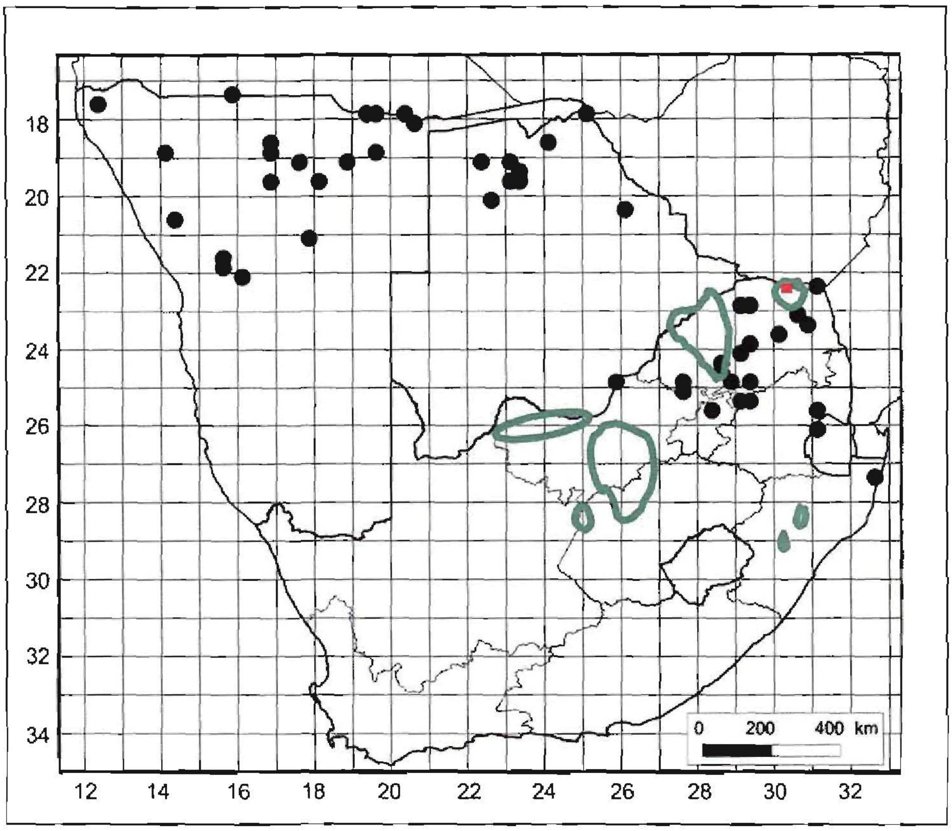

Figure 6.24. Distribution map of *Corchorus tridens* L. in southern Africa. Groundnut production areas are indicated in green.

