STUDIES ON INSECT PESTS OF *Sesbania sesban* WITH SPECIAL EMPHASIS ON *Mesoplatys ochroptera* (CHRYSOMELIDAE: COLEOPTERA) IN SOUTHERN AFRICA

BY

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DECLARATIONS

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

27th July 2000

Sileshi Gudeta Weldesemayat Date

I confirm that the work reported in this thesis was carried out by the candidate under my supervision. I have read and approved this thesis for examination.

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DEDICATION

I dedicate this dissertation to

My wife, Yimegne Berhane Mache

My sons, Kaleb and Cherubiel

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ABSTRACT

There has been considerable interest in *Sesbania sesban* (L.) Merrill and related species because these have consistently shown high biomass production in agroforestry systems. Damage by insect pests was found to be one of the limiting factors to the wide spread adoption of Sesbania by farmers. The objectives of this study were to (1) determine the distribution and abundance of insects feeding on *S. sesban*, (2) define the biology and population dynamics of *M. ochroptera* and *Exosoma* sp., (3) identify natural enemies of *M. ochroptera*, (4) identify accessions of *S. sesban* resistant to *M. ochroptera* and (5) determine the effect of damage by *M. ochroptera* on the growth and yield of *S. sesban*.

Over 105 species belonging to 56 families in 13 orders of arthropods were found associated with *S. sesban*. Herbivores were the most specious guild accounting for more than 50% of all species. They attacked all parts of *S. sesban* and caused varying degrees of damage at different growth stages of the plant. However, the most vulnerable was the seedling stage in the nursery or immediately after transplanting which was severely damaged by beetles and grasshoppers. The beneficial insects included 44 species of natural enemies and 9 species of pollinators. Most of the species were reported for the first time on *S. sesban* in southern Africa.

M. ochroptera and *Exosoma* sp. were the most serious pests on *S. sesban*, both in terms of numbers and the damage done to the foliage. The annual cycle of activity in *M. ochroptera* and *Exosoma* sp. followed the unimodal rainfall pattern of southern Africa. *M. ochroptera* females laid 2-70 eggs in a masses every day during an oviposition period of up to 56 days. The eggs took 2 to 9 days to hatch. There were three larval instars and larval development took 11 to 34 days. Pupation occurred in the soil and this took 4 to 16 days. The life cycle from egg to adult emergence took 16 to 43 days. The host plants of *M. ochroptera* in southern Africa included *S. bispinosa*, *S. brevipeduncula*, *S. leptocacrpa*, *S. macrantha*, *S. rostrata*, *S. sericea*, *S. sesban* and *S. tetraptera*.

Afrius yolofa (Guérin-Ménville), *Glypsus conspicuus* Westwood, *Macrorhaphis acuta* Dallas, *Mecosoma mensor* Germar, *Rhinocoris segmentarius* (Germar) *Deraeocoris ostentans* (Stål), *Cyaneodinodes fasciger* (Chaudoir), *Tetramorium sericeiventre* Emery, *Pheidole* sp. and *Mallada* sp. were recorded for the first time as predators of *M. ochroptera*. The braconid *Perilitus larvicida* van Achterberg and the nematode *Hexamermis* parasitized both the larvae and adults. No egg and pupal parasitoids of *M. ochroptera* were found.

Thirty accessions of *Sesbania* were screened for resistance against *M. ochroptera* and three mechanisms of resistance—antixenosis, antibiosis and tolerance—were found in the species. *Sesbania bispinosa*, *Sesbania leptocacrpa* and *Sesbania macrantha* accesions were more preferred to *Sesbania sesban* and *Sesbania rostrata* accessions. Antibiosis was manifested by a significant ($P<0.05$) reduction in foliage consumption by larvae, reduction in the weight of larvae and adults, reduction in larval and pupal survivorship and prolonged developmental period of the beetle on resistant *Sesbania* accessions. Two accessions of *S. sesban*—Kakamega and Kisii—showed tolerance to *M. ochroptera* damage.

Artificial infestation of 2-3 month old *S. sesban* seedlings with up to 30 larvae and adults per seedling produced less than 25% defoliation whereas more than 90 larvae per seedling caused 80-100% defoliation. Removal of up to 100% of the foliage manually at one, two and three months after transplanting did not significantly reduce (P>0.05) height growth, branch number, basal diameter, and leaf and stem fresh weights of *Sesbania*.

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CHAPTER 1

1.0 GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

In most of sub-Saharan Africa, heavy population pressure, exacerbated by a range of social and political factors have resulted in widespread land degradation and the expansion of agriculture on to marginal land and drier areas traditionally reserved for livestock grazing (Cooper *et al*., 1996). Such lands are prone to wind and water erosion of the topsoil where the bulk of soil nutrients available to crops are located. Human induced water erosion accounts for nearly 50% of land degradation in Africa (WRI, 1992).

As a direct consequence of forest and woodland clearing and the denudation of the landscape, shortages of building materials and fuelwood has drastically increased. Fodder shortages are also an important constraint, particularly in the sub-humid regions (Cooper *et al*., 1996).

Agroforestry, through both the services and production functions of trees, has the potential to alleviate many of the above problems through soil fertility replenishment, reduction of soil erosion, the provision of dry season fodder and generation of income (Cooper *et al*., 1996; Buresh and Tian, 1997; Sanchez *et al*., 1997). At the ecosystem level, trees in agroforestry systems have environmental benefits such as reduction of soil erosion, conservation of bio-diversity and carbon sequestration (Unruh *et al*., 1993; Sanchez *et al*., 1997). At the farm level, trees can improve soil fertility through maintenance of soil organic matter, biological nitrogen fixation, uptake of nutrients from below the reach of crop roots, increased water infiltration and storage, reduced loss of nutrients by erosion and leaching, improved soil physical properties, reduced soil acidity and improved soil biological activity (Sanchez *et al.*, 1997; Young, 1997). From a production perspective, trees provide fuelwood, building materials and dry-season fodder. They are also an important source of income generation through the provision of high-value products such as poles, timber, fruits, medicines, resins and gums (Cooper *et al.*, 1996).

Agroforestry is defined as a set of land use practices that involve the deliberate combination of woody perennials (shrubs, palms, bamboos) and agricultural crops and/or animals on the same land management unit in some form of spatial arrangement or in temporal sequence such that there are significant interactions between trees and agricultural components (Lundgren and Raintree, 1982; Nair, 1993; Sinclair, 1999). Agroforestry embraces an ecosystem focus considering the stability, sustainability and equitability of land-use systems, in addition to their productivity. Consideration of social as well as ecological and economic aspects is implied (Sinclair, 1999). A wide variety of both traditional, as well as relatively new agricultural systems fall under the umbrella of agroforestry (Nair, 1989; Sinclair, 1999) and review of all the practices is beyond the scope of this work.

There are both ecological and economic interactions between the woody and non-woody components in agroforestry systems (ICRAF, 1993; Nair, 1993). The net effect of these interactions is often determined by the influence of the tree component on the other components and/or on the overall system. The effect may be expressed in terms of quantifiable responses such as soil fertility changes, microclimate modification, resource availability and utilisation, allelopathy, and pest and disease incidence (Rao *et al.*, 1998).

1.2 LITERATURE REVIEW

1.2.1 Agroforestry practices in southern Africa

As in the rest of sub-Saharan Africa, southern African countries are faced with shortage of human food and animal feed, the degradation of non-renewable resources and decreasing access to forest products (ICRAF, 1995). The rapid increase in population (>3% per year) has led to deforestation to meet the requirements of fuelwood, charcoal, poles and timber, and clearing for agricultural land. In Zambia, for instance, the rate of deforestation is estimated to be 200,000 ha per year (Kwesiga and Kamau, 1989).

The main land-use system in southern Africa is maize cropping and livestock production, which are loosely integrated (ICRAF, 1998). Livestock production is extensive, depending mainly on traditional communal grazing by cattle and goats. Maize is the region's predominant food crop but sorghum, millet and various legumes are also grown. About 58% and 81% of all cultivated land is under maize in Malawi and eastern Zambia (Ngugi, 1988), respectively. Maize is a crop whose yield is highly sensitive to deficiencies in soil fertility. One way to replenish the soil is to use inorganic fertilisers and organic nutrient sources. However, inorganic fertilisers are expensive for cash-strapped farmers. This has been exacerbated by the devaluation of currencies and removal of government subsidies in countries like Zambia. In majority of the southern African countries, fertiliser is imported and quite often, countries do not have the necessary infrastructure to deliver it on time (Kwesiga and Beniest, 1998; Kwesiga *et al*., 1999).

In most parts of southern Africa, the traditional slash and burn shifting cultivation and fallow systems are no longer sustainable for crop production (Chidumayo, 1987; Matthews *et al*., 1992; Torquebieu and Kwesiga, 1996). Mansfield *et al*. (1976) estimated 20-30 years as the regeneration period required to sustain the *chitemene* system of shifting cultivation in northern Zambia. *Chitemene* is a form of slash-and-burn cultivation, but is unique in that the lopped area is much larger than the cropped area (Stromgaard, 1989). The destabilising effect of overpopulation on shifting cultivation systems has reduced the fallow periods from 25 to 12 years (Chidumayo, 1987). Similarly, on the plateau in eastern Zambia, bush and grass fallows of twenty years or longer sustaining modest maize yields with low financial inputs, have been abandoned and fallows of only one to five years are common today (Torquebieu and Kwesiga, 1996). Such shortened fallow periods are inadequate to restore soil fertility, and the decline of crop yields has led to increased clearing of even steep hillsides unsuitable for crop production (Banda *et al.*, 1994). Smallholder farmers are the worst affected by this situation and they are eagerly looking for alternative means of overcoming these problems.

In 1985, the International Centre for Research in Agroforestry (ICRAF) initiated agroforestry research to alleviate the above described land use problems. ICRAF's research in southern Africa is focused on the unimodal upland plateau eco-region including Malawi, Tanzania, Zambia and Zimbabwe (Fig. 1). This eco-region is characterised by a single rainy season (annual rainfall of 500-1200 mm) from December to April, followed by a severe dry season that lasts for seven to eight months. The upland plateau zone in which ICRAF works lies between 600-1200 m above sea level and is characterised by the *miombo* woodland. The *miombo* is a form of woodland vegetation dominated by slow growing mainly deciduous trees of the genus *Brachystegia*, *Julbernardia* and *Isoberlinia* forming a 15-20 meter high, single storey, light but closed canopy over a forest floor consisting mainly of the grasses *Hyperrhenia* and *Digitaria* species (Lawton, 1978). This ecosystem extends from southern Tanzania to Zimbabwe and is being threatened by the slash and burn agriculture.

Deforestation of the *miombo* woodland has created large tracts of land of declining productivity throughout the region, reducing diversity and eroding the genetic base of numerous tree species (ICRAF, 1998). ICRAF's research is also aimed at protecting this ecosystem.

Researchers have been examining many agroforestry technologies such as alley cropping (Matthews *et al.* 1992), relay intercropping (Maghembe and Prins, 1992) and short-rotation fallows (Kwesiga and Coe, 1994). Alley cropping has not significantly improved maize yields (Matthews *et al.* 1992) and was found unsuitable to replace the *Chitemene* system in northern Zambia (Holden, 1993). So far, short-rotation tree fallows (Kwesiga and Coe, 1994) and relay intercropping (Maghembe *et al.*, 1995) have shown promise in southern Africa.

Fallows are croplands left without crops for periods ranging from one season to several years. In the sub-humid tropics, fallows are used to occupy land that is not cropped for a few months or two to three years, in order to accumulate biomass and nutrients (Sanchez, 1999). According to Sanchez (1999) there are three distinct types of tropical fallows—natural, enriched and improved fallows. Natural fallows are early succession stages of secondary vegetation that comes after the land is taken out of cropping. Natural woody fallows are the backbone of shifting cultivation systems. Enriched fallows are those where certain tree species are planted at low densities into natural fallows to produce high value products such as fruits, medicines, or timber to provide economic benefits during the fallow period. Improved fallows on the other extreme consist of deliberately planted species—usually legumes with the primary purpose of fixing nitrogen as part of a crop-fallow rotation. Improved fallow species are normally planted shortly before or after the crops are harvested. On the unimodal rainfall plateau of eastern Zambia, short-duration improved fallows with leguminous shrubs such as *Sesbania* and *Tephrosia* are shown to improve soil fertility (Barios *et al.*, 1997) and increase crop yields (Kwesiga and Coe, 1994).

The small size of the holdings in parts of southern Africa precludes the widespread use of fallows and limits the introduction of agroforestry technologies in which trees occupy a high proportion of cropland (Minae, no date). With this constraint, ICRAF's collaborative programme in Malawi has been experimenting with relay intercropping since 1989 (ICRAF, 1993). Relay intercropping involves planting trees/shrubs between rows or within the rows of an already established crop. In Malawi, over 94% of the cropland is intercropped (Edje, 1979), so relay intercropping is an appropriate technology for this region (Phiri *et al.*, 1999).

1.2.2 Sesbania in agroforestry

There are over 50 known species of *Sesbania* in Africa (Onim *et al.*, 1990) and Africa is the region of its greatest diversity (Gillett, 1963; Evans & Rotar, 1987). There is considerable variation between species and within species in growth and biomass production (Otieno *et al.*, 1991; Maghembe and Prins, 1992; Rao and Gill, 1993; Karachi *et al.*, 1994), longevity, coppicing

(Maghembe and Prins, 1992) as well as in nitrogen fixation and nutrient mobilisation (Rao and Gill, 1993). Several species of *Sesbania* have been tested in agroforestry systems in southern Africa. So far the most successful species has been *Sesbania sesban* L. (Merrill) (Kwesiga *et al.*, 1999). *S. sesban* is commonly found along riverbanks, streams, and in waterlogged depressions, known as *dambos* in southern Africa. *S. sesban* provenances establish rapidly and grow fast in the *miombo* and have shown promise as a drought tolerant agroforestry species (Sandys-Winsch and Harris, 1992). In addition, they are nodulated well by the local rhizobium strains and the nitrogen content of their leaves is high. They are also easy to establish using seedlings (Kwesiga and Beniest, 1998). These characteristics make *S. sesban* ideal for replenishing fertility in nitrogen-depleted soils.

There has been considerable interest recently in *S. sesban* and its related perennial species because this group of species has consistently shown high biomass production in agroforestry systems (NAS, 1983; Otieno, *et al.*, 1991; Maghembe and Prins, 1992; Karachi *et al.*, 1994). The high biomass yields have been associated with high nutrient content of the foliage, especially nitrogen (Evans and Rotar, 1987; Ghai *et al.*, 1988; Onim *et al.*, 1990; Rao and Gill, 1993; Mafongoya *et al.*, 1998). Recent studies have capitalised these aspects and showed considerable improvement in crop yields using sesbania in short rotation fallows (Kwesiga and Coe, 1993) and relay intercropping (Maghembe and Prins, 1992). Positive results have also been demonstrated in the use of sesbania foliage as a green manure (Ghai *et al.*, 1988; Owino *et al.*, 1990).

Sesbania improved fallows were found to be attractive both biologically and financially in western Kenya (Jama *et al.*, 1998) and eastern Zambia (Barios *et al.*, 1997; Kwesiga *et al.*, 1999). In eastern Zambia, sesbania in three year fallows produced about 6 tons of leaf-fall ha^{-1} year^{-1} in on-station trials, which inputs into the soil about 120 kg N ha^{-1} (Torquebieu and Kwesiga, 1996). About 7 tons of roots ha^{-1} remain in the soil and slowly decompose to increase soil fertility over time (Kwesiga and Coe, 1994).

In addition to improving soil physical and chemical conditions (Barios *et al.*, 1997), sesbania also produces substantial amount of fuelwood. For instance, a two-year fallow is capable of producing 10 to 35 tons ha^{-1} (Torquebieu and Kwesiga, 1996). Sesbania also provides high quality fodder for animals (NAS, 1983; Heering, 1995). It can grow throughout the dry season as a browse species in semiarid areas (Wandera *et al.*, 1991). Sesbania has also been shown to serve as a "trap crop" to trigger suicidal germination of *Striga* (*S. hermonthica* and *S. asiatica*) (Oswald *et al.*, 1996). In Kenya, sesbania trees reduced the number of *Striga* seeds in the soil by 34% while in maize plots the *Striga* population increased over the same period by 11% (ICRAF, 1993). Similar results have also been observed in Zambia, showing the promise of sesbania fallows for the millions of farmers whose crops are devastated each year by *Striga* (ICRAF, 1993).

In southern Africa, eastern Zambia has been the focal point for research on improved fallows using sesbania and to date, substantial progress has been made there in terms of farmer adoption and impact on the livelihood of farm families (ICRAF, 1997). Short-rotation (2-3 years) sesbania fallows significantly improved maize yields without any inorganic fertilisers (Kwesiga and Coe, 1994; Torquebieu and Kwesiga, 1996). Promising results were also reported elsewhere in southern Africa. On-station research in Malawi, Tanzania and Zimbabwe has shown that two- or three-year sesbania fallows can double or treble maize yields over those obtained following natural grass fallows (ICRAF, 1998; Mafongoya and Dzowela, 1999). Maize yields following the two and three-year sesbania fallows were also statistically similar to the yields in fully fertilised controls (ICRAF, 1998). As a result, the adoption of sesbania-improved fallows is spreading rapidly in eastern Zambia (Kwesiga *et al.*, 1999). ICRAF and its collaborating partners are now working with thousands of farmers who are experimenting with sesbania-improved fallows in southern Africa (ICRAF, 1998). One of the main reasons that the improved fallows using sesbania seem to be taking off is that it is a modification of an existing technology and fits well into the farming system (Kwesiga and Coe, 1994; Kwesiga *et al.*, 1999).

Relay intercropping of *Sesbania* with maize has also shown some promise in Malawi (Snapp *et al.*, 1998; Phiri *et al.*, 1999). The technology was designed to maintain the full-recommended population of maize while utilising the soil improving capability of sesbania. Sesbania seedlings are planted in the standing maize, and after harvest the trees are allowed to grow until the end of the dry season. Then the trees are cut and the leaves, flowers, pods and twigs are incorporated into the soil and maize is sown (Maghembe *et al.*, 1995). This system allows growing maize continuously every year and *Sesbania* is grown essentially as a dry season fallow.

1.2.3 Pest management in relation to agroforestry practices

The inclusion of diverse species in agroforestry systems is generally believed to reduce pest incidence. This optimism is based on the observation that structural heterogeneity and genetic diversity in agro-ecosystems regulate pest populations (Van Emden and Williams, 1974; Vandermeer, 1989). Although greater plant diversity in agroforestry is expected to increase beneficial arthropods, diversity itself may not reduce pests (Rao *et al.*, 2000). Most of the experimental evidence for reduced herbivore attack in diversified agro-ecosystems comes from studies on mixtures of annual crops, especially intercrops. Three mechanisms—the disruptive crop effect, the natural enemies effect and trap-crop effect—are known to be responsible for the reduction of herbivore load in intercrops (Root, 1973; Trenbath, 1976; Vandermeer, 1989).

The disruptive-crop phenomenon may operate either because (a) one of the component species makes it difficult for the herbivore to locate the host by confusing it or (b) the insect leaves that patch because of presence of non-host plants (Bach, 1980; Risch, 1981; Uvah and Coaker, 1984). The disruptive species may exert its influence indirectly by creating an unfavourable microclimate for the pest. Intercropping may affect the quality of the individual host plants making them less attractive to the pest compared with that in monoculture (Bach, 1981). The disruptive-crop hypothesis is largely applicable to specialist herbivores (Vandermeer, 1989).

The natural enemies hypothesis (Root, 1973) attributes lower pest abundance in more diverse systems to a higher density of predators and parasitoids (Bach, 1980). The greater density of natural enemies may be caused by an improvement in conditions for their survival and reproduction. This may be due to the greater temporal and spatial distribution of nectar and pollen sources that may increase parasitoid reproductive potential and an abundance of alternative hosts/prey when the pest species are scarce or at an inappropriate stage (Risch, 1981).

The final mechanism by which an intercrop reduces pests is provided by the trap-crop hypothesis (Vandermeer, 1989). The presence of a second crop in the vicinity of a principal crop may attract a pest that would otherwise attack the principal crop (Sarup *et al.*, 1977). Trap cropping is generally applicable to generalist herbivores (Vandermeer, 1989).

All crop mixtures in intercrops do not necessarily lead to reduced herbivore attack. In an examination of 150 studies involving a total of 198 insect species, 53% were found to be less abundant in a more diversified system, 18% were more abundant, 9% showed no difference and 20% showed variable response (Risch *et al.*, 1983). Clearly the majority of the species were less abundant in more diversified systems but 38% were either more abundant or produced a variable response, which indicates the need for caution and greater understanding of the mechanisms involved.

Indeed, for the same cropping system and the same insect results can vary considerably (Vandermeer, 1989). Crop spacing, density and spatial arrangement within the same system may lead to variable response by the same pest species. For instance, in sorghum-haricot bean intercrops where three sorghum densities and four row arrangements were combined, Sileshi (1994) found significant differences in the incidence of the sorghum shoot fly, *Atherigona soccata*, between the different combinations. There are also cases where tree species mixtures have increased susceptibility to injurious agents (Perry and Maghembe, 1990). Response is highly dependent on both plant and pest species (Kareiva, 1983). Therefore, blind adherence to the principle that more diversified system such as agroforests will reduce pest infestation is clearly inadequate.

Unlike crop species mixtures, most agroforestry systems are characterised by both species and structural diversity, and close interactions between tree and non-tree components (Nair, 1989). The contrasts between the component species in their physical dimensions, their life span and their physiological responses may lead to complex interactions between the tree and crop species, pests and their natural enemies in the system. Therefore, pest management needs more complex technical, managerial and socio-economic considerations in agroforestry systems than in intercropping systems (Huxley and Greenland, 1989). The arrangement and management of trees in relation to crops within an agroforestry technology has a bearing on micro-climatic factors (Altieri *et al.*, 1987; Altieri, 1999) and thus may modify the environment and pest incidence on crops (Huxley and Greenland, 1989). A pest may also be shared between the tree and the associated crop and the resultant primary and secondary interactions may assume considerable significance. Therefore, tree fallows might have an impact on crops in terms of pests and diseases. As a result of the growing awareness of pest problems and the complexity of interactions in agroforestry systems, ICRAF has adopted pest management as a separate project in its Ecosystem Rehabilitation Programme. Survey of potential pest species, particularly during exploration for new germplasm, identification of potential pests of priority agroforestry species and field assessment of actuality of pest problems has been strongly recommended (Huxley and Greenland, 1989).

Today forest entomologists no longer think in terms of the control of pests, but rather of their management (Tho, 1985). The modern approach to pest control is to stress on integrated pest management (IPM). IPM is defined as a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilises all suitable techniques and methods in as compatible a manner as possible and maintains the pest population levels below those causing economic injury (Smith and Reynolds, 1966).

Integrated pest management hinges on two important prerequisites: (1) that the population ecology of the pest in the agro-ecosystem be well understood, and (2) that the pest population density at which economic damage to the crop occurs (economic threshold) be known (Dent, 1991). IPM represents a complete change in philosophy of pest control, away from pest eradication towards pest management, i.e. the management of entire populations, not just localised ones. IPM is a more ecologically oriented approach that incorporates the use of control techniques based on an understanding of the ecology (Varley *et al.*, 1973) and life history of the pest. Instead of a single control technique, an emphasis is placed on the use of a combination of methods, aimed at providing cheap but long term reliability with minimum of harmful side effects (Rabb, 1970).

Generally, in developing an IPM programme, the manager will need to evaluate carefully the extent and type of pest problem to be undertaken, and on the basis of this evaluation produce an initial appraisal from which a management strategy will evolve (Gotsch and Braunschweig, 1999). There are two elements to such an evaluation, the first concerns the pest and what is known about its interactions with the environment and the second element concerns the availability of potential control options for use in the management of the pest (Dent, 1991; Gotsch and Braunschweig, 1999). All relevant information on the pest (life cycle, host preference, mobility, fecundity), data on how the pest interacts with the physical environment (climate, weather and soil) and the biotic environment (the host, natural enemies, competing species) will be useful in selecting appropriate control measures and designing IPM programmes (Varley *et al*., 1973; Dent, 1991).

Sufficient information must also be gathered about the farming system to permit the development of an appropriate pest management programme that will take into account the environment, farm enterprises and the household resources at the disposal of the farmer. The type of farming practised by a farmer will also be influenced by such factors as culture, tradition, religion, wealth and education (Dent, 1991). The social circumstances of farmers are intrinsically linked to their interest in and ability to protect their crops and livestock against pests. Therefore, insect pest management must not be treated in isolation of these social factors. Pest management must also be compatible with environmental quality and conservation of biological diversity.

1.2.4 Pests of sesbania

Despite great promise for *S. sesban*, pest problems are likely to become a major constraint to adoption of sesbania fallow systems. In many African countries, the establishment of sesbania has failed because of damage by the root knot nematodes (Karachi, 1995). A number of insects have also been reported to damage *Sesbania* species in Africa and Asia. For example, based on a literature search, Singh Rathore (1995) compiled a total of 26 records of insect species reported to have infested Sesbania. He also reported five other insect species feeding on Sesbania in Kenya and Rwanda, based on field observations. Besides the insects in the native plant range, a number of insects of exotic plant range were found associated with Sesbania (Murphy, 1990).

The insects known to feed on *Sesbania* species in Africa include *Mesoplatys ochroptera* Stål, *Mesoplatys cincta* Olivier (Chrysomelidae: Coleoptera), *Formicomus* sp. (Coleoptera: Anthicidae), *Medythia quaterna* (Fairmaire) (Coleoptera: Galerucinae), *Trochalus* sp. (Melolonthidae: Coleoptera), *Hilda patruelis* Stål (Homoptera: Tettigometridae), *Rhiptorus* sp., *Anoplocnemis curvipes* (Coreidae: Heteroptera) (Hill, 1966; Toguebaye and Marchand, 1986; ICRAF, 1991; Mchowa and Ngugi, 1994; Wightman and Wightman, 1994; Critchley *et al.*, 1999).

Recent reports have indicated the defoliating beetle, *M. ochroptera*, as one of the most serious insect pests of Sesbania in Ethiopia and Malawi (Mchowa and Ngugi, 1994; Wale *et al.*, 1996). The beetle has been reported to damage Sesbania in the seedling stage to cause failure of stand establishment, and to defoliate trees at later stages to deprive the foliage of its economic value (Steinmüller, 1995; Wale *et al.*, 1996). An undescribed species of *Exosoma* was also found to be one of the serious defoliator of *S. sesban* in agroforestry in southern Malawi (Mchowa, Personal Communication).

Apart from these isolated reports of the occurrence of particular insects and the literature reviews by Evans and Rotar (1987) and Murphy (1990), no systematic studies have been published on insects damaging *Sesbania sesban* in Africa. Information is also lacking on beneficial insects such as natural enemies and pollinator insects associated with sesbania. The present work is an attempt to provide an adequate understanding of the pest problems on sesbania and the ecological processes involved in the interaction between its major pests and their natural enemies in agroforestry systems.

1.3 HYPOTHESES

- Several insects feed on *S. sesban* in natural stands and in agroforestry
- *M. ochroptera* is a key "pest" of *S. sesban*
- There is no information on the biology of *M. ochroptera*
- *M. ochroptera* does not have natural enemies
- There are no *Sesbania* accessions resistant to *M. ochroptera*
- Damage by *M. ochroptera* does not reduce growth and yield of *S. sesban*

1.4 OBJECTIVES OF THE STUDY

The general objective of this work is to contribute towards the development of an IPM program for the key pests of *S. sesban*. Towards that end the following specific objectives were formulated:

- To determine the distribution and abundance of insects feeding on *S. sesban* in agroforestry systems in southern Malawi and eastern Zambia,
- To study the biology and population dynamics of *M. ochroptera* on *S. sesban*.
- To identify natural enemies of *M. ochroptera*
- To assess the potential of host-plant resistance in the management of *M. ochroptera*.
- To determine the effect of damage by *M. ochroptera* on the growth and yield of *S. sesban*.

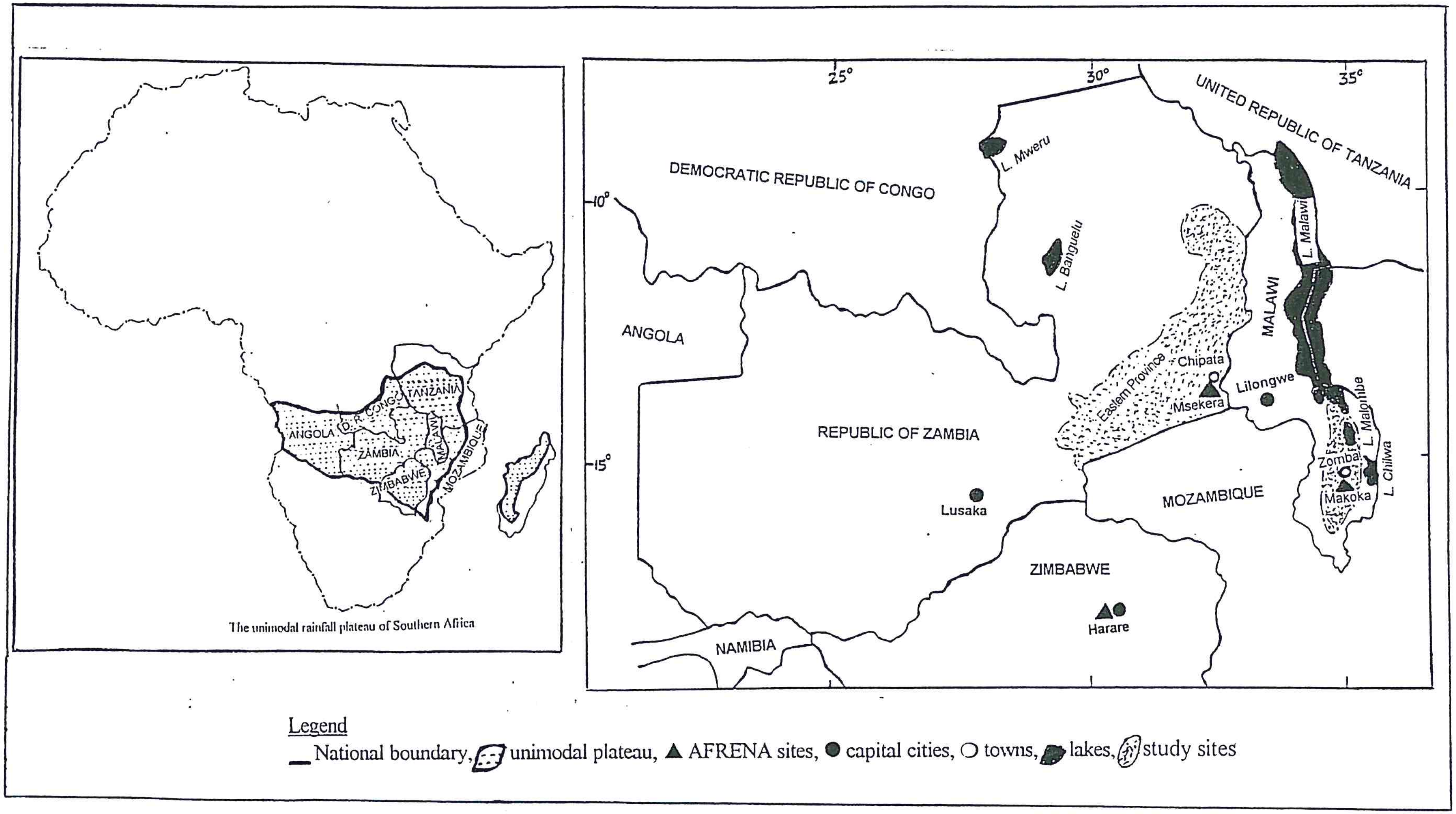

Fig. 1. The unimodal rainfall plateau of Southern Africa, AFRENA sites and the study area

CHAPTER 2

2.0 ARTHROPODS ASSOCIATED WITH SESBANIA[ǂ]

2.1 INTRODUCTION

Although *S. sesban* is being tested widely and promoted in agroforestry systems in eastern and southern Africa (ICRAF, 1995; Kwesiga *et al.*, 1999), there is limited knowledge about insect fauna attacking the tree in sub-Saharan Africa. Knowledge of the injurious and beneficial arthropods associated with sesbania is worthwhile not only for the information of agroforestry practitioners but also for the benefit of economic entomologists in the region. Information is also scanty on the biology and ecology of insects feeding on *Sesbania* spp. and the threshold levels of damage for *S. sesban* grown in different systems for different purposes. This information is essential in order to determine the pest status of insects and to plan for appropriate management strategies.

Huxley and Greenland (1989) emphasised the need for undertaking surveys to identify pests of trees and crops and studying the influence of tree–crop interactions on pests in agroforestry systems. As the use of *Sesbania* in agricultural systems is relatively new in southern Africa, monitoring *Sesbania* on farms alone would not give a complete picture of the insect's status.

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A series of surveys were undertaken in natural stands, on farms and research stations to monitor insect fauna associated with *S. sesban*. The objectives of the surveys were to (1) identify the range of harmful and beneficial arthropods associated with *Sesbania* species, particularly *S. sesban* and (2) identify the insects that may potentially become pests of *S. sesban* and other *Sesbania* species in agroforestry.

2.2 MATERIALS AND METHODS

2.2.1 The study areas

2.2.1.1 Southern Malawi

The study area (Mangochi and Zomba districts) in southern Malawi (Fig. 2.1) lies between 14°3' S and 15°5' S latitudes and 34°8' and 35°5' E longitudes, with altitudes ranging from about 400 m near the lakeshore (L. Malawi) to about 1050 m in the Zomba plateau. The area receives rainfall varying from 750 to 1050 mm in one rainy season, from November to April.

The vegetation consists of lakeshore savannah grassland and thickets. The major crops grown in the area include maize (*Zea mays* L.), groundnut (*Arachis hypogaea* L.), bean (*Phaseolus vulgaris* L.), cow pea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan* (L.) Millsp), cotton (*Gossypium hirsutum* L.), tobacco (*Nicotiana tabacum* L.) and cassava (*Manihot esculenta* Crantz). Except for tobacco, all other crops are interplanted with maize.

2.2.1.2 Eastern Zambia

The study area covered most of Eastern Province of Zambia. The Province is situated between latitudes 10° and 15° south and longitudes 30° and 33° east (Fig 2.2). Eastern Province covers a total area of approximately 70,000 square kilometres. The Province is characterised by gentle to moderate slopes that are punctuated with hills, ridges, and minor escarpments in a rolling landscape that is the chief characteristic of the dissected plateau of Zambia. Seasonally waterlogged, low-lying areas (*dambos*) are also a common feature. The plateau area rises to an altitude of 900 -1200 m a.s.l., while in some low lying areas, depressions and the lower reaches of the Luangwa valley rise to altitudes of 300-600 m a.s.l.

The soils of the eastern plateau are variable, the most dominant being the sand veldt group. In the well-drained, hilly areas and escarpments the common soils are ferric luvisols and lithosols. The sand veldt soils are moderately leached, well drained, relatively fertile and suitable for both rain-fed and irrigated crop production. However, owing to the sandy nature of the predominant soil type, they are characterised by low water and nutrient-holding capacity (Ngugi, 1988).

The climate is classified as subtropical with three distinct seasons: the warm wet season (November to April), the cool winter (May to August) and the hot, dry season (September to October). The rainfall averages about 960 mm per year (range 887-1014 mm) with approximately 85% of the rains falling during December-March. The average air temperatures vary between the means of 15° and 18° C during the coldest months of June and July; and between 21° and 26° C during the hottest months of September and October. The growing season starts in November and lasts between 135 and 155 days (Ngugi, 1988).

The crops grown in the farming systems include maize, groundnuts, sunflower, beans, finger millet and cassava. The major crops are planted on the upland during the rainy season while the *dambos* are reserved for assorted vegetables and fruit crops in the dry season (Ngugi, 1988).

2.2.2 The sampling procedure

2.2.2.1 Southern Malawi

Natural stands of *S. sesban* were sampled at four sites outside farms (Nkope, Kadawere, Palm Forest and Palm Beach) and three sites on farms in Mangochi District. Three separate surveys were undertaken around the lakeshore, one in December 1997 and two in February 1998. The surveys were conducted during the rainy period when insects were expected to be abundant. *S. sesban* plants were visually examined for insects. The adult insects were collected by hand, using a sweep net or an aspirator (pooter), depending on the size and agility of the insects. Insects in immature stages (such as caterpillars) were collected by hand for rearing to the adult stage. Some of the larvae failed to develop into adults. The adults collected from the field and reared in the laboratory were placed in a killing jar containing cotton wool soaked in ethyl acetate. In order to catalogue alternative hosts of the insects, specimens of host plants were collected and identified with the help of taxonomists at the National Herbarium and Botanical Gardens (NHBG) of Malawi.

In each area visited, populations of the most prevalent insect species (*M. ochroptera* and *Brachyplatys testudonigro* F.) were counted on the *Sesbania* species encountered. Ten plants of approximately the same size (less than 1 m tall) were selected for each *Sesbania* species and the number of insects per plant recorded. For all insects observed on *S. sesbania*, the potential for each to damage crop plants was judged qualitatively, based on visual observations of frequency of occurrence and host range. Literature was consulted wherever possible (Lee, 1971; Bohlen, 1973; Hill, 1983).

A seed orchard of *S. sesban* established by ICRAF at Palm Forest was visited during the first and last surveys. The orchard was 2 years old, and half of the plot (about 10 m x 10 m) was weeded 1 month before the survey. The rest was left unweeded. While the trees in the weeded area were free from *Mesoplatys* beetles and *Brachyplatys* bugs, those in the unweeded area were severely infested by both these insects. Following this observation, adults of *M. ochroptera* and *B. testudonigro* were counted on two shoots (branch tips with 10 fully expanded leaves) of 10 randomly selected trees from each of the sub-plots. The data were transformed into $\log_{10}(x+1)$ values and the difference between the two was tested by t-test.

Research plots on farms around Govala (altitude 600 m), Thondwe (950 m) and Makoka (1029 m), seed orchards, and nurseries and research plots at the Makoka Research Station in Zomba District were visited two or more times during the rainy season (November 1997 to February 1998). In all these visits, no attempt was made to quantify the populations of different insect species observed on their respective host plants, but only qualitative observations were made on the abundance of insects relative to those in natural stands.

2.2.2.2 Eastern Zambia

The surveys were conducted in improved fallows at the Msekera Research Station, farmers' fields and natural stands. At the research station, several fallow fields of *Sesbania sesban* and *Sesbania macrantha* scattered over an area of 407 ha were monitored fortnightly from October 1997 to March 2000. In addition, over 30 farmers' fields were visited at different periods in five districts (Chadiza, Chipata South, Chipata North, and Katete) in eastern Province (Fig. 2.2).

Seedlings and trees were sampled separately. In sampling seedlings, the direct count method was used. In the case of big trees, sedentary insects were counted by visual examination of the shoots, branches and the trunk. Agile insects were collected by means of an aspirator and a standard sweep net. Insects in immature stages were collected by hand for rearing to the adult stage. Where aerial parts of the plant were not accessible, insects were sampled by beating the branches and tree trunk with a stick, and collecting the insects on a tray of white calico stretched across a wooden frame. Plants showing symptoms of root attack were uprooted and examined for root feeding insects.

Flowers were cut and placed in specimen tubes containing 70% alcohol and insects were separated and preserved. Pods and seeds of sesbania were visually examined for seed-feeding insects in the field and insects found feeding or laying eggs were collected. During each sampling, 30-50 pods with different levels of maturity were collected and placed individually in Petri dishes for rearing seed-feeding insects and their natural enemies. Adult insects collected from the field and reared in the laboratory were killed and then preserved in 70% alcohol for identification.

The direct count and visual observation methods gave an indication of what the species was doing and on what part it was feeding. Frequency of occurrence of an insect was scored based on percentage infested plants (in seedlings) or plant parts (shoots, flowers, pods, etc. in mature plants) as follows: <5% (rare), 5-50% (common) and >50% (abundant). A provisional pest status was assigned to some of the injurious insects based on their frequency of occurrence and subjective evaluation of the damage they caused.

Insect specimens were identified by specialists of the NHM, CABI, TM, PPRI (see Appendix 1), and by being compared with specimen collections available at the FRIM and the Makoka Agricultural Research Station.

2.3 RESULTS

2.3.1 Southern Malawi

A total of 30 species belonging to 7 orders of insects and 1 mite were observed to attack *S. sesban* in natural stands (Table 2.1.). Of these species, the most common were *M. ochroptera* and *B. testudonigro*. Among other species, *Eurytoma* sp., *Euproctis rubricosta* Fawc., *Plusia orichalcea* F., *Tetranychus* sp. and an unidentified moth (Tortricidae) were found frequently on naturally growing *S. sesban*. A number of insects that attacked *S. sesban* were found to damage many other agroforestry tree species, crops and weeds (Table 2.2). However, *M. ochroptera* attacked only plants of the genus *Sesbania* (*S. bispinosa*, *S. leptocarpa*, *S. macrantha*, *S. rostrata*, *S. sericea*, *S. sesban* and *S. tetraptera*). In contrast, *B. testudonigro* was found to feed on a number of legume genera (Table 2.3).