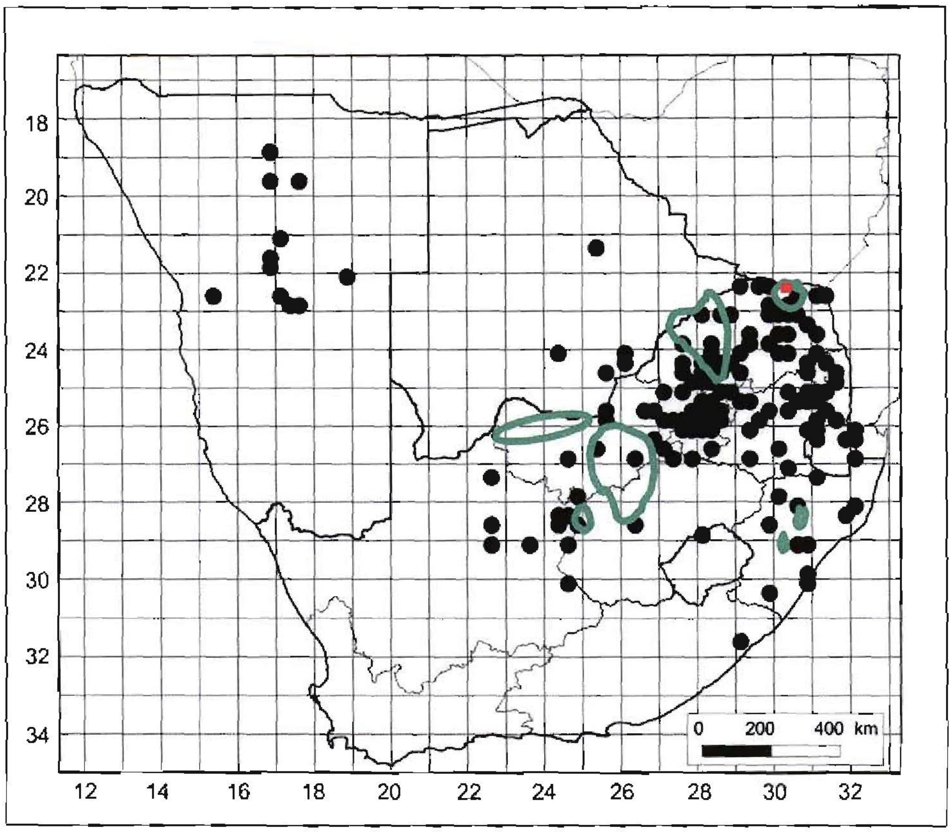

Figure 6.25. Distribution map for *Cleome monophylla* L. in southern Africa. Groundnut production areas are indicated in green.

Out of the eleven plant species collected at the Tshiombo irrigation scheme, all the species except *Senna obtusifolia* occurred in the Limpopo province with *Ipomoea sinensis* and *Crotalaria vasculosa* only occurring in the northern part of the Limpopo province. Eight of the plant species, *viz. H. schinzii, H. physaloides, H. nigricaulis, Senna occidentalis, Sesamum alatum, Crotalaria vasculosa, Ipomoea sinensis* and *Cleome monophylla* occurred in Kwazulu Natal. *Cleome monophylla* was the only species that occurred in all the groundnut production areas of South Africa. Few of the possible wild host plant species recorded in this study occur in the groundnut production areas of the Northern Cape and North-West provinces. This result possibly indicates that other wild host plants are present in these areas which allow for the off season survival of GLM.

None of the wild host plant species collected during this study was previously recorded as wild host plants of GLM except for another *Indigoferea* species, *Indigofera histuta* L. recorded in India. GLM has to be reared through all its development stages on these possible host plants to confirm their status as hosts. Once this has been done, suitability of these plants as possible trap crops as well as their roles in the off-season survival of GLM can be investigated. The same experimental procedures that were used in this study in order to determine GLM preference for other host plants compared to groundnut, can be used in future studies to determine the suitability of these plants as trap crops. The distribution of plant species need to be taken in consideration when trap crops are chosen for a certain area, since the plant species do not occur in all the groundnut production areas of South Africa.

6.4 Conclusion

Results provided in this chapter indicated that the infestation level of GLM on groundnut was lower than that on soybean. The survival rate of GLM on groundnut and the response of most moths to groundnut rather than soybean, resulted in the conclusion that groundnut probably was the preferred host plant of GLM. Eleven possible wild host plant species were collected from the Tshiombo irrigation scheme and the occurrence of these species were compared to the groundnut production areas of South Africa on distribution maps. Further studies need to be conducted in to determine if these plant species plays an important role in the off season survival of this pest.

6.5 References

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Chapter 7

Conclusions

The groundnut leafminer (GLM), Aproaerema modicella are an important pest of groundnut in Asia and was only reported recently in southern Africa during 2000 (du Plessis, 2003). GLM can reduce the yield of the crops by feeding on leaves and thereby reducing the leaf area for photosynthesis (Shanower *et al.*, 1993). Groundnut is an important cash crop to small holder farmers at the Tshiombo irrigation scheme where GLM were observed by farmers as a pest on groundnut since 2000. During 2001 GLM was also found causing damage to groundnut crops over the entire groundnut production area in the Free State, Northern Cape, North-West and Mpumalanga provinces (du Plessis, 2003). *A. modicella* was also observed on soybean in Mpumalanga and lucern in the Northern Cape province in 2001 (du Plessis, 2003)

Since GLM is a new pest in South Africa, no integrated management program for control of the insect exists in South Africa except the use of chemical insecticides. The farmers of the Tshiombo irrigation scheme depend on their farming practices for an income and survival, therefore the use of insecticides are mostly to expensive to use as the only control method in their fields. A study on GLM in Uganda by Page *et al.* (2000) showed that many subsistence farmers were unable to afford chemicals. Farmers at the Tshiombo irrigation scheme also do not have the appropriate equipment and facilities in order to apply and store the chemical insecticides needed to control GLM infestations effectively. Therefore integrated pest management strategies are needed in this area.