As the range of *Sesbania* species in the natural stands at Palm Beach and on farm sites was limited and insect populations were low, quantitative results are reported only from three sites (Table 2.3). *Sesbania* species showed substantial differences in the degree of infestation by *M. ochroptera* and *B. testudonigro*. Compared with the perennial *S. sesban*, the fast-growing annual species were more heavily infested by these insects. *Sesbania* species ranked for the relative density of *M. ochroptera* and *B. testudonigro* populations as follows: *S. tetraptera* = *S. bispinosa* = *S. leptocarpa* > *S. sericea* > *S. sesban* > *S. rostrata*.

The trend was similar at all the three sites visited (Table 2.3). In sesbania-maize relay intercropping systems at Makoka, the biennial *S. macrantha* was attacked more severely than the perennial *S. sesban*. In another field experiment at Makoka where *S. macrantha*, *S. tetraptera* and *S. sesban* were planted side-by-side, *S. sesban* was the least affected.

Natural stands of *Sesbania* hosting *M. ochroptera* and *B. testudonigro* occurred in two distinct habitats: the well-drained plains and the seasonally flooded areas, including the lakeshores. In the well-drained plains, *S. bispinosa, S. tetraptera* and *S. leptocarpa* were common and *S. sesban* was rare. These species were found growing mixed with a number of legume shrubs such as *Aeschynomene indica*, *Crotalaria, Indigofera, Chamaesyce*, *Senna* and *Tephrosia* species and grasses such as *Dactyloctenium*, *Digitaria*, *Panicum* and *Setaria* species. *M. ochroptera* and *B. testudonigro* occurred in large numbers in such areas. Along the lakeshores and in seasonally flooded areas, *S. sesban, S. sericea* and *S. rostrata* were found growing in association with the shrubs *Aeschynomene afraspera*, *A. cristata* and *A. elaphroxylon* and the grasses *Eriochloa borumensis*, *Panicum repens, Phragmatis mauritianus* and *Vossia cuspidata.* Infestations by *M. ochroptera* and *B. testudonigro* in these areas were light and sporadic compared with those in the well-drained plains. *S. rostrata* was relatively free from infestation by both insects.

Ootheca sp. and *Exosoma* sp. were more common in *Sesbania*/maize relay intercropping on farms and at the Makoka Research Station than in the natural stands. In both Mangochi and Zomba districts, *Ootheca* sp. was found mainly in gardens (locally called *dimbas*) located in *dambos* where leguminous crops such as cow pea and bean were grown with *S. sesbania*. *Exosoma* sp. occurred in large numbers only in the *S. sesban* seed orchard at Palm Forest and in farms in Zomba district. The frequency of occurrence of other insects such as *Anoplocnemis curvipes*, *Aphis fabae*, *Hilda patruelis*, *Megalurothrips sjostedti*, *Mylabris dicincta* and *Nezara viridula* was similar in natural stands and farmers' fields. These insects also attacked other agroforestry trees and crops in addition to damaging *S. sesban* (Table 2.2).

In the seed orchard at Palm Forest, *S. sesban* trees in the unweeded plot contained three times more populations of *M. ochroptera* and eight times that of *B. testudonigro* per shoot than the trees in the weed-free plot (Table 2.4). The predominant weeds in the unweeded plot included *Crotalaria virgulata, Desmodium demissa*, *Indigofera astragalina* and *Tephrosia purpurea* (Leguminosae), *Abutilon angustifolia* (Malvaceae), *Ceratotheca sesamoides* (Pedalaceae), *Boerhavia erecta* (Nyctaginaceae), *Corchorus olitorius* (Tiliaceae), and *Dactylactenium aegyptiaca* and *Setaria* sp. (Poaceae). The leguminous weeds *C. virgulata, D. demissa*, *I. astragalina* and *T. purpurea* were severely infested by *B. testudonigro.*

In addition to insects, natural enemies were also recorded in the study area. Predatory insects on *M. ochroptera* included *Afrius yolofa*, *Glypsus conspicuus*, *Macrorhaphis acuta* and *Mecosoma mensor* (Pentatomidae:

Heteroptera), *Rhinocoris segmentarius* (Reduvidae: Heteroptera), *Cyaneodinodes faciger* (Carabidae: Coleoptera), and two unidentified spider species (Aranae). Adults and nymphs of the Pentatomidae occurred in large numbers and attacked eggs, larvae and adults of *M. ochroptera*. The predatory species were more abundant in the well-drained plains, where *S. bispinosa, S. tetraptera* and *S. leptocarpa* grew together with *Panicum maximum* grass, than in the other habitats. An unidentified hymenopteran egg parasite was observed on *B. testudonigro* in the natural stands and farms.

2.3.2 Eastern Zambia

Over 105 arthropod species belonging to 56 families in 11 orders of insects were found associated with *S. sesban*. The species composition of each order was Hymenoptera (35%), Coleoptera (23%), Heteroptera (16%), Homoptera (5%), Lepidoptera (5%), Thysanoptera (4%), Isoptera (4%), Diptera (3%), Orthoptera (3%), Neuroptera (1%) and Dictyoptera (1%). In addition to insects, two families of spiders (Agriopidae and Thomisidae: Aranae) were commonly found preying on other insects. Herbivores were the most specious (52 species) guild accounting for over 50% of all species. Beneficial insects accounted for 50% (49 species.) of which natural enemies were 42% (44 spp.) and pollinator insects were 8% (9 spp.). In this comparison "tourists" (*sensu* Moran and Southwood, 1982) or insects that have no intimate or lasting association with sesbania were not included. These included several families of Diptera (Anthomyidae, Cecidomyiidae, Chloropidae, Diopsidae, Drosophilidae, Lonchaidae, Milichidae, Muscidae, Psychodidae, Sarcophagidae, Tephritidae), Dictyoptera (suborder Blattodea) and Hymenoptera (Formicidae) that may be attracted to sesbania for shelter, as a site for sun basking and sexual display or honeydew.

2.3.2.1 Herbivore insects

Most of the herbivore insects occurred during the rainy season while few were observed during the cold winter and the hot seasons (Table 2.5). Herbivore insects attacked every part of *S. sesban* causing damage of varying degree at different growth stages of the plant. However, the most vulnerable was found to be the seedling stage in the nursery and soon after transplanting which was severely damaged by defoliator insects. Many ecologists have found it useful to group insects into feeding guilds (*sensu* Root, 1973) in order to study the ecological interactions between insects, their hosts, their natural enemies, and climate (Speight *et al.*, 1999). Accordingly, insects feeding on *S. sesban* were conveniently divided into five major guilds as root-feeders, leaf-feeders, sap-feeders, flower-feeders and seed-feeders.

2.3.2.1.1 Root-Feeders

The main root-feeding insects were termites and white grubs (Table 2.5). The crater termite *Odontotermes* spp. and three other species were common in the sesbania fallows. In most of the fallow fields visited, farmers attributed death of plants to termite damage. However, close examination of dead plants revealed no visible termite damage. Root damage by white grubs was also sporadic and less conspicuous. In most cases, attempts to rear white grubs into the adult stage failed. On a few occasions, the larvae of *Schizonycha* sp., found in roots of dead plants were successfully reared.

2.3.2.1.2 Leaf-feeders

This feeding guild consisted of the most serious pests of *S. sesban* (Table 2.5). *Mesoplatys ochroptera* Stål, *Exosoma* sp., *Ootheca benningseni* Weis., *Diaecoderus* sp. (near *ater* Mschl), *Zonocerus variegatus* L and thrips were the most common leaf-feeding insects in improved fallows. Mixed infestations of *M. ochroptera*, *Exosoma* sp. and *O. benningseni* were common in January-February and this was found to be the major cause for the loss of seedlings in the nursery and immediately after transplanting. *M. ochroptera* was judged as the key pest (*sensu* Hill, 1983) of *S. sesban* in the study area and a detailed account of its biology and population dynamics is given in chapter three.

Exosoma sp. was found to be the second most serious defoliator of sesbania in the areas surveyed in eastern Zambia. *Exosoma* sp. fed on *S. bispinosa*, *S. leptocarpa*, *S. macrantha* and *S. sesban*, but high densities were observed on *S. sesban*. Feeding by adult *Exosoma* took place in the aerial parts of

S. sesban plants. The larval feeding habit is not yet known. Damage was done to both seedlings and mature plants, but generally seedlings were more prone to defoliation. Seedlings in the nursery and those immediately after transplanting were preferred to trees. Beetles fed on both leaves, the upper tender part of the shoots in seedlings and branches in mature plants. Leaf feeding involved scraping of the petiole and lower surface (backside) of leaflets leading to withering of the entire leaf. Feeding on the shoots involved chewing on one side of the shoot, causing the tip to bend down and wither. The beetles also chewed the bark tissue of seedlings down to ground level when the leaves and shoots were exhausted and this consequently led to death of the seedling. In most cases damage by *Exosoma* led to complete loss of seedlings in the nursery. For instance during the 1998-99 season many farmers who established nurseries in Chadiza, Katete and Chipata districts lost all seedlings in the nursery. In those farms where damaged seedlings were transplanted, establishment was very poor. Whenever attacked plants recovered, severe bark canker and stem deformation were observed.

Ootheca benningseni severely damaged *S. sesban* seedlings in the field. In the 1999-2000 rainy season, the beetle occurred in large numbers on both sesbania and other legumes. The beetle density and damage was higher in farms where sesbania was planted in the same field with legumes such as cow pea (*Vigna unguiculata*), bean (*Phaseolus vulgaris*), soybean (*Glycine max*) and bambara groundnut (*Vigna subterranea*). For instance in two farms in

Katete District where *S. sesban* was planted next to cow pea and Hyacinth bean (*Dolichos lablab*) the beetle caused 100% defoliation of both *S. sesban* and the other legumes. The *S. sesban* plants were finally lost as a result of a second attack by *Exosoma* sp.

In November-December 1999, *Zonocerus variegatus* occurred in large numbers in the nurseries in Katete district and some farmers completely lost their sesbania seedlings. Seedlings were frequently attacked and damage was more or less severe because *Zonocerus* nymphs not only defoliated the plants but also ate the growing points.

In mature plants, the most serious leaf-feeders were at least two species of thrips (Table 2.5). *Megalurothrips sjostedti* Trybom was the most common and caused severe discoloration (silvering) and crinkling of leaves. Infestation by this species was found to be severe at the station, in natural stands of sesbania in the *dambo*s and along riverbanks.

2.3.2.1.3 Sap-feeders

Several insects were found to suck the sap from leaves, stem and pods of *S. sesban* (Table 2.5). The common insects were an undescribed species of *Lipaleyrodes*, *Anoplocnemis curvipes* (F.) and *Aphis fabae* Scopoli in both natural stands and planted fallows. *Lipaleyrodes* sp. was the most serious pest causing severe discoloration of leaves and stunted growth. Infestation by this species was found to be severe both at the station and in natural stands of *S. sesban* and

S. macrantha in the *dambos*. *A. curvipes* sucked sap from the young shoots and occasionally caused dieback in seedlings.

2.3.2.1.4 Flower-feeders

Among the flower feeders the most common were the blister beetles *Mylabris dicincta* Gerst and *Coryna mylabroides* Lap, and the flower thrips (Table 2.5). The blister beetles were usually observed when sesbania was in bloom. These beetles ate the flowers and pollen and prevented pod formation. The thrips *M. sjostedti* and three other species, *Haplothrips gowdeyi* Franklin, *Sericothrips adolfifriderici* Karny and *Haplothrips nigricornis* (Bagnall) were also common in flowers.

2.3.2.1.5 Seed-feeders

Herbivores of this feeding guild included *Eurytoma* spp., *Pseudotorymus* sp., *Bruchidius* spp., *Spermophagus* sp. and *Phalacrus* sp. (Table 2.5). *Eurytoma* spp. and *Pseudotorymus* sp. were the most common insects damaging green sesbania seeds. The larvae of *Eurytoma* spp. feed on the cotyledons as well as the embryo. Among the beetles, *Bruchidius* spp. were the most common insects damaging both green and dry sesbania seeds. *Spermophagus* sp. and *Phalacrus* sp. were reared on a few occasions from dry pods in the field at Msekera. The beetles probably fed on sesbania seeds already damaged by other seed-feeding insects. Preliminary studies showed that up to 50% of the seeds/pod were damaged and such seeds had very low (<25%) germination rate.

2.3.2.2 Beneficial insects

2.3.2.2.1 Natural enemies

Several natural enemies were found associated with insects damaging sesbania (Table 2.6). These were grouped into two as parasitoids and predators. The parasitoids attacked the egg, larva or adults of the herbivore insect. The egg parasites, *Telonomus* and *Trisolcus* spp. (Scelionidae: Hymenoptera) were mainly reared from eggs of the heteropteran bugs *B. testudonigro*, *Macrorhaphis acuta* Dallas, *Mecosoma mensor* Germar and *Nezara viridula* L. *Telonomus* sp. caused 36 to 58% parasitism in eggs of *B. testudonigro* during November-January at Msekera and this was suspected to be the major factor that kept *B. testudonigro* populations in check.

The larval parasitoids *Dinarmus* sp. (Pteromalidae: Hymenoptera), *Elasmus* spp. (Elasmidae: Hymenoptera), *Entedon* sp. (Eulophidae: Hymenoptera), *Eupelmus* spp. (Eupelmidae: Hymenoptera), *Pediobius* sp. (Eulophidae: Hymenoptera) attacked seed-feeding insects. *Perilitus larvicida* van Achterberg and *Aphidius* sp. (Braconidae: Hymenoptera) attacked both adults and immature stages of *M. ochroptera* and *A. fabae*, respectively. Detailed descriptions of natural enemies of *M. ochroptera* are given in chapter

4. Several other species of predators were also common in the fallows and preyed on a wide range of insects (Table 2.6).

2.3.2.2.2 Pollinators

The annual and biennial species of *Sesbania* flowered during February-April. The perennial *S. sesban* flowered mainly between June and September, but flowering could occur throughout the year. Pollinator insects were observed in the sesbania fallows when *S. sesban* is in bloom. At least two species of *Anthophora*, the honeybee *Apis mellifera* L., *Ceratina* sp., *Coeloxys* sp., *Xylocopa* sp. and three megachilid bees *Hoplitis* sp., *Megachile centuncularis* L. and *Megachile* sp. visited flowers of sesbania (Table 2.7).

2.4 DISCUSSION

2.4.1 Southern Malawi

The survey in natural stands of sesbania has indicated the potential for a number of insects to assume pest status on *S. sesban* if the use of this species intensifies in agroforestry. The most important among them were the leaf beetles, *M. ochroptera*, *Exosoma* sp. and *Ootheca* sp. Severe defoliation of *Sesbania* species by *M. ochroptera* has also been recorded earlier in Malawi (Smee, 1935; Mchowa and Ngugi, 1994).

Although *Sesbania* species appeared to be the preferred hosts of *M. ochroptera*, the beetle could be found resting or laying eggs on non-host plants growing near *Sesbania*. For instance, females were seen laying eggs on maize and pigeon pea in the *Sesbania*-maize-pigeon pea relay intercropping systems, but the larvae usually died after hatching. This insect was not found to attack other crops such as cotton, pigeon pea, bean, cow pea and groundnut. Therefore, plants on which the beetles are found laying eggs should not automatically be assumed to be suitable hosts. Larvae from eggs laid on non-hosts have been found to migrate in search of host plants. Considering its limited host range, it is unlikely that *M. ochroptera* will pose any threat to crops or other trees in agroforestry systems in the near future.

Many *Sesbania* species, in addition to *S. sesban,* have been reported in eastern Africa to host *M. ochroptera* (Onim *et al*., 1990; Singh Rathore, 1995; Steinmüller, 1995). The beetle may probably breed on *S. goetzii*, *S. grandiflora*, *S. mossambicensis*, *S. rogersii* and *S. speciosa,* which are known to occur widely in different parts of Malawi (Drummond, 1972; NHBG, unpublished checklist). These and other naturally growing *Sesbania* species could become a source for the multiplication and spread of *M. ochroptera* to *S. sesban* in agroforestry systems.

Since *S. sesban* is apparently a less preferred host of the beetle than the other *Sesbania* species and given the wide genetic diversity in this species (Gillett, 1963), there are possibilities for identifying provenances, populations and/or individual trees that are tolerant to beetle attack. Such germplasm could be found in areas where the beetle has exerted sufficient selection pressure leading to the development of resistance.

It appears that *Aeschynomene, Crotalaria, Indigofera* and *Tephrosia* species are the primary hosts of the bug *B. testudonigro,* as it attacked these legumes in large numbers even in the absence of *Sesbania* species. Although *B. testudonigro* can be considered unimportant on *S. sesban* in Malawi, this should not be neglected as outbreaks of the bug were noted in the tree nursery in Chipata (Zambia). Given the wide variety of crops and weeds that it attacks, there is a real danger that it may become a pest to many other agroforestry trees and shrubs such as *Crotalaria*, *Desmodium, Sesbania* and *Tephrosia* and crops such as bean and cow pea. The bug has been reported to attack many shrubs in Chikangawa in northern Malawi (Lee, 1971). The frequency of occurrence of this bug must therefor be noted whenever explorations for new germplasm of agroforestry trees are conducted.

According to Huxley and Greenland (1989), 'primary interactions' (where the tree species and the associated crop share pests and their natural enemies) are not common. In contrast, this study showed that a number of insect herbivores are common to *S. sesban* and crops, indicating the complexity of tree/crop associations. Although the relative host status of a tree and a crop may differ for a shared insect pest, the agroforestry system combining both the hosts will assume considerable significance to the pest (Huxley and Greenland, 1989). Polyphagous insects such as *A. curvipes*, *A. fabae*, *H. patruelis, M. dicincta, M.*

sjostedti, *N. viridula* and *Ootheca* sp., which feed on a number of crops (Bohlen, 1973; Hill, 1983; Wightman and Wightman, 1994), could pose a serious problem to agroforestry systems involving *S. sesban* and the insects' crop hosts.

Increased populations of *M. ochroptera*, *B. testudonigro* and predators of *M. ochroptera* on *S. sesban* in *Sesbania*–weed association were probably brought about by the favourable conditions the mixed vegetation offered to both the pestiferous and beneficial insects. Significantly higher numbers of pre-pupal and pupal stages of the above insects were also observed in unweeded *S. sesban* fallows, particularly under broad-leaved weeds such as *Tridax procumbens* (Asteraceae) and *Clerodendrum uncinatum* (Verbenaceae), than in clean-weeded fallows. Similar observations have been reported from Ethiopia (Wale *et al.*, 1996). Larvae prefer moist and shady areas (such as under broad-leaved weeds) for building the pupal cell. Populations of *B. testudonigro* tended to be higher in weedy areas, probably because most of the weeds were hosts to the bug and they provided an unlimited food supply for its multiplication. Weeding sesbania plots may be beneficial as it reduces the population of beetles and bugs, but it may be disadvantageous if it reduces the natural enemy population. Therefore, knowledge on how weedy vegetation influences other insect pests and natural enemies is essential to determine the trade-offs for weed control at different stages of sesbania growth.

S. sesban and *S. macrantha* seedlings from direct-seeding or natural regeneration grow slowly and experience weed competition in their first 2 months (ICRAF, 1995). *Sesbania* fallows established with nursery-raised seedlings may suffer less from weeds. At the Makoka Research Station, voluntary seedlings from previous *Sesbania* plantings (*S. sesban* and *S. macrantha*) and weedy *Sesbania* species (*S. bispinosa* and *S. leptocarpa*) have been observed to build populations of *M. ochroptera* at the commencement of the rainy season. In such situations, prompt weeding early in the season is necessary to reduce both weed competition and the build-up of the pest on voluntary seedlings, no matter what method was used for establishing the *Sesbania*.

Only two insect species were common in the reports of Singh Rathore (1995) and the current work, indicating that most previous recorded insects on sesbania were probably from outside Malawi or Africa. Two of the species [*Coccus hesperidium* L. and *Hemiberlesia rapax* (Comst.)] previously recorded by Lee (1971) in the same study area and *Formicomus* sp. reported by Mchowa and Ngugi (1994) were also not found. As this study was conducted over a relatively short period, there is a probability that the complete insect fauna associated with sesbania may not be fully documented. Considering this and the obvious limitations of rearing and identifying immature stages of the insects, the list of insects given here should not be considered complete.

Obviously, periodic and repeated surveys covering a wider geographic area are required to get a full picture of the insects that affect *S. sesban*, their host range and natural enemies.

2.4.2 Eastern Zambia

2.4.2.1 Herbivores

Various herbivorous insects attacked different growth stages and parts of *S. sesban*. Almost all of the insects recorded in southern Malawi were found in eastern Zambia. Ten genera of insects reported by Critchley *et al.* (1999) from western Kenya were also found in eastern Zambia. Most of the herbivorous insects occurred in the sesbania fallows during the rainy season while few were observed during the cold winter and the hot seasons. This is probably due to the shortage of food and the harsh weather experienced during the dry season in southern Africa. Seasonal fluctuation in weather and food resources are known to be an important source of variation in insect population size in the tropics (Wolda, 1978). As for most of the tropical insects, very little is known about the biology and population ecology of the majority of the insects associated with *S. sesban*. The data presented on the occurrence of the insects was essentially based on qualitative observations and should not be extrapolated to other areas.