To develop an integrated GLM management strategy, research addressing several objectives was conducted at the Tshiombo irrigation scheme as well as some other groundnut production areas in South Africa. These areas included the Vaalharts irrigation scheme, Brugershall irrigation scheme, Brits and Potchefstroom. Research objebtives were:

- To do a survey of small holder farming practices and to determine farmers' perceptions of crop pests.
- To evaluate the preference of GLM moths for groundnut and other host plants.
- To identify characteristics that would enable distinction between male and female larvae and pupae.
- To collect natural enemies of GLM and determine parasitism levels.
- To determine infestation levels of GLM.
- To identify wild host plants of GLM.
- To evaluate the suitability of other host plants for survival of GLM larvae

Farmers play a key role in any research regarding pests and their control in the world of small scale farming (Dicko, 1998). In order to develop a sound management program for GLM, one needs to take cogniscence of farmer's knowledge of this insect pest as well as general socio-economic factors and farming practices before any management program or advice can be introduced and implemented amongst the small scale farmers of the Tshiombo irrigation scheme. Results on the socio-economic factors as well as farming practices of these farmers indicated that chemical control are to expensive and unpractical for them to use successfully. Most of the farmers are between the age of 41 and 60 and they have to walk between 500 m and 3 km to their fields each day. No storage places are available near the groundnut fields in order to store the insecticides and necessary equipment near their fields. Results showed that farmers are aware of pests on all their crops but they do not actively employ any pest management strategies, except for the use of insecticides in some instances.

Farmers at this irrigation scheme did adopt some new technologies such as the use of hybrids, purchasing of seed and mechanical cultivation. Another good custom most of the farmers learned to implement was removing the groundnut residue from their fields and using it as food for their animals. All groundnut farmers were aware of GLM as a "new" invasive pest and were of the opinion that infestation resulted in economic losses. In conclusion, these farmers are in need of simple but effective and suitable management strategies in order to control and keep GLM infestation levels low in the future.

The infestation levels of GLM were studied and large population fluctuations between generations and seasons were recorded and results in an evident reason for a suitable and continues IPM program in order for farmers to be prepared in controlling GLM as a pest. Infestation levels of GLM larvae, pupae and total GLM were higher during 2007 with a similar tendency for both seasons. The mean number of larvae per plant reached 15.9 (SE= ±1.70) during 2007, this being higher than the number of larvae (five to ten) per plant observed in order for insecticides to be applied in India (Shanower *et al.*, 1993). In southern Mozambique, 29-38 larvae per plant were recorded (Kenis & Cugala, 2006) and indicates the high infestation levels that GLM can attain outside it's area of origin.

During the survey done at Tshiombo amongst the farmers, most of the farmers were of opinion that they do not plant late, because damage to late planted groundnut were more severe. This was not practiced over the sampling period at Tshiombo, since the sampling dates run until March (2006) and May (2007) when groudnut were still percent on farmers fields. Therefore the high incidence of GLM infestations during 2007 can also be due to the fact that farmers planted late and only harvested in May 2007. Planting dates are important as part of a strategy for controlling a pest and need to be implemented successfully amongst these farmers along with other IPM methods.

The mortality levels for GLM larvae and pupae resulted in the number of larval and pupal deaths being much lower during 2007. Although the causes of these deaths were unknown, it was concluded that the techniques used could have played a role. In future studies it is recommended that larvae and pupea reared form groundnut or any other plant species should be placed in petri dishes with a thin layer of agar. A thick layer of tissue paper should be placed on the agar layer before the infested leaves are placed in the petri dishes. The lid of the petri dish should also be sealed in such a way that larvae would not be able to escape during the experiment. Leaves and the tissue paper should be changed regularly in order to protect the larvae from excessive water on the one hand and the drying of leaves on the other hand.

Wheatley *et al.* (1989) indicated that GLM numbers can increase up to 20 % per generation in the absence of natural mortality factors and this can result in high population densities present during the pod-filling stage In India, GLM numbers were reported to be higher on the most drought stressed plants and where the leaf surface temperatures were highest through genotypic variation (Wheatley *et al.*, 1989). These are examples of natural mortality factors that were favorable to GLM survival. Temperatures also seem not to have to much of an influence on GLM survival, especially when GLM pupae are enclosed between two GLM leaves.

Even though no fungal and bacterial infections was observed in this study in contrast to studies by Ranga Rao & Reddy (1997) who reported fungal and bacterial infections that caused high levels of mortality during their studies, it can be regarded as mortality factors that can contribute to higher mortality levels of GLM.. Shanower *et al.* (1992) also reported black, "muschy-bodied" larvae and larvae with fungal hyphae growing out of the bodies.

Ranga Rao and Reddy (1997) reported that amongst the various control options, natural control agents play a significant role in the population suppression of GLM. No parasitoids emerged from larvae and pupae sampled at Vaalharts irrigation scheme and Burgershall. One Pteromalus sp. (Pteromalidae) was reared from GLM larvae sampled in Brits on soybean and a Brachymeria sp. (Calcididae) emerged from a GLM pupa on groundnut sampled in Potchefstroom. Six of the parasitoid species reared from groundnut leafminer larvae and pupae were previously recorded in India and Africa as parasitoids of GLM, viz. *Goniozus* sp., *Apanteles* sp., *Brachymeria* sp., *Eupelmus* (Macroneura) sp., *Eurytoma* sp. and *Pteromalus* sp. (Shanower et al., 1993, Cugala & Kennis, 2006 and Muthiah & Kareem, 2000). Three of the species were not previously mentioned as parasitoids of GLM *viz. Hypomicrogaster* sp. and *Cotesia* sp. from the Braconidae family and *Baryscapus* sp. from the Eulophidae family. Some of the Braconidae species were unidentified during this study and future studies need to focus on the identification of these species. Further studies also need to be conducted in order to determine the suitability of these parasitoid species as natural enemies being used in an

IPM program.

Although GLM is a new pest in South Africa, high levels of parasitism occurred with the percentage larval parasitism reaching 54.2% during 2007 and pupal parasitism reaching 43.7% also during 2007. The percentage larval and pupal parasitism were higher for 2007 than 2006. Biological control will therefore play an important role in an integrated control program for GLM in South Africa. This aspect should be taken into consideration when decisions are made on the time of application and which insecticides to use for control of GLM in groundnut fields.

The distribution of GLM on groundnut were concluded to vary all over groundnut plants with no preference for some parts of the plants. Although it seemed as if numbers were lower on young leaves during 2006, it does not indicate that mature leaves are preferred because at the time of egg laying mature leaves could have been regarded as young leaves. GLM infestations therefore occur all over groundnut plants.

Host plant preference of pests can be exploited to manipulate pests in order to limit damage to crops. Since GLM is new invasive pest in South Africa, the need existed to identify its preference for the host plants it were previously recorded on. Insects use chemical information from their environment at all stages of development, to locate food, oviposition and hibernation sites, to come together with conspecifics and sexual partners, and to avoid dangerous situations or unsuitable habitats (Agelopoulos *et al.*, 1999). GLM were previously reported on two other cultivated host plants, soybean and in South Africa (du Plessis, 2003). It can be concluded that groundnut compared to the other possible hosts, was the most preferred by groundnut leafminer moths. Soybean was also a highly preferred host for GLM moths. These results therefore show that moths do have preferences for certain cultivated host plant species that may also be planted in groundnut farming systems. This study therefore provide a basis for future development of trap cropping as a pest management tool for GLM. However, more experiments, for example experiments where the survival of GLM on these plants are calculated need to be conducted. It is important that the trap crop is more attractive to the pest than the main crop, at least at some critical time, but preferably over long periods (Hokkanen, 1991). This needs to be kept in mind when the above mentioned plants are discussed as possible trap crops for GLM.