Termites and white grubs sporadically damaged S. sesban roots. According to Kwesiga *et al.* (1999) over 48% of the farmers believe that termites are the major cause of mortality of sesbania seedlings in eastern Zambia. Similarly, Critchley *et al.* (1999) reported that up to 40% of the trees are attacked by the termites in western Kenya. Contrary to these reports, the field observations showed that most of the termite damage on sesbania was secondary and followed weakening by disease causing organisms (J. Bridge, personal Communication), drought or damage by other insects.

Chrysomelid and curculionid beetles were the most important defoliators of *S. sesban*. So far beetle damage to seedlings was attributed solely to *M. ochroptera*. However, this study has conclusively shown that at least three species—*M. ochroptera*, *Exosoma* sp. and *O. benningseni*—are involved in damaging seedlings. *M. ochroptera* has been reported as a serious defoliator of *S. sesban* in Ethiopia (Hill, 1966; Steinmüller, 1995; Wale *et al.*, 1996), Kenya (Onim *et al.*, 1990; Critchley *et al.*, 1999), Malawi (Smee, 1935; Mchowa and Ngugi, 1994), Tanzania (Pfeiffer, 1990), Zambia (Kwesiga, 1990; Kwesiga *et al.*, 1999) and Uganda (Hargreaves, 1924). Sometimes there was total defoliation, depriving the benefits of sesbania to farmers. Though the denotation of the term "major pest" to a species is somewhat arbitrary, *M. ochroptera* may be treated as a major pest of *S. sesban* as it has been reported as an economically important defoliator in the distributional range of *S. sesban* in sub-Saharan Africa.

The second most serious species is probably *Exosoma* sp., but the biology of this species is still unclear. Most of the published information on *Exosoma* is restricted to the Palearctic species *Exosoma lusitanica* L. (Crowson and Crowson, 1996; Steinhausen, 1996a), while virtually nothing is known about the European and Afrotropical species. For instance, *Exosoma* species do not feature in the results of 40 years of rearing and collection of the European chrysomelid larvae (Steinhausen, 1996b). The egg-adult development probably takes place in the soil. According to Crowson and Crowson (1996) larvae of *Exosoma* spp. are not strictly subterranean but feed internally in bulbs of Liliaceae (e.g. *Narcisus* spp. and *Muscari* spp.) and Amaryllidaceae, while the adults feed on vines.

Ootheca benningseni severely damaged seedlings at the station and in farmers' fields. The adults of *O. benningseni* are defoliators of legumes while the larvae feed on roots (M.L. Cox, Personal Communication). *Ootheca mutabilis* Sahlb has also been reported to cause serious defoliation of *S. sesban* and *S. macrantha* elsewhere in Zambia (Annon, 1987). *Ootheca* spp. are widely distributed in Africa (CIE Map No. 488) and are pests of bean, cow pea, pigeon pea, groundnut and other legumes (Raheja, 1981; Hill, 1983; Karel and Rweyemamu, 1984; Mensah, 1988; Ofuya, 1991).

A weevil provisionally identified as *Diaecoderus* sp. (near *D. ater* Mschl) was very common not only on *S. sesban*, but also on other agroforestry species such as *Cajanus cajan*, *Crotalaria grahamiana*, *Gliricidia sepium* and *Tephrosia vogelii*. *D. ater* has been reported as a common pest of several trees and legume crops in Malawi (Lee, 1971; Whitman and Whitman, 1994). The larvae (grubs) of *Diaecoderus* sp. commonly called "Fat John" are known to attack maize roots in Zambia.

The other major defoliators on *S. sesban* included the grasshoppers of which *Z. variegatus* was the most serious. In many parts of Africa, *Z. variegatus* is a sporadically severe pest of many crops and tree seedlings (Hill, 1983) and a wide range of young trees in nursery and newly planted stock (Lee, 1971).

Among the sap-suckers, *A. fabae* was reported to attack legumes (*Phaseolus*, *Glycine*, *Vicia* and *Vigna* spp.), a wide range of other crops and weeds (Hill, 1983). It is also known to be a vector of over 30 viral diseases. *A. curvipes* sucked sap from the young shoots of *S. sesban* and occasionally caused severe damage. It is known to attack shoots of a wide range of trees and shrubs causing dieback in seedlings (Lee, 1971). So far species of *Lipaleyrodes* are known only to feed on Euphorbiacea and the host record of this sample is unusual. G.W. Watson (CABI) and J. H. Martin (NHM) who identified the specimen believe the species is probably undescribed.

Flower damage was mainly due to the flower beetles, *M. dicincta* and *C. mylabroides*, and flower thrips. *Mylabris* and *Coryna* species are pests of flowers of pulse crops, cotton and many flowering plants in Africa (Hill, 1983). *M. sjostedti* caused flower damage to *S. sesban* and other agroforestry species such as *Tephrosia vogelii*, *Cajanus cajan* and *Crotalaria grahamiana*. It is also known to cause severe defoliation on *S. sesban* and *S. macrantha* in Malawi

(Julian Mchowa, Personal Communication). *M. sjostedti* and *H. gowdeyi* were also reported to be abundant on *S. sesban* in western Kenya (Critchley *et al.*, 1999). *M. sjostedti* is a major pest of beans and grams throughout Africa although it is also found on groundnut, coffee, avocado and many other plants (Hill, 1983; Whitman and Whitman, 1994; Klashorst and Tamo, 1995). *S. adolfifriderici* and *H. nigricornis* were occasionally found on leaves, but their role as defoliators, flower feeders or predators is uncertain.

Eurytoma spp., *Pseudotorymus* sp., *Bruchidius* spp. and *Spermophagus* sp. are probably the most important seed-feeding insects in southern Africa. *Bruchidius* spp. and *Spermophagus* sp. have been reported to damage common bean, cow pea (Dobie *et al.*, 1991; Alzouma, 1995) and *Acacia* seeds (Mucunguzi, 1995). *Callosobruchus* sp. reported to be a seed feeder in Kenya (Critchley *et al.*, 1999) was not recorded here. Elsewhere the Eurytomidae (*Bruchophagus mellipes* Gahan, *Eurytoma* sp.) and Torymidae (*Megastigmus* sp.) have been reported to damage seeds of *Sesbania* species (Evans and Rotar, 1987; Hellum and Sullivan, 1990).

2.4.2.2 Beneficial insects

Some of the insects do not cause economic damage probably because of the action of natural enemies. *B. testudonigro*, *E. rubricosta* and *M. inopheron* offer good examples. *B. testudonigro* suffered heavy parasitism from the scelionid egg parasite *Telonomus* sp. at Msekera. A heavy population of the bugs was observed in the nursery in December 1997, but the population declined. A preliminary observation showed that up to 58% of individual eggs were parasitised by the scelionids. Probably that is the reason why *B. testudonigro* failed to reach outbreak populations at Msekera as they did in southern Malawi. Similarly, several egg and larval parasitoids attacked *E. rubricosta* at Msekera. Predators such as *A. yolofa*, *G. conspicuus*, *M. acuta* and *R. segmentarius* also preyed on its larvae (see Chapter 4). *M. inopheron*, a mealy bug that attacks sesbania, pigeon pea and *Tephrosia vogelii*, was heavily preyed on by the ladybird beetle *Chilocorus angolensis* (Crotch). The mealy bug population increased rapidly during September-January and then dramatically declined. This decline followed rapid build up of *C. angolensis* population. Mchowa and Ngugi (1994) attributed the sparse population of *M. inopheron* on pigeon pea in small-scale farmers' fields to predation by *C. angolensis*.

The list of natural enemies given is by no means complete. Within the brief study period, only the most common natural enemies associated with some of the herbivorous insects were collected and identified.

Apart from herbivore insects and their natural enemies, *S. sesban* also attracted several species of pollinator bees that could help in the pollination of crop plants. The honeybee (*A. mellifera*), carpenter bees and megachilid bees frequently visited sesbania flowers. Elsewhere, *A. mellifera*, *Megachile bituberculata* Rite and *Chalicodoma* sp. were reported to visit sesbania flowers

(Heering, 1994). *S. sesban* may probably constitute a useful source of pollen for honey bees and other related species.

The identification of arthropods associated with *S. sesban* was taken as a priority in this work. Knowledge of the precise taxonomic status and correct name of the pest in question are of prime importance. Control efforts without this knowledge would be difficult especially where insects belonging to different genera or families cause similar damages. Neglect of taxonomic studies has in the past resulted in the mis-management of a number of crop pests in Africa. Efforts in the biological control of *Planococcus kenyae* (LePelley), a coffee pest in Kenya (Abasa, 1975; Hill, 1983), and chemical control of cereal shoot flies in Ethiopia (Sileshi, 1995a; Sileshi, 1997a) offer instances of pest-mismanagement as a result of misidentification of the target pest. At the moment, correct identification of some pests of *S. sesban* is difficult especially where species-complexes (e.g. *Bruchidius* spp., *Eurytoma* spp., *Ootheca* spp.) are involved. Many of the specimens were only identified up to the genus level mainly because the taxonomists believed that some of the genera need revision and correct identification to the species level was not possible. In spite of being examined by taxonomists, some insects still remain unidentified. In future, correct identification of the pests should be given priority and investment in control measures must be based on adequate knowledge of the biology and population dynamics of the insect in question.

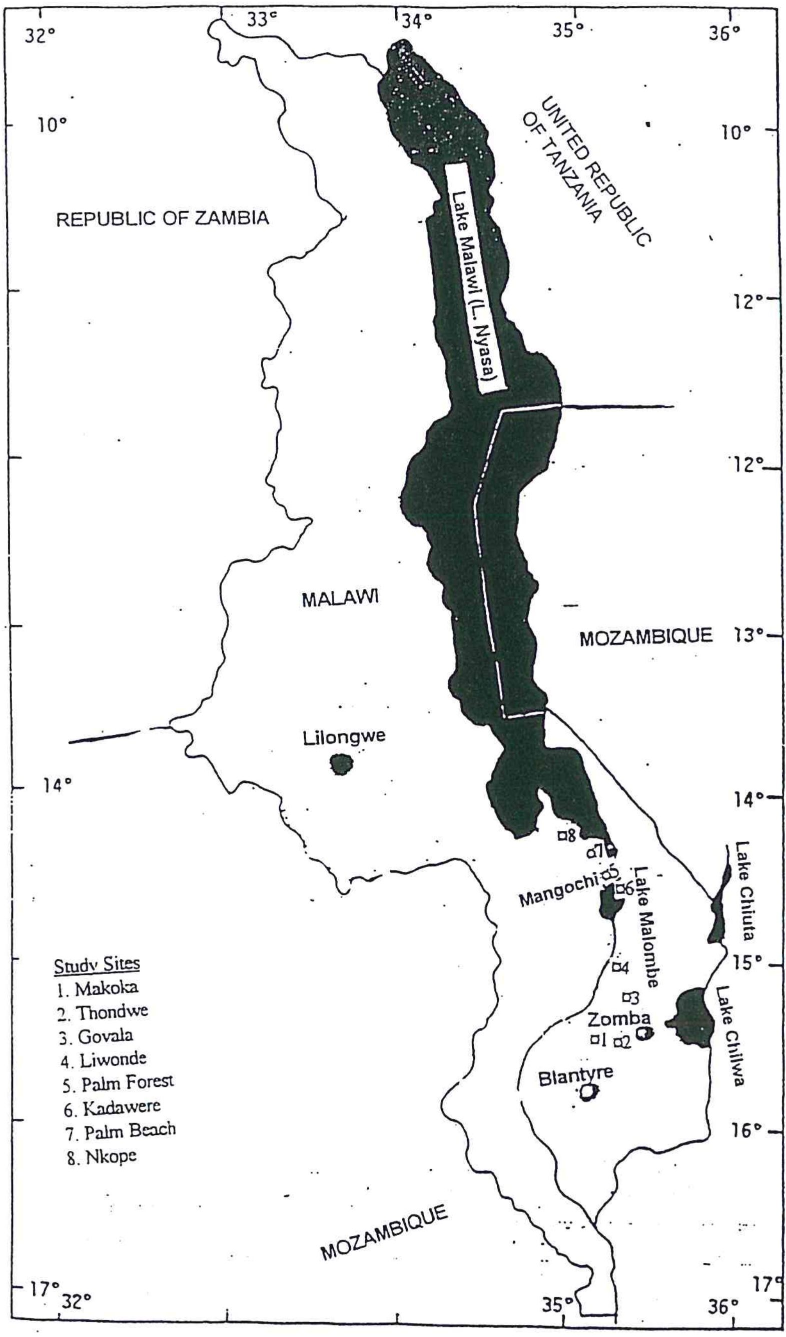

Fig.2.1. The study sites in southern Malawi

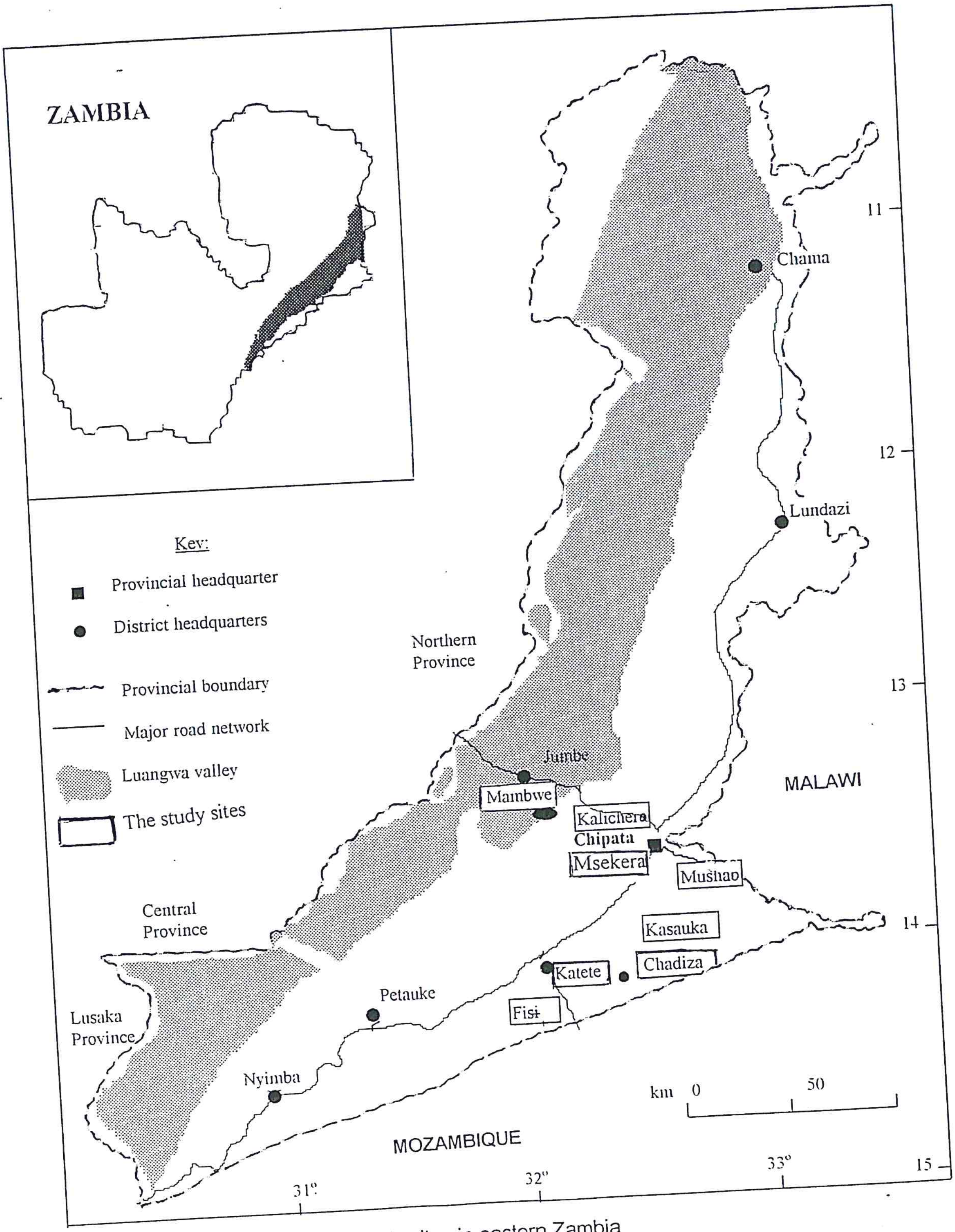

Fig.2.2. The study sites in eastern Zambia

Table 2.1. Insects feeding on natural stands of *S. sesban* in Mangochi District, southern Malawi

Insect species	Family: Order	Potential for crop Damage@	Occurrence on *S. sesban*#
Sucks sap			
Agonoscelis pubescens Thunb.	Pentatomidae: Heteroptera	1	+
Anoplocnemis curvipes (F.)	Coreidae: Heteroptera	1	+++
Aphis fabae Scopoli	Aphididae: Homoptera	1	+++
Brachyplatys testudonigro F.	Plataspidae: Heteroptera	1	+++
Coptosoma sp.	Plataspidae: Heteroptera	0	+
Ferrisia sp.	Pseudococcidae: Homoptera	0	+
Graptostethus sp.	Lygaeidae: Heteroptera	1	+
Hilda patruelis Stål	Tettigometridae: Heteroptera	1	++
Icerya purchasi Mask	Margarodidae: Homoptera	1	+
Leptocoris amicta Germ	Phyrrhocoridae: Heteroptera	1	+
Lipaleyrodes sp.	Aleyrodidae: Homoptera	0	++
Nezara viridula L.	Pentatomidae: Heteroptera	1	+
Spilostethus sp.	Lygaeidae: Heteroptera	1	+
Oxyrachis tarandus F.	Membracidae: Heteroptera	1	+

@ 0 = unknown, 1 = exists, 2 = does not exist (based on literature)

+ = rare; ++ = sporadic; +++ = frequent

Table 2.1. Continued

Insect species	Family: Order	Potential for crop damage@	Occurrence on *S. sesban*#
Causes defoliation			
Chrysolagria sp.	Lagriidae: Coleoptera	0	+
Euproctis rubricosta Fawc	Lymantriidae: Lepidoptera	1	+++
Exosoma sp.	Halticidae: Coleoptera	0	+++
Lagria villosa F.	Lagriidae: Coleoptera	1	+
Medythia quaterna Fairmaire	Chrysomelidae: Coleoptera	0	+
Mesoplatys ochroptera Stål	Chrysomelidae: Coleoptera	2	+++
Ootheca sp.	Chrysomelidae: Coleoptera	1	+++
Plusia orichalcea F.	Noctuidae: Lepidoptera	1	+
Tetranychus sp.	Tetranychidae: Acari	0	+
Zonocerus variegatus L.	Acrididae: Orthoptera	1	+
Unidentified Tortricid	Tortricidae: Lepidoptera	0	++
Damages flowers			
Alcidodes erythropterus (Chevr.)	Curculionidae: Coleoptera	0	+
Megalurothrips sjostedti Trybom	Thripidae: Thysanoptera	1	+
Mylabris dicincta Gerst.	Meloidae: Coleoptera	1	+++
Damages seeds			
Bruchidus sp.	Bruchidae: Coleoptera	1	+
Eurytoma sp.	Eurytomidae: Hymenoptera	0	++

@ 0 = unknown, 1 = exists, 2 = does not exist (based on literature); # + = rare; ++ = sporadic; +++ = frequent

Table 2.2. Host range of some insects recorded on *Sesbania sesban* in Mangochi District, southern Malawi.

Insect species	Host plants recorded during the survey		
	Crops	Agroforestry trees	Weeds
A. curvipes	*Phaseolus vulgaris* *Vigna unguiculata*	*Sesbania sesban*	*Sesbania* spp., *Aeschynomene indica*
A. fabae	*Arachis hypogaea*	*Cajanus cajan* *Gliricidia sepium*, *S. sesban*	*Aeschynomene afraspera*, *A. cristat*, *Sesbania rostrata*
B. testudonigro	*P. vulgaris*, *V. unguiculata*	*Sesbania macrantha* *S. sesban*	*Aeschynomene afraspera*, *A. cristata*, *A. indica*, *Chamaesyce parva*, *Crotalaria barkae*, *C. ochroleuca*, *C. polysperma*, *C. senegalensis*, *C. virgulata*, *Desmodium demissa*, *Indigofera antunesiana*, *I. astragalina*, *Indigofera dyeri* var. *congesta*, *Mucuna poggei*, *Senna absus*, *Sesbania leptocarpa*, *S. tetraptera*, *Tephrosia elata* subsp. *heckmanniana*, *T. purpurea* var. *elagonsis*, *T. richardsiana*

Table 2.3. Adult density of *Mesoplatys ochroptera* and *Brachyplatys testudonigro* on different *Sesbania* species in natural stands in Mangochi District, southern Malawi.