In the Y-tube olfactometer experiment the moths selected a plant on the basis of plant volatiles, while the survival of GLM on these plants were recorded in chapter 6. The mean number of days until first lesions were visible, mean number of lesions per plant and the survival rate of GLM on the four different crops were conducted in a study comparing the three plant species that were also used in the Y-tube olfactometer experiment to groundnut. Results indicated that the larval development rate was higher on groundnut compared to soybean, lucern and cowpea with visible damage by GLM larvae observed on groundnut eight (SE= ± 2.08) days after egg laying. No damage by GLM were observed on cowpea during this study, even though moths did respond to cowpea in the Y-tube olfactometer experiment. The reason for this cannot be explained, but it might be possible that GLM moths preferred cowpea by the presence of green leaf volatiles during the Y-tube experiment, but the leaves were not suitable for ovipostion or survival of larvae during the no-choice test. Another reason that may be contributing to the observed results indicating some degree of acceptance of cowpea is that male moths, which may respond differently to host plant odors, were also used in these bioassays.

This is because some factors make it impossible to distinguish between live male and female GLM moths. These factors include the small size of GLM moths, the fact that the whole body of GLM moths are covered with small featherlike scales and the fact that these moths are very active.

Cowpea could be a suitable plant to use in intercropping systems because of the results. The fact that no infestation levels of GLM occurred on cowpea, although GLM moths responded to cowpea in the Y-tube olfactometer experiments, does not mean that cowpea cannot be used in intercropping. Intercropping includes planting different crops on the same field, either in different rows or as a mixture as is often done by subsistence farmers. Logiswaran and Mohanasundaram (1985), cited by Shanower *et al.* (1993)

reported lower GLM larval densities when groundnut was intercropped with sorghum, millet or cowpea, than in monoculture groundnut. Further studies need to be done in order to confirm these findings.

Further results indicated that the infestation level of GLM pupae on groundnut was lower than that on soybean. The mean number of lesions per plant was highest on soybean with a mean of 19 lesions per plant, 28 days after egg laying. The standard error of soybean in the calculation for the mean number of pupae per plant (14.67, SE= ± 12.72) was ascribed to the fact that a very high number of pupae was reared from one of the replications, compared to the other two replications. This also influenced the reason why the infestation rate on soybean were higher than that of groundnut. The survival rate of GLM on groundnut and the response of most moths to groundnut rather than soybean, resulted in the conclusion that groundnut probably was the preferred host plant of GLM.

Wild host plants play an important role in the ecology of many pest species (Norris & Kogan, 2000). Fourteen host plant species of which nine are cultivated as crops have been reported to host GLM in India (Shanower *et al.*, 1993). Eleven possible wild host plant species were collected from the Tshiombo irrigation scheme and the occurrence of these species were compared to the groundnut production areas of South Africa on distribution maps. Further studies need to be conducted in order to determine if these plant species play an important role in the off season survival of this pest. Most of the plant species compared on the distribution maps, were commonly found in the Limpopo province and may result in suitable host plants that might play a role in the off season survival of GLM. None of the wild host plant species collected during this study was previously recorded as wild host plants of GLM except for another *Indigoferea* species, *Indigofera histuta* L. recorded in India (Shanower *et al.*, 1993).

As mentioned above, research on oviposition behavior and host plant preference of GLM is hampered by the fact that male and female moths cannot easily be distinguished. Previous studies done by Shanower et al. (1993), only indicated that GLM male and female could be distinguished during the larval stage by the presence of pink gonads of the male which are visible through the cuticle but did not provide more detail.

GLM larvae, pupae and moths were studied intensively in order to determine any differences between male and females other than at the larval stage. The position of the male genital aperture on GLM pupae is a useful distinguishing characteristic. The male genital aperture is further away from the proximal side of the last abdominal segment, compared to the aperture of the oviduct and bursa copulatrix of the female. The genital aperture of the male pupa is approximately in the middle third of the last abdominal segment while the genital aperture is in the upper third of the last abdominal segment, closer to the proximal side of the segment. This creates the impression that a male pupa has an additional segment before the segment on which the genital aperture and the anus occur. These differences are illustrated in Chapter 4 in figure 4.1 to 4.5.

7.1 References

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