Locality	*Sesbania* species	Mean number per plant ± Standard error	
		M. ochroptera	*B. testudonigro*
Nkope	*S. tetraptera*	12.6±4.6	446.0±63.9
	S. bispinosa	8.1±1.8	151.4±57.4
	S. leptocarpa	5.9±2.3	138.0±54.3
	S. sesban	1.6±0.2	15.1±2.8
Palm forest	*S. tetraptera*	8.3±2.3	4.2±2.2
	S. bispinosa	7.4±2.4	5.5±2.5
	S. leptocarpa	3.4±1.1	16.4±10.3
	S. sesban	2.2±1.0	25.5±24.9
	S. sericea	2.3±0.8	16.4±11.8
Kadawere	*S. tetraptera*	34.7±5.3	1.0±0.1
	S. bispinosa	18.2±2.8	1.0±0.1
	S. sesban	5.1±1.2	2.5±1.4
	S. rostrata	1.8±0.1	1.0±0.2

Table 2.4. *Mesoplatys ochroptera* and *Brachyplatys testudonigro* populations in weedy and weed-free plots in the seed orchard at Palm Forest in Mangochi District, southern Malawi.

Plots	Mean number per shoot	
	M. ochroptera	*B. testudonigro*
Weedy	3.47a	8.51a
Weed-free	1.32b	1.05b
t-test (probability)	<0.05	<0.05

Treatment means followed by different letters within a column differed significantly at 5% probability. t-test was conducted on log transformed data.

Table 2.5. Herbivore insects recorded on *Sesbania sesban* in eastern Zambia, 1997-2000

Feeding Guilds/Species (Family: Order)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Root-feeders												
Ancistrotermes sp. (Termitidae: Isoptera)	+	+	+	+	?	?	?	?	?	?	+	+
Microtermes sp. (Termitidae: Isoptera)	+	+	+	+	?	?	?	?	?	?	+	+
Odontotermes pp. (Termitidae: Isoptera)	+	+	+	+	?	?	?	?	?	?	+	+
Trinervitermes sp. (Termitidae: Isoptera)	+	+	+	+	?	?	?	?	?	?	+	+
Schizonycha sp. (Scarabaeidae: Coleoptera)	+	+	+	?	?	?	?	?	?	?	+	+

? = uncertain, + = rare (on <5% plants), ++ = common (5-50% plants), +++ = abundant (on >50% plants). Abundance was visually scored over three rainy and two dry seasons based on presence or absence

Table 2.5. Continued

Feeding Guilds/Species (Family: Order)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
<u>Leaf-feeders</u>												
Acrida sp. (Acrididae: Orthoptera)	?	?	?	?	?	?	?	?	?	?	?	+
Apion sp. (Apionidae: Coleoptera)	+	+	++	++	+	?	?	?	?	?	?	+
Diaecoderus sp. (Curculionidae: Coleoptera)	+++	+++	+++	-	-	-	-	-	-	-	-	++
Chrysolagria sp. (Lagriidae: Coleoptera)	+	+	+	?	?	?	?	?	?	?	?	+
Cyrtacanthacris sp. (Acrididae: Orthoptera)	+	+	+	?	?	?	?	?	?	?	?	?
Euproctis rubricosta Fawc. (Lymantriidae: Lepidoptera)	++	++	++	++	++	++	-	-	-	-	++	++
Exosoma sp. (Chrysomelidae: Coleoptera)	+++	+++	++	-	-	-	-	-	-	-	++	+++
Helicoverpa armigera (Hub) (Noctuidae: Lepidoptera)	-	-	+	+	+	-	-	-	-	-	-	-
Lagria villosa F. (Lagriidae: Coleoptera)	+	+	+	+	+	?	?	?	?	?	+	+
Medythia quaterna Fairmaire (Chrysomelidae: Coleoptera)	+	+	+	+	?	?	?	?	?	?	?	+
Megalurothrips sjostedti Trybom (Thripidae: Thysanoptera)	+++	+++	+++	+++	+	?	?	?	?	++	++	+++
Mesoplatys ochroptera Stål (Chrysomelidae: Coleoptera)	+++	+++	+++	+++	+++	+	+	+	+	+	++	+++
Ootheca benningseni Weis (Chrysomelidae: Coleoptera)	+++	+++	++	-	-	-	-	-	-	-	++	++
Plusia orichalcea F. (Noctuidae: Lepidoptera)	+	+	+	+	?	?	?	?	+	?	+	+
Tylopsis sp. (Tettigonidae: Orthoptera)	+	+	+	?	?	?	?	?	?	?	?	+
Zonocerus variegatus L. (Acrididae: Orthoptera)	++	-	-	-	-	-	-	-	-	++	++	++
Unidentified sp. (Tortricidae: Lepidoptera)	++	++	++	-	-	-	-	-	-	-	++	++
Unidentified bagworm (Psychidae: Lepidoptera)	+	+	+	+	?	?	?	?	?	?	?	?

-= not found, ? = uncertain, + = rare (on <5% plants), ++ = common (5-50% plants), +++ = abundant (on >50% plants).

Table 2.5. Continued

Feeding Guild\Species (Family: Order)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<u>Sap-feeders</u>												
Agonoscelis pubescens Thunb. (Pentatomidae: Heteroptera)	+	+	+	+	?	?	?	?	?	?	?	+
Anoplocnemis curvipes (F.) (Coreidae: Heteroptera)	++	++	++	++	-	-	-	-	-	-	-	++
Aphis fabae Scopoli (Aphididae: Homoptera)	++	++	-	-	-	-	-	-	++	++	++	++
Brachyplatys testudonigro F. (Plataspidae: Heteroptera)	+	+	-	-	-	-	-	-	+	+	+	+
Coptosoma sp. (Plataspidae: Heteroptera)	+	+	-	-	-	-	-	-	-	-	-	+
Graptostethus sp. (Lygaeidae: Heteroptera)	+	+	+	?	?	?	?	?	?	?	-	+
Helopeltis sp. (Miriidae: Heteroptera)	+	+	+	?	?	?	?	?	?	?	-	+
Hilda patruelis Stål (Tettigometridae: Heteroptera)	++	+	+	?	?	?	?	?	+	+	+	+
Leptocoris amicta Germ (Phyrrhocoridae: Heteroptera)	+	+	+	?	?	?	?	?	?	?	-	+
Lipaleyrodes sp. (Aleyrodidae: Homoptera)	++	++	++	+	+	+	-	-	++	++	+++	+++
Macropulvinaria inopheron (Liang) (Coccidae:	+	+	-	-	-	-	-	-	-	+	+	+
Homoptera)	+	+	+	?	?	?	?	+	+	+	+	+
Nezara viridula L. (Pentatomidae: Heteroptera)	+	+	+	?	?	?	?	?	?	?	?	+
Spilostethus sp. (Lygaeidae: Heteroptera)	+	+	+	?	?	?	?	?	?	?	?	+
Oxyrachis tarandus F. (Membracidae: Heteroptera)	+	+										

-= not found, ? = uncertain, + = rare (on <5% plants), ++ = common (5-50% plants), +++ = abundant (on >50% plants). Abundance was visually scored over three rainy and two dry seasons based on presence or absence

Table 2.5. Continued

Feeding Guild\Species (Family: Order)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flower-feeders												
Alcidodes erythropterus (Chevr.) (Curculionidae: Coleoptera)	+	+	+	+	-	-	-	-	-	-	-	+
Haplothrips nigricornis (Bagnall) (Phlaeothripidae: Thysanoptera)	+	+	+	?	?	?	?	?	?	?	?	?
Haplothrips gowdeyi (Franklin) (Phlaeothripidae: Thysanoptera)	+	+	+	?	?	?	?	?	?	?	+	+
Megalurothrips sjostedti Trybom (Thripidae: Thysanoptera)	++	++	+	++	+++	+++	+++	++	++	++	+	++
Sericothrips adolfifriderici Karny (Thripidae: Thysanoptera)	+	+	+	?	?	?	?	?	?	?	?	?
Mylabris dicincta Gerst. (Meloidae: Coleoptera)	++	++	+	+	++	+++	+++	+++	++	++	++	++
Coryna mylabroides Lap. (Meloidae: Coleoptera)	++	++	+	+	++	+++	+++	+++	++	++	++	++

-= not found, ? = uncertain, + = rare (on <5% flowers), ++ = common (5-50% flowers), +++ = abundant (on >50% flowers). Abundance was visually scored over three rainy and two dry seasons based on presence or absence

Table 2.5. Continued

Feeding Guilds/ Species (Family: Order)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Seed-feeders												
Eurytoma sp. 1 (Eurytomidae: Hymenoptera)	+	+	-	-	+	+	+	+	+	+	+	+
Eurytoma sp. 2 (Eurytomidae: Hymenoptera)	++	++	-	-	++	++	++	++	++	++	++	++
Pseudotorymus sp. (Torymidae: Hymenoptera)	+	+	-	-	+	+	+	+	+	+	+	+
Bruchidius sp. 1 (Bruchidae: Coleoptera)	++	++	+	+	+	+	+	+	++	++	+	+
Bruchidius sp. 2 (Bruchidae: Coleoptera)	++	++	+	+	+	+	+	+	++	++	+	+
Bruchidius sp. 3 (Bruchidae: Coleoptera)	++	++	+	+	+	+	+	+	++	++	+	+
Spermophagus sp. (Bruchidae: Coleoptera)	+	+	+	?	?	?	?	+	++	++	+	+
Phalacrus Sp. (Phalacridae: Coleoptera)	+	+	?	?	?	?	?	+	+	+	+	+

-= not found, ? = uncertain, + = rare (on <5% pods), ++ = common (5-50% pods), +++ = abundant (on >50% pods). Abundance was visually scored over three rainy and two dry seasons based on presence or absence

Table 2.6. Natural enemies recorded on insects attacking *Sesbania sesban* in eastern Zambia, 1997-2000

Parasitoids

Parasitic species	Family: Order	Prey insect
Ammophila sp.	Sphecidae: Hymenoptera	*Plusia* sp.
Aphidius sp.	Braconidae: Hymenoptera	*A. fabae*
Chalcis sp. ? (Hyperparasite)	Chalcididae: Hymenoptera	*Charops* sp.
Charops sp.	Ichneumonidae: Hymenoptera	*H. armigera*
Cryptocheilus sp.	Pompiliidae: Hymenoptera	various spiders
Sp. #1	Tachinidae: Diptera	*E. rubricosta*
Sp. #2	Tachinidae: Diptera	*E. rubricosta*
Sp. #3	Ichneumonidae: Hymenoptera	*E. rubricosta*
Sp. #4	Ichneumonidae: Hymenoptera	*E. rubricosta*
Dinarmus sp.	Pteromalidae: Hymenoptera	*Bruchidius* spp.
Elasmus sp.	Elasmidae: Hymenoptera	*Eurytoma* sp.
Encarsia sp.?	Aphilenidae: Hymenoptera	*Lipaleyrodes* sp.
Entedon sp.	Eulophidae: Hymenoptera	*Bruchidius* spp.
Eupelmus orientalis Crawford	Eupelmidae: Hymenoptera	*Bruchidius* spp.
Eupelmus urozonus Dalman	Eupelmidae: Hymenoptera	*Bruchidius* spp.
Hexamermis sp.	Mermithidae: Nematoda	*M. ochroptera*
Pediobius sp.	Eulophidae: Hymenoptera	*Bruchidius* spp.
Perilitus larvicida van Achterberg	Braconidae: Hymenoptera	*M. ochroptera*
Polistes sp.	Vespidae: Hymenoptera	several spp.
Telonomus sp.#1	Scelionidae: Hymenoptera	*B. testudonigro*
Telonomus sp.#2	Scelionidae: Hymenoptera	*Nezara viridula*
Telonomus sp. (group *podisi*)	Scelionidae: Hymenoptera	*Macrorhaphis acuta* *Mecosoma mensor*
Tetrastichus sp.	Eulophidae: Hymenoptera	*Bruchidius* spp.
Trisolcus sipiodus Johnson	Scelionidae: Hymenoptera	*Mecosoma mensor* *Macrorhaphis acuta*
Trisolcus sp.	Scelionidae: Hymenoptera	*N. viridula*

Table 2.6. Continued: Predators

Predator Species	Family: Order	Prey Species
Afrius yolofa (Guérin-Ménville)	Pentatomidae: Heteroptera	*M. ochroptera,* *H. armigera, E. rubricosta,*
Cheilomenes lunata F.	Coccinelidae: Coleoptera	*A. fabae*
Cheilomenes sulfurea (Olivier)	Coccinelidae: Coleoptera	*A. fabae*
Chilocorus angolensis (Crotch)	Coccinelidae: Coleoptera	*M. inopheron*
Cyaneodinodes faciger (Chaudoir)	Carabidae: Coleoptera	*M. ochroptera*
Deraeocoris ostestans Stal	Miridae: Heteroptera	*M. ochroptera*
Glypsus conspicuus Westwood	Pentatomidae: Heteroptera	*M. ochroptera, H. armigera,* *E. rubricosta, P. orichalcea*
Macrorhaphis acuta Dallas	Pentatomidae: Heteroptera	*M. ochroptera, H. armigera* *E. rubricosta, P. orichalcea*
Mallada sp.	Chrysopidae: Neuroptera	*M. ochroptera*
Mantis sp.	Mantidae: Dictyoptera	various insects
Mecosoma mensor Germar	Pentatomidae: Heteroptera	*M. ochroptera* *H. armigera,* *E. rubricosta, P. orichalcea*
Pheidole sp.	Formicidae: Hymenoptera	*M. ochroptera*
Platynaspis capicela (Crotch)	Coccinelidae: Coleoptera	*A. fabae, Lipaleyrodes* sp.
Rhinocoris segmentarius (Germar)	Reduvidae: Heteroptera	*M. ochroptera, H. armigera,* *E. rubricosta, P. orichalcea*
Tetramorium sericeiventre Emery	Formicidae: Hymenoptera	*M. ochroptera*
Xanthogramma aegyptiaca Wied.	Syrphidae: Diptera	*A. fabae*
Sp. #5	Thomisidae: Aranae	*M. ochroptera*
Sp. #6	Miridae	*M. sjostedti*

Table 2.7. Pollinator insects collected from *Sesbania sesban* in eastern Zambia, 1997-2000

Species	Family	Order
Anthophora spp.	Anthophoridae	Hymenoptera
Apis melifera L.	Apidae	Hymenoptera
Ceratina sp.	Xylocopidae	Hymenoptera
Coeloxys sp.	Melitidae	Hymenoptera
Hoplitis sp.	Megachilidae	Hymenoptera
Megachile centuncularis L.	Megachilidae	Hymenoptera
Megachile sp.	Megachilidae	Hymenoptera
Gen.? Sp.?	Megachilidae	Hymenoptera
Xylocopa sp.	Xylocopidae	Hymenoptera

CHAPTER 3

3.0 BIOLOGY OF *Mesoplatys ochroptera* STÅL[=]

3.1 INTRODUCTION

With the widespread adoption of sesbania in agroforestry land use systems, *Mesoplatys ochroptera* Stål (Chrysomelidae: Coleoptera) has become one of the most serious pests of the tree (Kwesiga, 1990; Onim *et al.*, 1990; Pfeiffer, 1990; Mchowa and Ngugi, 1994; Wale *et al.*, 1996). Adults and larvae of the beetle feed on leaves and stems of sesbania leading to complete defoliation and drying. The defoliation hazard at the seedling stage can prevent stand establishment (Pfeiffer, 1990; Wale *et al.*, 1996).

In addition to specific studies, most of the information on the Chrysomelidae has been published in the form of reviews in the "Biology of the Chrysomelidae" (1988), "Novel Aspects of the Biology of Chrysomelidae" (1994) and the three volumes of "Chrysomelidae Biology" (1996). However, little information could be found on the biology of *M. ochroptera* except the mentioning of its phylogeny (Suzuki, 1996), its distribution (Daccordi, 1996) and pupal characteristics (Cox, 1996a).

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Most of the published information is also restricted to the reports of occasional outbreaks and cursory observations in Africa. A better knowledge of the insect's biology and ecology will form a basis for developing an IPM strategy. Knowledge of the distribution and farmers' perception of the insect is also essential in the development of a research agenda targeted towards viable management options.

The objectives of this study were to (1) determine the incidence of *M. ochroptera* in farms and awareness of farmers on the pest problem and (2) describe the biology and population dynamics of the beetle in southern Africa.

3.2. MATERIALS AND METHODS

3.2.1. Survey

The surveys were conducted in southern Malawi from December 1997 to March 1998 and in eastern Zambia from December 1997 to May 1999. The surveys in southern Malawi were conducted in Zomba and Mangochi districts (Fig. 2.1.) and covered a total area of over 9,000 square kilometres. In Zomba district, 11 farms where sesbania was relay-intercropped with maize were visited in Govala, Thondwe and Makoka areas. Those in Mangochi district covered mainly the shores of Lake Malawi and Malombe where many *Sesbania* species grow naturally (Ndungu and Boland, 1994). A number of seasonally waterlogged depressions locally called *dambos* were also visited in both the countries and plants were examined for adults and immature stages of *M. ochroptera*.

In eastern Zambia, a total of 32 farms having sesbania planted fallows were visited in Chipata South, Chipata North, Chadiza, Katete and Mambwe districts (Fig. 2.2.) covering a total area of 18,000 square kilometres. During each farm visit, farmers' name, farm size, date of planting, frequency of weeding, farmers' perception about insect pests and their control measures were recorded (Appendix 2). As the sesbania plants were not of uniform stand and growth stage in the study areas, no attempt was made to quantify pest population or damage levels; data were recorded only on the presence or absence of the beetle. Additional information on the importance of the beetle was collected by perusal of the reports of governmental and non-governmental organisations involved in the dissemination of agroforestry technologies in eastern Zambia.

3.2.2 Life history

To determine the duration of the different life stages of *M. ochroptera* on sesbania, studies were conducted in a glasshouse and an insectary at Makoka and Msekera research stations, respectively. Due to the lack of facilities, it was not possible to study the life history at constant temperatures. The glasshouse at Makoka had an inside daily temperature ranging from 25 to 33°C. The daily temperature in the insectary at Msekera was 23-30°C during January-February, 21-29°C during March-April and 18-27°C during May-June. sesbania seedlings were raised in pots and placed under muslin cages of 30-cm width x 30-cm breadth x 50-cm height. A pair of newly emerged adult beetles (aged 24 hours) was introduced into each cage containing potted seedling. Virgin (unmated) females and females that had mated only once were also separately kept in similar cages. Once introduced, the adults were observed daily and the pre-mating and pre-oviposition periods monitored. In addition, 30 pairs of adults placed individually in Petri dishes containing fresh leaves were observed every two hours and the time of mating and oviposition recorded. In all observations, the photo-phase was 06.00 to 18.00 h and the scoto-phase 18.00 to 06.00 h. The number of egg batches produced per female per day, the total number of eggs per female and adult life span were recorded by monitoring each adult. Additional information was obtained on the oviposition sites and the number of eggs produced per batch by sampling monthly from the field.

Batches of eggs were removed from the cages by excising the leaves and were then transferred to Petri dishes containing moist tissue paper. The incubation period and the time of hatching were determined by monitoring hatching every two hours. The larvae that hatched were transferred to potted seedlings in cages and monitored to determine the development period of each instar. The number of larval instars was determined by the technique of measuring head capsule width (Leibee *et al.*, 1980). The head capsules of larvae collected from the fields were measured using a stereoscopic microscope fitted with a calibration slide.

The pre-pupae were placed separately in Petri dishes containing moist soil and filter paper. These were monitored every two hours to determine the duration of the pupal stage and the time of eclosion (adult emergence). In addition, field observations were made in sesbania fallows at Msekera to identify the preferred sites of pupation. For this purpose, quadrates of one square meter were laid in sesbania fields and along the field margins and, pupae and the holes from which adults had emerged were counted. Counts of the common weed species were also taken at the same time.

To determine the diurnal rhythm of adult activity, field observations were carried out in March 1998. In the field, eight randomly selected plants (used as replicates) were marked and visited three times a day: early in the morning (8.00 h), at noon (12.00 h) and late in the afternoon (16.00). This observation was done on two contrasting days, a sunny and rainy days. The leaf canopy of each plant was divided into three layers—lower, middle and upper—based on the number of nodes and the number of adults found in each canopy layer recorded. The data collected were transformed into log (x+1) and subjected to analysis of variance.

3.2.3 Host plants

Close observations were made during the field surveys in Malawi and Zambia on the species of plants reported (Harris, 1937, Mchowa and Ngugi, 1994) as hosts of the beetle. The species observed were *Aeschynomene afraspera, Aeschynomene americana, Aeschynomene cristata, Aeschynomene elaphroxylon, Aeschynomene indica, Sesbania bispinosa, Sesbania brevipeduncula, Sesbania leptocarpa, Sesbania macrantha, Sesbania rostrata, Sesbania sericea, Sesbania* *tetraptera*, pigeon pea (*Cajanus cajan*), groundnut (*Arachis hypogaea*), bean (*Phaseolus vulgaris*), cow pea (*Vigna unguiculata*) and cotton (*Gossypium hirsutum*). The acceptability of these plant species as food was verified by providing leaves as food to larvae and adults confined to Petri dishes in the insectary.

3.2.4 Pattern of population fluctuations

To determine the pattern of population fluctuations, field assessments were made from October 1997 to April 2000 at the Msekera Research Station. Density estimates of *M. ochroptera* were obtained by sampling seedlings (0-2 m high) and one-year-old trees (2-4 m high) in experimental plots. In all cases, the spacing was 1-m between plants and 1-m between rows of sesbania. The plot size was 10-m x 10-m and consisted of ca. 100 plants. The plots were divided into two rectangular blocks of 50 plants each; 50 plants in the middle formed a central block and the remaining 50 around the central plants formed a peripheral block. 15 trees (primary sampling units) were randomly selected from each block. The foliage canopy of each tree was divided into upper, middle and lower strata and 2 shoots were randomly selected from each stratum. Egg masses, larvae and adults were counted on each shoot every two weeks. Using these data, parameters of the spatial distribution of *M. ochroptera* were obtained following Iwao's model (Iwao, 1968). Enumerative and sequential sampling plans were developed incorporating distribution parameters of the beetle into Kuno's (1976) equation.

Insect density was estimated using the sampling protocol described above at fortnightly intervals. The numbers of shoots per plant were counted at the same time when the number of adults, egg masses and larvae were recorded. The logarithms ($\log_{10}$) of insect densities were plotted against time to show the population fluctuations. Weather data were obtained from the Msekera Research Meteorology station.

To determine the survival of *M. ochroptera* during the dry period, beetles were monitored in the field from May to November. During the same period, observations were also made in the insectary on populations that emerged from egg batches collected from the field in May. Subsequent generations were maintained throughout the dry season and egg, larval and pupal development monitored continuously.

To determine the time when *M. ochroptera* enters winter refuges monitoring was done fortnightly beginning from mid-April. Plant litter and the soil under fallow trees and in the field margin were turned over and thoroughly searched for adults, larvae and pupae. A total of 249 and 130 beetles were collected on 25 April 1998 and 5 May 1999, respectively. The beetles were maintained in Petri dishes containing plant litter brought from the field and their longevity and survival in an insectary was recorded. The beetles that survived the dry season in 1999 were transferred to the field in small gauze cage within one week of the onset of the rains. The emergence of these beetles was monitored every day and emerged beetles were brought to the insectary to determine their longevity and fecundity. At the same time, 30 pairs of adults that were over-wintering in the field were collected as they emerged from winter refuges. The beetles were supplied with excised sesbania leaf as this was the food source that was naturally available at the time of emergence. Mating and oviposition by over-wintered beetles was monitored every day and the number of eggs produced by each female per day and adult longevity recorded. Masses of eggs were removed from each of 15 females every day and transferred to Petri dishes containing moist tissue paper. The hatchability of these eggs was monitored and the proportion of eggs hatching in each mass was recorded.

The longevity of over-wintering adults in the field was estimated indirectly by computing the proportion of adults sampled at different times in the rainy season. The proportion of over-wintered adults in the total population during the rainy season was determined by fortnightly sampling. The over-wintered adults were distinguished from adults of the first generation by the colour of the elytron. The elytron is dark brown in the over-wintered adults, tawny in teneral (newly emerged) adults and light brown in older adults of the current generation.

3.3 RESULTS

3.3.1 Survey

3.3.1.1 Distribution of *M. ochroptera* in farms

In almost all the areas surveyed, *M. ochroptera* was recorded in sesbania stands. In addition to *S. sesban*, the beetle also infested natural stands of *S. brevipeduncula*, *S. bispinosa*, *S. leptocarpa*, *S. sericea* and *S. tetraptera*. The beetle was recorded in all the 11 farms visited in southern Malawi and in 72% of the farms surveyed in the Eastern Province of Zambia.

The majority of farms (61%) where *M. ochroptera* infestation was recorded had two or more cycles of sesbania fallows planted earlier. However, 28% of the farmers that had planted sesbania since 1992 in eastern Zambia did not experience the beetle problem. One source of initial beetle infestation appeared to be the seedling infested in the nursery. Until recently, almost all farmers received seedlings from nurseries at the Msekera Research Station.

3.3.1.2 Farmers' perception and control practices

Of the 32 farmers interviewed in Zambia, 66% considered *M. ochroptera* as one of the factors limiting planting sesbania. The beetle was considered the number one pest of sesbania by 34% of the farmers, while 31% reckoned it as second to termites. Only 9% of the farmers interviewed (all of them in Katete District) sprayed insecticides to control the beetle, while 6% attempted picking and crushing them.

There was also widespread awareness among research and extension staff on the beetle problem. Of the 13 institutions involved in promoting sesbania fallows in eastern Zambia, eight mentioned *M. ochroptera* and termites as the two major constraints in planting *S. sesban*.

3.3.2 Life history of *M. ochroptera*

M. ochroptera laid yellow eggs in batches composed of neat double rows (Plate 1). The eggs were laid mainly on the underside of the leaf along the rachis. During heavy outbreaks, eggs were also laid on all parts of the plant including dry wood and on non-host plants. In the field, the number of eggs per batch ranged from 2 to 70. In the insectary, oviposition took place every day. Oviposition occurred only during the photo-phase with over 95% of the egg batches being laid between 10.00 and 16.00 h (Fig.3.1). One batch of eggs was laid per female per day. The number of eggs produced per day (averaged over 30 females) ranged from 11 to 35 and 13 to 36 per female in those mated only once and mated repeatedly, respectively. A female produced up to 52 such batches in its lifetime.

In the first generation insects, the average (mean±SE) fecundity of a repeatedly mated female was 1007.4±37.0 eggs while that of a female mated only once was 980.3±42.4 eggs (Table 3.1). There was no significant difference between the two groups ($P>0.05$; $t'= 1.39$, $DF = 28$). The fecundity of females of the over-wintered generation ranged between 87 and 783 eggs (Table 3.2). The fecundity of females declined with age (Fig. 3.2a and 3.2b) showing a significantly negative correlation ($r = -0.84$, $p<0.01$, $n=30$) between fecundity and age.

Females of the first generation produced more eggs per day in the first two weeks after emergence from the pupal stage. Maximum oviposition (52.3±0.6 eggs) was observed during the first two weeks after adult emergence and this gradually declined as beetles aged (Fig. 3.2). In the field, the number of eggs per batch was found to be higher between February and April while fewer eggs were laid at the beginning and end of the rainy season (Fig. 3.3).

The incubation period of eggs ranged from two to nine days (Table 3.3). Hatching occurred throughout the day and night (Fig. 3.1), but over 60% of the egg masses hatched between 12.00 and 20.00 h. All the eggs in an egg mass hatched within two hours. On average, the hatchability of eggs produced by current generation females was 82.6±2.0% and 86.2±1.5% for the eggs produced by females mated only once and those mated repeatedly, respectively. The percent hatchability of eggs produced by over-wintered females was 85.3±3.4. Hatchability of eggs gradually declined with the age of the adults in both over-wintered and current generation insects (Fig. 3.2a and 3.2b). At the beginning and the end of the oviposition period, the eggs were laid loosely and such eggs had lower hatchability.

Upon hatching, the first instar larvae were yellowish and turned black within a day. The larval development took place on host plants. The three larval instars were recognised by the width of the head capsule (Fig. 3.4) and the number of exuvia left after moulting. After feeding for 2 to 10 days, the first instar larvae moulted into the second instar. The first instar larvae of the same egg batch and second instars dispersing from other egg batches also ate unhatched eggs of *M. ochroptera*. On average 9.3±2.3% of the egg batches were depredated by *M. ochroptera* larvae.

The second instar larvae fed by scraping on the lower or upper leaf surface. After 3 to 10 days of feeding, these moulted into the third instar larvae (Table 3.3). The third instar larvae were found to be the most serious defoliators of sesbania. They fed on leaves (of any quality), the growing tips, flowers, pods as well as the bark of the stem. During peak population, 100% of the seedlings and mature plants could be defoliated.

The third instar larva dropped to the ground and searched for moist and shady places before digging into the soil to pupate (Plate 1). Within the soil, it constructed an earthen cell and underwent a pre-pupal development. The pre-pupa then moulted into a yellow, exarate-adecticous pupa. The pupal period ranged from 4 to 16 days. The majority of the pupae were found in the top 15-cm layer of soil, mainly under weeds, dead wood and plant litter. In weedy fallows, greater number of pupae and adult emergence holes were found under dense weed cover. Among the common weeds in sesbania fallows, the broad-leaved species such as *Tridax procumbens*, *Ageratum conyzoides* (Asteraceae), *Clerodendron uncinatum* (Verbenaceae), *Euphorbia hirta* (Euphorbiaceae), *Indigofera* sp. (Fabaceae), and the grasses *Eleusine indica* (Poaceae) and *Cyperus esculentus* (Cyperaceae) supported more pupae and emergence holes. The larvae crawled away from clean-weeded fallows and the largest number of pupae and adult emergence holes were found along the field margins within two to four meters from the sesbania plots.

Eclosion occurred throughout the day and night, with over 75% eclosing between 02.00 and 10.00 h (Fig. 3.1). The teneral (newly emerged) adults were pale-yellow except for the head and thorax that were black. As the beetles matured, the colour of the elytron gradually turned dark-brown while the head and thorax remained black. The male to female ratio was 1:1 in adults emerging at the same time.

Adult beetles were poor in flight; if they ever flew it was only for a few meters. Flying adults were mostly observed at the beginning of the dry season when they were migrating to the field margins. The number of adults and their position on a plant did not vary between different times of the day and they did not show diurnal rhythm of movements (Table 3.4). Adults also stayed for several days feeding and mating on the same plant.

Mating started within two to four days after emergence from the pupal stage. Over-wintered adults also mated within two days after emergence from hibernacula. Unlike many insects, elaborate courtship displays were absent in *M.*

ochroptera. When the male encountered a female, it mounted the female and copulation took place immediately. The female moved around and fed without disrupting copulation while the male remained in copula. Adults also mated repeatedly throughout the day and the night (Fig. 3.1).

Females of the current generation laid eggs within three to seven days after emergence from the pupal stage (Table 3.3) while those of the over-wintered generation started ovipositing within three days after emergence from winter refuges. In insects of the current generation, the average oviposition period was 36.8±1.3 days for repeatedly mated females and 39.6±1.5 for those separated from the male after one mating (Table 3.1). However, there was no significant difference (P>0.05; t'= 1.39, DF = 28) between the two groups. Virgin females also produced normal sized egg batches for as many as 32 days (26.5±0.9), but the eggs failed to hatch. The oviposition period ranged between 5 and 29 days for females of the over-wintered generation (Table 3.2).

The longevity of current generation adults ranged from 20 to 55 days with a mean of 40.6±1.6 and 40.2±1.2 days for females and males, respectively. There was no significant difference between female and male longevity (P>0.05; t'= 0.18, DF = 28). The post-emergence longevity of over-wintered adults was 21.7±0.8 and 25.5±0.5 for males and females, respectively (Table 3.2).

3.3.3. Host plants

In the field, adults and larvae of *M. ochroptera* were not found feeding on the species of *Aeschynomene.* Cotton, pigeon pea, groundnuts, beans and cow pea growing near sesbania fallows at Makoka and Msekera were also not attacked. Adults and larvae confined with leaves of these plants in Petri dishes also did not feed on them. The larvae and adults fed freely on *S. bispinosa*, *S. brevipeduncula*, *S. leptocarpa*, *S. macrantha*, *S. rostrata*, *S. sericea* and *S. tetraptera.*

3.3.4 Pattern of population fluctuations

Build up of *M. ochroptera* populations started from over-wintered adults emerging at the beginning of the rainy season. The first continuous rains of the season were received on October 21, November 22 and 12 in 1997, 1998 and 1999, respectively, and the over-wintering adults started emerging on October 23, November 27 and 21 in 1997, 1998 and 1999, respectively. The beetle emergence was delayed by about a month in 1998 and 1999 compared to 1997 (Fig. 3.5).

Beetles of the current generation appeared within three weeks of the onset of the rains. During November-January, field populations of adults were composed of a mixture of over-wintered and current generation insects (Table 3.5) of differing maturity. There was an overlap of 3-5 weeks between the over-wintered and the current generations. Over-wintered adults were absent from the population by the end of January. This is presumably due to mortality of over-wintered adults through ageing. Breeding occurred continuously during the rainy season and overlapping generations were produced.

In 1998 the build up of the population was slower than in 1997 and 1999, and appreciable numbers were observed only in February (Fig. 3.5). A small number of adults appeared at the beginning of the rainy season; 80 beetles per m^2 in November 1997 and 74 beetles per m^2 in January 1999. Then the population built up rapidly on wildings (volunteer seedlings) and coppicing (regeneration after cutting) plants. The maximum population was recorded in March; 845 adults and 3342 larvae per m^2 in 1998 and 807 adults and 4072 larvae per m^2 in 1999. By mid-April the beetles converged in shady places within the fallows before entering winter refuges. Over-wintering adults first entered winter refuges in the first week of May. The winter refuges included mainly broad-leafed weeds, plant litter, rocks and cracks in the soil within the fallow and the surrounding vegetation. The beetles crawled away from weed-free fallows to the field margins or hid in the litter in weedy fallows.

From May to November 1998, no egg masses and larvae were found in the fallows (Fig. 3.5). In 1999, some larvae and adults were seen feeding in May and June mainly in the *dambos*. Following the unusual showers (0.6-mm rainfall) received on August 6, 1999, some adult feeding was also noted in the fallows at Msekera. In both years, reproduction stopped and no eggs, larvae and pupae were observed from July to November.

During the same time, populations raised from eggs collected at the beginning of the dry season remained active and breeding continued in the insectary (May to September). The egg to adult development took place normally but the duration of each stage was longer than in the rainy season (Table 3.3). In contrast, over-wintering adults collected from the field showed no activity when maintained under the same conditions in the insectary.

The survival of over-wintering populations was estimated indirectly from the adult densities at the beginning of the winter and the end of the dry season. The density of adults entering winter refuges was 502.3 and 1995.3 per square meter at the beginning of the 1998 and 1999 winter seasons, respectively. The density of emerging over-wintered adults in the same fallows was 2.0 and 51.3 per square metre at the beginning of the rainy season in 1998 and 1999, respectively. Based on a comparison of the adult density, the effective survival (defined as the portion of over-wintered beetle populations which lived long enough to produce at least one mass of eggs after emergence from winter refuges) was estimated at 0.4% and 2.8% in 1998 and 1999, respectively. As *M. ochroptera* adults do not actively fly, migration of adults to other places before over-wintering was assumed to be negligible. The effective survival of beetles over-wintering in the insectary was 18.1% (N = 249) and 37.7% (n = 130) in 1998 and 1999, respectively.

3.4 DISCUSSION

Earlier reports of *M. ochroptera* from southern Africa were restricted to Zomba district in southern Malawi (Smee, 1935; Mchowa and Ngugi, 1994), and Katete and Chipata South districts in eastern Zambia (Kwesiga F., personal communication). During the course of the study, the beetle was recorded in almost all farms where *S. sesban* was planted and in natural stands of several *Sesbania* species. The beetle was also found to be common in agroforestry systems in neighbouring countries like Tanzania (Pfeiffer, 1990) and Zimbabwe (Ayuk, E. T., Personal communication). *M. ochroptera* is apparently widespread in the Afro tropical Region (Daccordi, 1996) and probably an endemic pest of *S. sesban* in southern Africa.

The eggs apparently matured throughout the adult life of *M. ochroptera* and the beetle produced eggs every day. The number of eggs produced per egg mass was greater than the range of 9 to 16 reported in Ethiopia (Wale *et al.*, 1996). The number of eggs produced by each female per day varied with the age of the female. The actual number of eggs per day is known to vary with size or age of the female (Richards and Waloff, 1954) or from generation to generation (Southwood, 1978). Within-season variation in egg production is influenced by changes in the nutritional conditions of the host plant which in turn is influenced by changes in rainfall and temperature (Ridsdill-Smith, 1986). The factors that contribute to within-season variation in egg production by *M. ochroptera* are not yet known.

A large proportion of the eggs produced within the first two to three days by both over-wintered and current generation beetles had lower hatchability. This is probably because some females laid eggs before insemination. Under the conditions of this study, the majority of egg masses hatched in the afternoon with all eggs in the same batch hatching synchronously. The occurrence of hatching at a particular time of day has been observed in many insects (Lockwood and Story, 1985) and this has been found to be very important for the survival of the larvae (Chapman *et al.*, 1983). The embryonic development and hatchability of eggs may vary considerably depending on temperature, light and relative humidity (Lockwood and Story, 1985). This should be investigated in *M. ochroptera* by conducting further studies under controlled laboratory conditions.

Egg cannibalism by larvae was found to be common in *M. ochroptera*. The Chrysomelidae are known to be hetero-cannibals and three types of cannibalism—siblicide by first instar larvae, oophagy by older larvae that encounter eggs and egg consumption by adult females—have been reported (Dickson, 1992a; Selman, 1994; Mafra-Neto and Jolivet, 1996). Both in the laboratory and in the field siblicide and oophagy were common, but egg consumption by adults was not observed. In some chrysomelid beetles, eggs are known to act as a nutritional supplement to the young larvae (Selman 1994; Mafra-Neto and Jolivet, 1996). In other beetles such as the Coccinelidae, sibling cannibalism is a self-regulatory mechanism (Mills, 1982) that can increase in intensity as egg density rises (Banks, 1956). The adaptive significance and ecological role of cannibalism in *M. ochroptera* needs to be further studied.

Pupal development took place in an earthen cell in the soil. The largest number of pupal cells and adult emergence holes were found under broad-leaved weeds and plant litter. Similarly, Wale *et al.* (1996) found the highest density of adult emergence holes under dense vegetation. Dense vegetation cover probably favoured larval survival and successful construction of the pupal cell.

Adults remained on the same plant mating repeatedly. Similarly, in another chrysomelid, *Labidomera clivicolis* Kirby, mating accounted for 12 to 18% of adult life (Dickson, 1986; 1992b). Frequent copulation is associated with the inability of the female to store sperms in the spermatheca for a long time in some other insects. However, females separated from the males after one mating produced fertile eggs for up to 56 days indicating the capability of *M. ochroptera* to retain sperms for a long time after one mating. Many chrysomelid beetles are known to mate frequently, though a few such as *Plagiodera versicolora* Laich, mate in autumn and retain the sperm in their bodies to fertilise the eggs in the following spring (Dickson, 1992b; Selman, 1994). The adaptive significance of the mating behaviour in *M. ochroptera* is not clear.

As a result of the limited flight of adults, migration from one field to another appeared to be very slow and took place mainly by the crawling adults. Similarly, Steinmüller (1995) compared the migration of the beetles in an upland

and valley bottom fields 500m apart and found that the adult population in the bottom-land reached its peak 20 days and the larval population 50 days after the population peaked in the upland.

In the laboratory, *M. ochroptera* did not feed on *Aeschynomene*, *Erythrina*, cotton and various legumes reported to be its host plants (Harris, 1937; Mchowa and Ngugi, 1994). Field observations (see Chapter 2) also confirmed this. All the *Sesbania* species were attacked by *M. ochroptera*, but some were less preferred (see also Chapter 5). The species which have been reported to be its hosts include *S. bispinosa*, *S. brevipeduncula*, *S. cinerascens*, *S. coerullescens*, *S. goetzii*, *S. kenyansis*, *S. leptocarpa*, *S. macowaniana*, *S. macrantha*, *S. microphylla*, *S. pachycarpa*, *S. rostrata*, *S. sphaerosperma* and *S. tetraptera* (Onim *et al.*, 1990; Kwesiga, 1990; Steinmüller, 1995). The preferred host range of the beetle seems to be restricted to the genus *Sesbania*. Over 50 species of *Sesbania* are known to occur in Africa (Onim *et al.*, 1990) and *M. ochroptera* populations may build-up on any of these species in the absence of *S. sesban*.

The annual cycle of reproduction and subsequent decline of *M. ochroptera* appeared to follow the unimodal rainfall pattern of Southern Africa. In Ethiopia, where the rainfall pattern is bimodal, the build-up of the beetle population is directly related to rainfall patterns and several population peaks were recorded (Steinmüller, 1995; Wale *et al.*, 1996). In the current study, the beetle showed clear seasonality of reproduction with population peaks occurring between February and April every year. The peak populations of *M. ochroptera* coincided with the period when sesbania plants were two to three months old and are thus vulnerable to the beetle damage. Similarly, Kwesiga (1990) reported heavy damage in farmers' fields in March in eastern Zambia.

From May to November, over-wintering adults survived probably in a state of oligopause as defined by Mansingh (1971). Oligopause species are known to inhabit areas of moderate winters and have evolved a definite period of dormancy that occurs only at a fixed stage of development, in this case the adult. Adult diapause is well documented in the subfamily Chrysomelinae (Cox, 1994a). For instance, *Leptinotarsa* species (Chrysomelidae: Coleoptera) undergo adult diapause as a strategy to survive during unfavourable conditions. But the factors responsible for induction of diapause are known to vary in populations of the same species (e.g. *L. decemilineata*) inhabiting different latitudes (Hsiao, 1981). In this genus, photoperiod is the most important factor inducing 'hibernal diapause' in temperate species while deterioration in the quality and/or a shortage of their host plants induces 'aestival diapause' in populations from warmer and arid regions (Hsiao, 1988).

The physiological processes and the factors involved in the induction of diapause in *M. ochroptera* are not yet known. The low temperature and the dry condition that prevail during May-June are suspected to be the factors inducing adult diapause. Field observations also suggest that diapause is terminated by rainfall because the emergence of the beetles coincided with the first heavy rains continuously received for 2 to 5 days in the three years of investigation. Further studies are needed to determine the nature and the factors responsible for induction and termination of diapause in *M. ochroptera.*

Since larvae and pupae of *M. ochroptera* do not appear to over-winter, the contribution of the over-wintered generation to the new generation depended on the number of adults surviving between May and October. Over-winter survival is perhaps important in that it would determine the size of the reproductive population and hence the potential damage to sesbania seedlings during the rainy season. The agronomic and economic feasibility of resorting to early/late planting of sesbania would depend on the extent of effective survival of the beetles. The concept of effective survival during over-wintering was found to have practical application in adjusting planting dates for weevil control in cotton (Rummel and Carroll, 1983; 1985). In years with a dry winter and delayed rains as in 1998, the survival of adults may be reduced and early-planted sesbania may escape severe infestation. A large proportion of the adults appeared to survive in years with some showers during the winter and early rains as in 1997 and 1999. In such years, synchronous emergence of the surviving adults may accentuate the defoliation and loss of seedlings since this offers the plants little chance to compensate for damage.

At least three factors are likely to be important in the mortality of over-wintered adults in the field: natural enemies, bush fires and weather. Bush fires are common during August-September in eastern Zambia. Farmers deliberately burn fallow fields, previously cropped land or *miombo* forests in preparation for planting new crops (Kwesiga and Beniest, 1998). Some times sesbania fallows are burnt as uncontrolled bush fires spread into the farms. Though difficult to quantify, the mortality of over-wintered beetles due to bush fires may significantly contribute to the overall generation mortality.

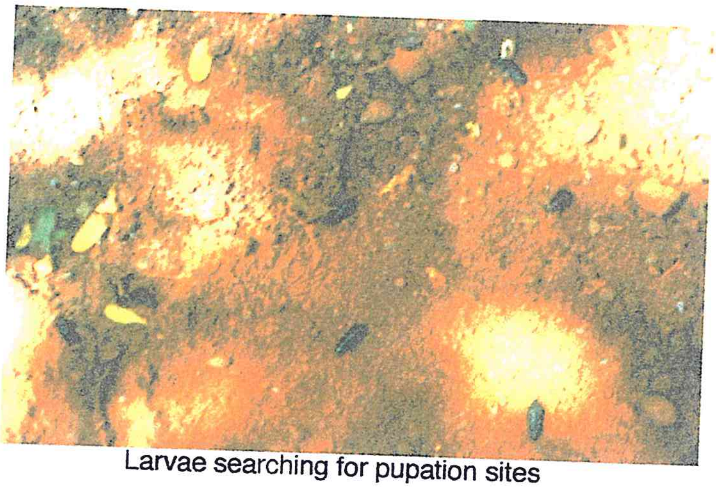
The prolonged dry weather and its consequences, depletion of food reserves and physiological ageing, may also contribute to reduction in the effective survival of beetles. Over-wintering insects are known to accumulate fats and glycogen prior to entering diapause (Goldson, 1981; Barker *et al.*, 1988). The fat deposits act as reserve food and are also involved in resistance to cold winter weather in some insects (Buffington and Zar, 1968). When the rains are delayed, over-wintering adults may die due to depletion of the food reserves. Similarly, the low and high temperatures experienced during June-July and September-October, respectively, may have negative effects on beetle survival.

The range of biological studies on *M. ochroptera* discussed in this chapter has provided new information, especially on fecundity of females, egg hatchability, developmental time, host range, over-wintering and adult diapause. It is hoped that this contribution will foster more research on the biology of *M. ochroptera*. It is also hoped that the knowledge gained would contribute significantly towards the development of management options suited to the socio-economic conditions of small-scale farmers in southern Africa.

Mating adults of *Mesoplatys ochroptera*

Mesoplatys ochroptera
larvae feeding

Egg mass of *M. ochroptera*



Larvae searching for pupation sites

Plate1: Life cycle of *Mesoplatys ochroptera*

Table 3.1. Oviposition period and egg laying potential of the current generation adults of *M. ochroptera* in the insectary at Msekera, Eastern Zambia, 1998-99. The inside temperature of the insectary ranged from 23-30°C when this study was undertaken.

Variables observed	Virgin (unmated) females Mean ± S.E (range)	Females mated only once Mean ± S.E (range)	Repeatedly mated females Mean ± S.E (range)
Oviposition period#	26.5±0.9 (18-32)*	39.6±1.5 (25-56)	36.8±1.3 (20-53)
Egg batches/female	21.9±1.1 (15-29)	38.8±1.3 (22-52)	38.7±1.5 (21-52)
Eggs/female/day	22.7±1.1 (18-36)	25.5±1.3 (11-35)	25.6±1.2 (13-36)
Fecundity	527.5±28.8 (294-659)	980.3±42.4 (721-1663)	1007.4±37.0 (725-1555)
Hatchability (%)	0	82.6±2.0 (56-98)	86.2±1.5 (70-97)

In days

Table 3.2. Post-emergence longevity, fecundity and oviposition period of adult *M. ochroptera* over-wintered in the field and the insectary at Msekera, eastern Zambia, 1998-99

Variables observed		Field populations Mean ± S.E (range)	Insectary populations Mean ± S.E. (range)
Longevity:	Males	21.7±0.8 (12-30)*	24.2±1.0 (6-31)
	Females	25.5±0.5 (18-29)	24.8±1.3 (14-31)
Fecundity		352.7±26.4 (87-632)	443.8±37.2 (129-783)
Oviposition period (days)		19.8±0.8 (11-25)	17.9±1.4 (5-29)

Table 3.3. Duration (days) of the different stages of *M. ochroptera* in the glasshouse at Makoka (Malawi) and the insectary at Msekera, Zambia, 1997-98

Developmental period (days)	Makoka	Msekera	
	January-February	January-April	May-June
	Mean ± S.E (range)	Mean ± S.E (range)	Mean ± S.E (range)
Incubation	4.7±0.1 (4-5)*	4.8±0.2 (2-9)	6.6±0.2 (3-8)
1st instar larva	2.8±0.1 (2-4)	5.5±0.2 (3-10)	5.3±0.1 (4-8)
2nd instar larva	2.4±0.1 (2-4)	5.4±0.2 (3-7)	4.6±0.1 (3-6)
3rd instar larva	4.4±0.2 (3-6)	4.3±0.1 (3-8)	7.4±0.2 (5-10)
Pre-pupa	ND	4.8±0.1 (4-7)	6.1±0.3 (3-10)
Pupa	5.2±0.1 (4-6)	10.1±0.4 (6-16)	8.4±0.2 (4-13)
Egg to adult	19.5±0.3 (16-23)	34.9±0.4 (26-39)	38.1±0.4 (30-43)
Pre-oviposition	3.4±0.1 (3-5)	5.8±0.3 (3-7)	4.7±0.2 (3-6)

n = 30; ND= no data available

Table 3.4. Analysis of variance table for diurnal rhythm in *M. ochroptera* on sesbania in the field at Msekera, eastern Zambia, March 1998

Source of Variation	Degrees of freedom	Mean Squares	F value	Probability
Canopy (C)	2	0.113	1.033	0.359
Time of day (T)	2	0.159	1.459	0.236
Days (D)	1	0.161	1.476	0.226
CXT	4	0.370	3.384	0.012*
CXD	2	0.131	1.203	0.304
TXD	2	0.0006	0.006	0.994
CXTXD	4	0.127	1.160	0.332
Error	126	0.109		

Table 3.5. Proportion of over-wintered and first generation adult *Mesoplatys ochroptera* in the field population at the beginning of the rainy season at Msekera, eastern Zambia, 1999-2000

Date of Collection	Number collected	% Over-wintered adults	% Current Generation
23/11/99	60	100	0
5/12/99	89	100	0
22/12/99	162	60.0	40.0
5/1/2000	140	15.0	85.0
17/1/2000	130	5.4	94.6
2/2/2000	243	0	100

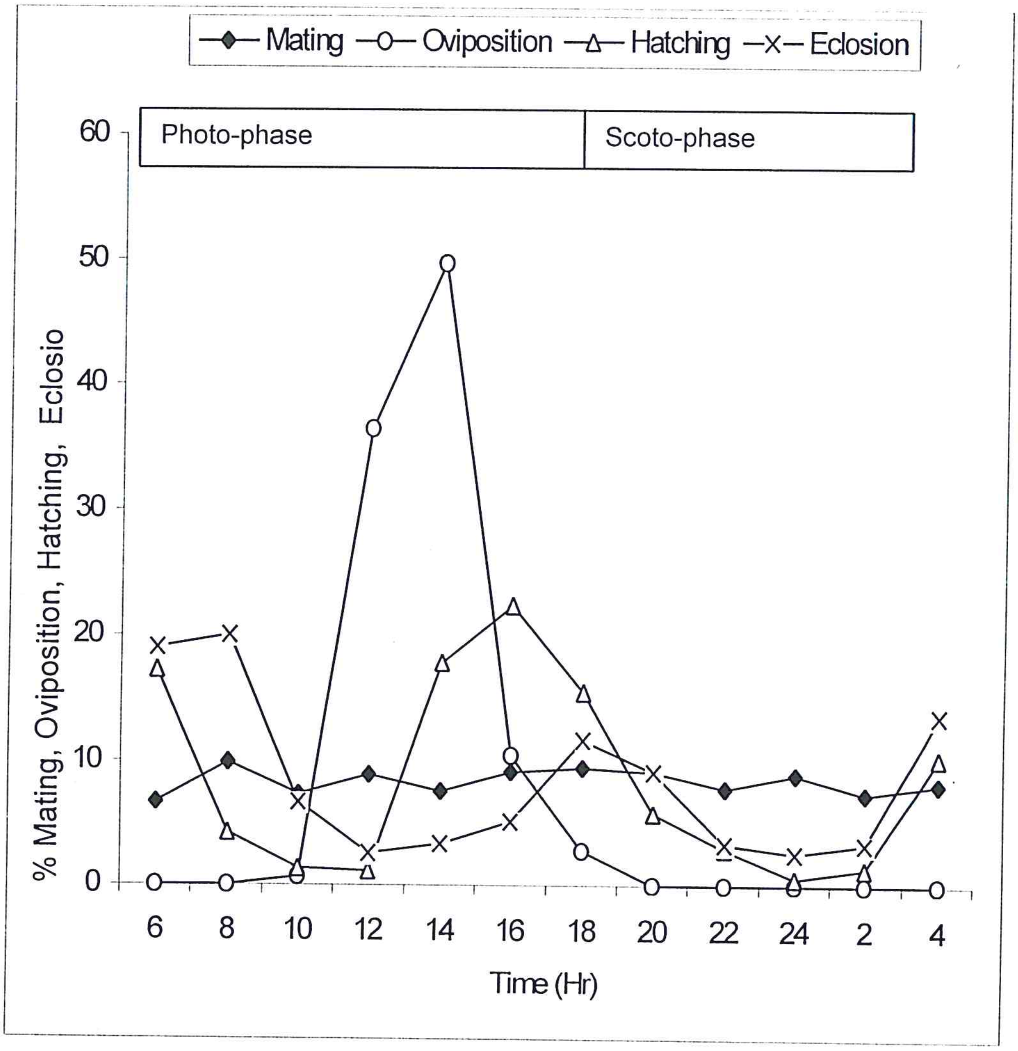


Fig. 3.1. The proportion of mating adults, egg laying (oviposition), hatching and adult emergence from the pupal cell (eclosion) of *M. ochroptera* observed at different times of the day in the insectary at Msekera Research Station, eastern Zambia

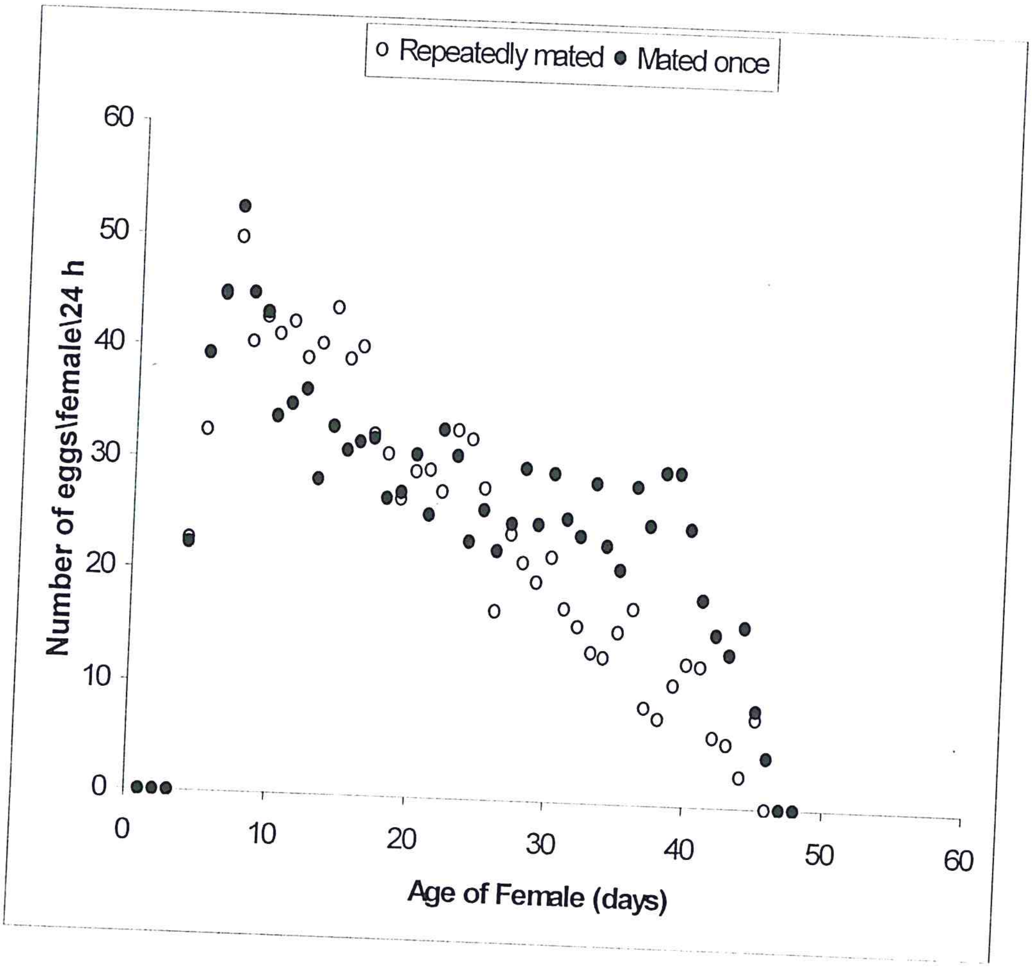


Fig. 3.2a. Age-specific fecundity of current generation *M. ochroptera* females in the insectary at Msekera Research Station, eastern Zambia

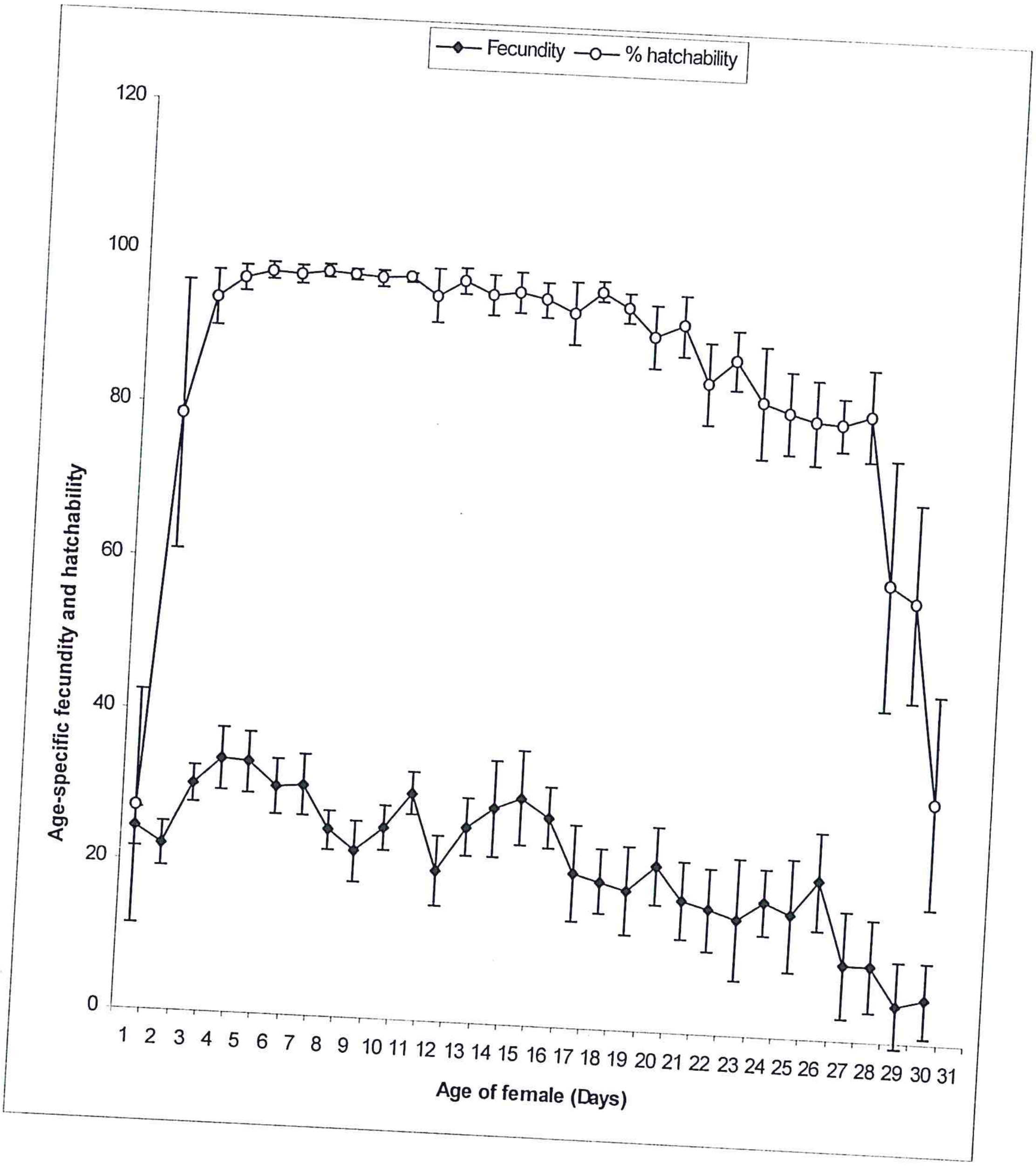


Fig. 3.2b. Age-specific fecundity and hatchability of eggs for over-wintered *M. ochroptera* females in the insectary at Msekera Research Station, eastern Zambia

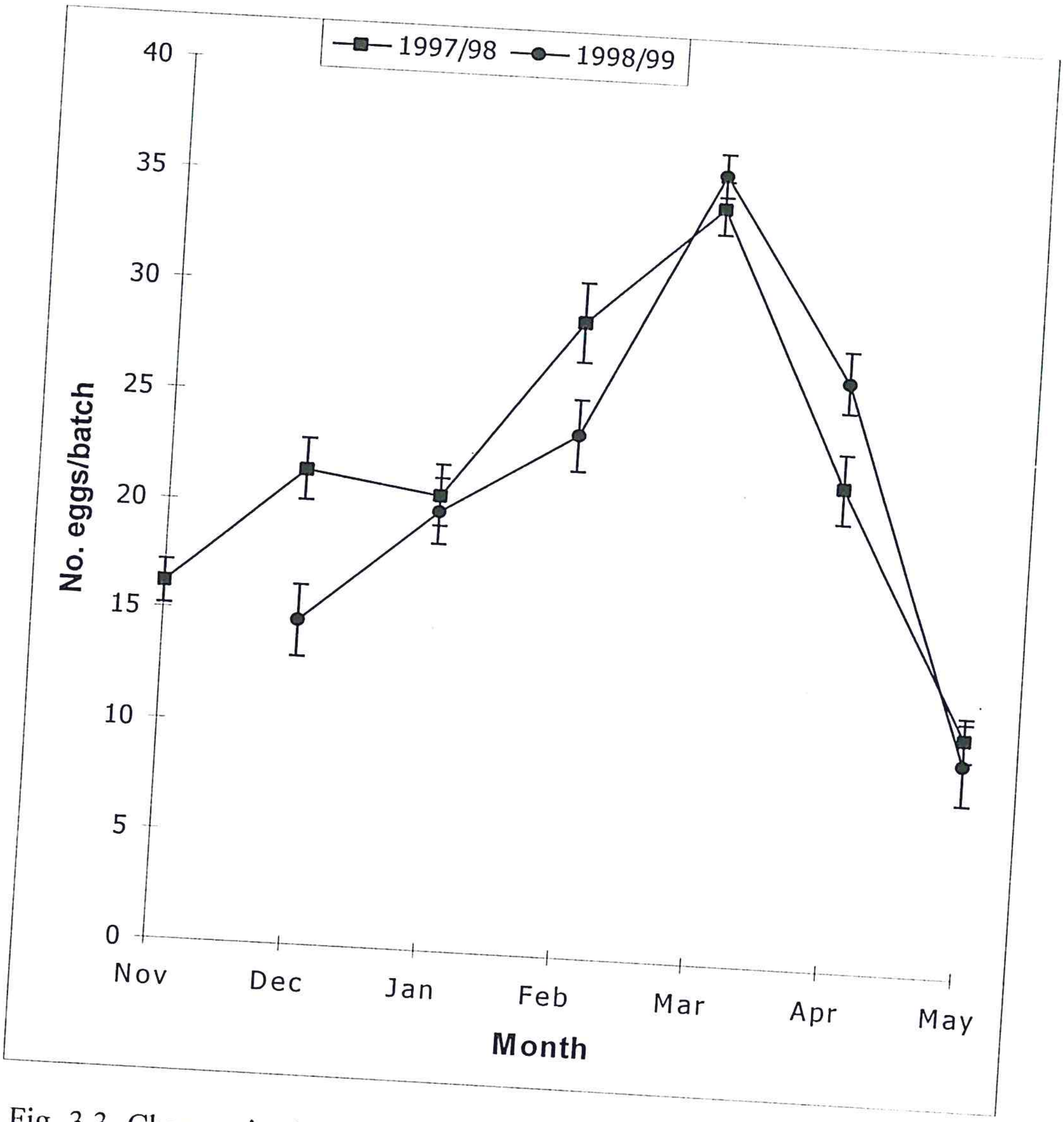


Fig. 3.3. Changes in the number of eggs per batch produced by *M. ochroptera* during the 1997/98 and 1998/99 rainy seasons in the field at Msekera Research Station, eastern Zambia. Error bars represent standard errors of means (n=30 batches of eggs)

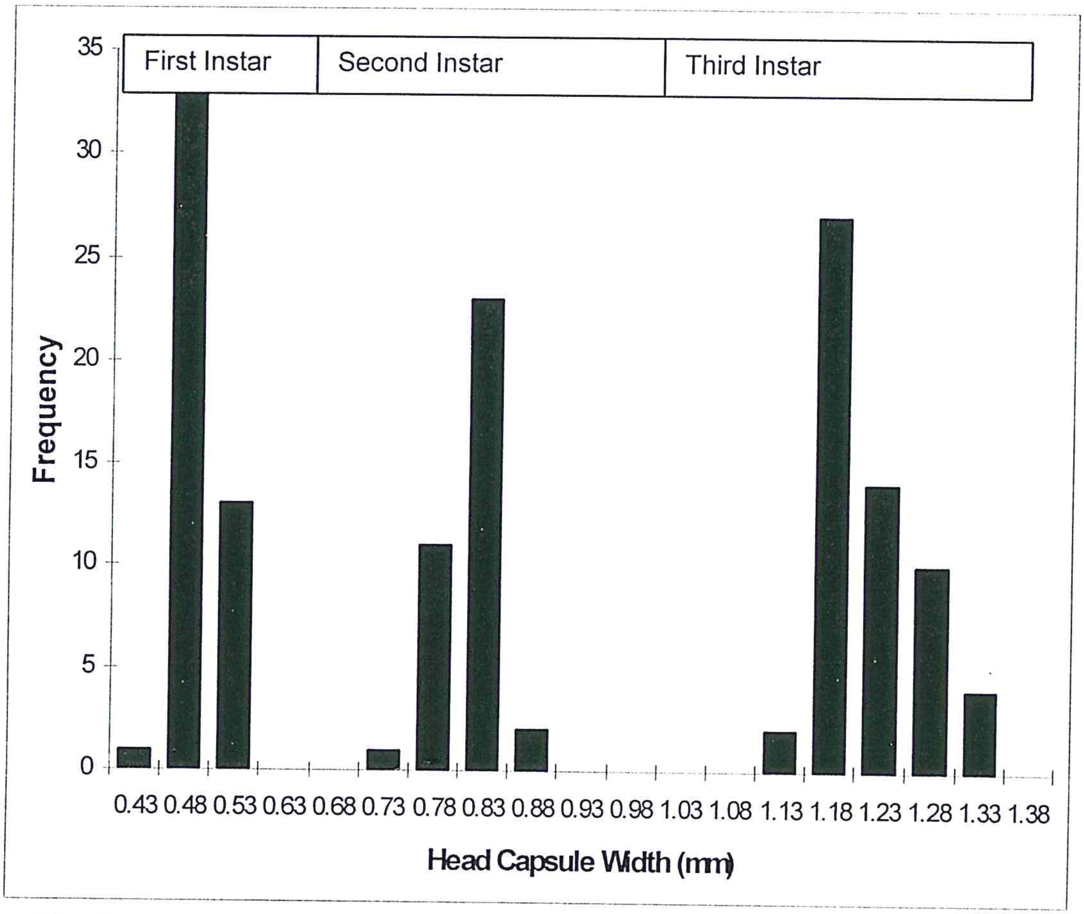


Fig. 3.4. Frequency distribution of head capsule widths of the three instars of *M. ochroptera* larvae.

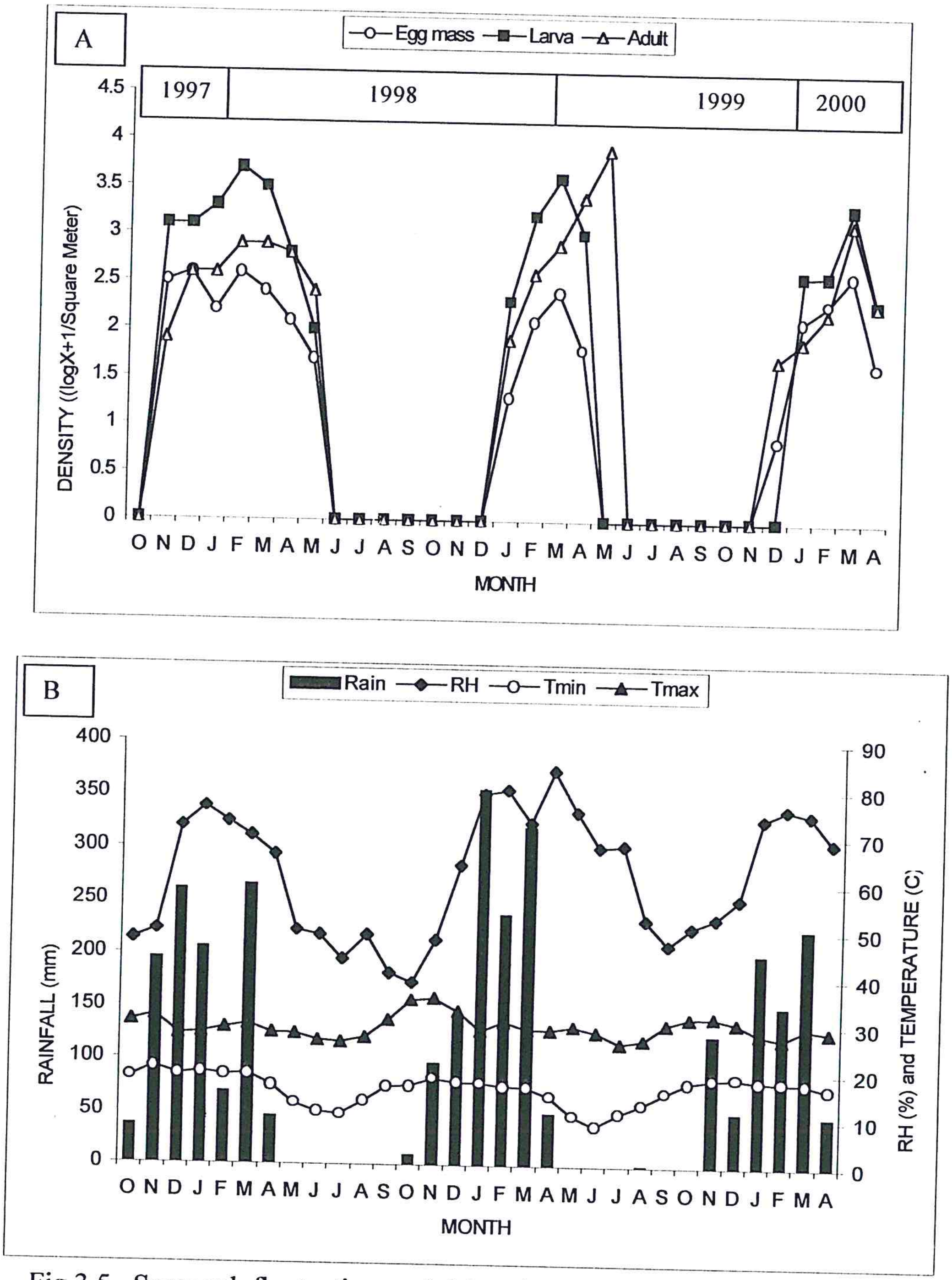


Fig.3.5. Seasonal fluctuations of *M. ochroptera* populations in *S. sesban* fallows (A) and monthly rainfall (mm), relative humidity (%) and minimum (Tmin) and maximum (Tmax) temperatures (°C) (B) recorded at Msekera Research Station, eastern Zambia

CHAPTER 4

4.0 NATURAL ENEMIES OF *Mesoplatys ochroptera* [1]

4.1 INTRODUCTION

According to Greathead (1986), the use of natural enemies instead of insecticides produces dramatic savings. Cox (1994b, 1996b) gives an extensive account of natural enemies of the Chrysomelidae and there are several examples of successful biological control of chrysomelid beetle pests in agriculture and forestry. However, there is no published literature on the predators and parasites of *M. ochroptera*.

Methods to evaluate predation have been reviewed extensively by Southwood (1978) and Luck *et al.* (1988). Observations on the abundance of insects and their potential predators can be used as a first step to discover which species are important in reducing the numbers of a particular insect species (Speight *et al.*, 1999). Visual recording of predation events in the field is the most bias-free and convincing way to evaluate predators (Kiritani *et al.*, 1972). One situation where field observations, augmented by laboratory studies, have played a particularly important role is in the study of polyphagous predators.

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[1] Part to be published as: Sileshi, G., Kenis, M., Ogol, C.K.P.O., and Sithanantham, S. 2001. Predators of *Mesoplatys ochroptera* Stal in sesbania-planted fallows in eastern Zambia. *BioControl* (In Press)

This type of study may usefully identify which predator species merit further research. An index of some kind may be calculated (e.g. Sunderland and Vickerman, 1980) and different predators can be ranked accordingly leading to detailed studies on potentially important species (Speight *et al.*, 1999).

The impact of parasites is generally measured as apparent mortality, i.e. the number of individuals of a host stage dying in relation to the number that entered the stage (Southwood, 1978). Traditionally parasitism has been estimated through field samples, which is easy to obtain, and requires no experimental set-up. Host stages are collected, parasites reared out, and the level of parasitism calculated (Sasaba and Kiritani, 1972). Alternatively, to avoid larvae dying during the process of rearing, field-sampled hosts can be dissected to record parasitoid eggs or larvae in the host (Southwood, 1978). Rearing typically underestimates parasitism in comparison with dissection by 12-44% (Day, 1994). Even though dissection improves the estimate of parasitism, it is time consuming and small parasitoid stages may be overlooked (Evenhuis, 1962). Dissection can also lead to underestimation of parasitism because a proportion of parasitized hosts die due to oviposition trauma (Jervis *et al.*, 1992) or feeding by female parasitoids (Johnston, 1915; Hamerski and Hall, 1988; Sileshi, 1997b). Day (1994) argued that to give the most comprehensive results both methods should be used concurrently.

Field sampling, and subsequent rearing or dissection are hampered by several sources of error (Driesche, 1983). When the sources of error are taken into account, or avoided, samples can estimate the percentage parasitism at a particular time in the field. A simple and widely used method of estimating the rate of parasitism involves pooling all samples and dividing the number of emerged parasites by the total number of susceptible host stages collected (Barbosa *et al.*, 1975). As the rate of parasitism varies throughout a generation of the host, a single assessment will not give an adequate degree of precision (Southwood, 1978).

The objectives of this study were (1) to identify the predators and parasites of *M. ochroptera* and (2) to assess their potential as components of integrated management of *M. ochroptera* in *S. sesban* fallows.

4.2 MATERIALS AND METHODS

4.2.1 Predation

4.2.1.1 Field study

The field study was conducted between October 1997 and June 1999 in sesbania planted-fallows in Eastern Province of Zambia. The study was conducted at Msekera Research Station and Kalunga (Chipata South District), Chadiza (Chadiza District) and Kagoro (Katete District). The sesbania fields at Msekera were continually monitored throughout the study period for predatory arthropods near the eggs, larvae and adults of *M. ochroptera*. Spider webs, trails of ants, and nests of wasps were examined for corpses of the different life stages of the beetle. Once a predator was spotted, its feeding activity was monitored and the kinds of prey eaten were recorded. The fields in Kalunga were visited twice while those in Chadiza and Kagoro were visited only once during the peak population of *M. ochroptera* (March-April 1999). Plants were visually examined by walking through naturally infested sesbania fields and the species of predators attacking the beetle and its larvae recorded.

Density estimates of predators and *M. ochroptera* were obtained by sampling at monthly intervals at Msekera Research Station. During each sampling, the different stages of the beetle and its predators were counted on 30 infested plants. Absolute density estimates were obtained from these data and natural logarithms of population densities plotted against time. Predation of eggs by *Deraeocoris ostentans* was assessed fortnightly by counting the number of egg masses preyed, the number of adult bugs and nymphs on three to four months old sesbania plants.

4.2.1.2 Laboratory studies

Studies were conducted in an insectary at Msekera during February-May 1998 and1999. The inside temperature of the insectary was recorded in the morning, at noon and in the evening. The mean (±S.E) monthly temperature of the unit was 26.2±0.2, 25.5±0.2, 24.5±0.3 and 24.7±0.3 in February, March, April and May, respectively. The life history of the three most common predators was studied in the insectary. The adult predators were collected from the field, maintained in Petri dishes and were daily supplied with last (third) instar larvae of the beetle. When eggs were laid, the development from egg to adult stage was followed up and the duration of each stage recorded.

The voracity of last instar (fifth) nymphs and adults of *G. conspicuus*, *M. acuta* and *M. mensor* was tested after preconditioning to standardise their hunger level. Healthy last instar nymphs and adults reared in the laboratory were selected and starved for 24 h. Each of the nymphs were then offered with 5, 10, 15, 20, 25 and 30 last instar larvae separately. Then individuals were used as replicates for each treatment and these were observed for 7 to 9 days. Records on any predator that died or looked unhealthy during the course of observation was discarded. Since the consumption rate of nymphs was variable, this was recorded separately for each day and plotted against days after the fourth moult. To elucidate the functional response of adults, the daily (based on 24-h) consumption by adults of each species was plotted against the number supplied. The data were tested for fitness to the Type-1 and Type-2 functional responses (Holling, 1959) using linear and non-linear models.

To test prey preference of adult *G. conspicuus*, *M. acuta* and *M. mensor*, free- and no-choice tests were made. In the no-choice condition, each adult predator was supplied with 5 larvae, 10 larvae, 5 adults and 10 adults of *M. ochroptera* separately. In the free-choice test, a mixture of 5 larvae + 5 adults and 10 larvae + 10 adults of *M. ochroptera* were supplied. For all treatments, healthy adults obtained from the insectary culture were used. Eight such adults were confined in Petri dishes with the prey and the number of larvae and adults consumed recorded for two consecutive days, making 16 observations per treatment. Paired and unpaired t-tests were used to compare the daily consumption in the free-choice and no-choice tests, respectively.

4.2.2 Parasitism

Surveys were conducted to identify parasites of *M. ochroptera* during the rainy season in 1998-2000 at several sites (see 4.1) in the Eastern Province of Zambia. An intensive survey was conducted in March-April 1999 to determine the occurrence of the two important parasites in farmers' fields and natural stands in eastern province. This was planned to coincide with the peak population of *M. ochroptera*. Twenty-one farms were visited, but only 11 of them had *M. ochroptera* infestation.

Egg masses, larvae, pupae and adult *M. ochroptera* encountered during field sampling were collected and reared individually. Egg masses of *M. ochroptera* were kept in plastic Petri dishes (diameter 11cm, max.) lined with moistened tissue paper until hatching. Field-collected larvae were separated by instar and were reared in plastic Petri dishes on cut *S. sesban* leaves placed on cellulose paper that was moistened regularly to prevent it from drying out. Fresh leaves were supplied every second day until the host larvae pupated or died. Some of the larvae collected were preserved in 70% alcohol and dissected. Dr. Marc Kenis at CABI Bioscience Centre, Switzerland performed most of the dissection. Pupae were collected from the soil and kept in plastic Petri dishes on cellulose paper that was moistened regularly. Adults collected from the field were kept in Petri dishes and fed with fresh *S. sesban* leaves for at least 2 weeks.

Immature parasitoid stages (larvae, cocoons) were collected as they emerged, kept in Petri dishes individually and were allowed to develop into the adult stage. Juvenile nematodes were placed in moistened natural soil in glass jars. After about two months the adult nematodes were killed and relaxed in hot water and preserved in 40% formaldehyde and TAF (triethanolamine, acetic acid, and formaldehyde) mixture for taxonomic studies.

4.3 RESULTS

4.3.1 Predators of *M. ochroptera*

Afrius yolofa (Guérin-Ménville), *Glypsus conspicuus* Westwood, *Macrorhaphis acuta* Dallas, *Mecosoma mensor* Germar (Heteroptera: Pentatomidae), *Rhinocoris segmentarius* (Germar) (Heteroptera: Reduviidae), *Deraeocoris ostentans* (Stål) (Heteroptera: Miridae), *Cyaneodinodes fasciger* (Chaudoir) (Coleoptera: Carabidae), *Tetramorium sericeiventre* Emery, *Pheidole* sp. (Hymenoptera: Formicidae) and *Mallada* sp. (Neuroptera: Chrysopidae) were recorded for the first time as predators of *M. ochroptera*.

The pentatomid and reduviid bugs attacked the beetles and larvae by inserting their proboscis into the body of the prey and sucking out the body fluid, leaving only the evacuated skin. In all the observed cases, no prey escaped once in the grip of the predator; the prey became passive after a few escape attempts.

Glypsus conspicuus Westwood

G. conspicuus was the most common predator of *M. ochroptera* in the study area (Table 4.1). Its population built up during the rainy season and peaks were observed in April-May. This generally overlapped with the phenology of *M. ochroptera*, but there was a delay in the build up of the predator population (Fig. 4.1).

G. conspicuus laid eggs in masses of 35 to 121 (Mean± S.E = 77.5±3.8) on sesbania leaves. The average incubation period was 12.4 days (±0.2). The nymphal development passed through five instars. The duration of the different life stages is given in Table 4.2.

The second to fifth nymphal instars and adults of *G. conspicuus* preyed on eggs, larvae and adults of *M. ochroptera*. In the field second to fourth instar nymphs attacked their prey in a group while fifth instar nymphs were solitary. The nymphs were also observed to stick their proboscis into plant tissue on several occasions, apparently sucking sap. In the insectary, adult *G. conspicuus* consumed more larvae ($P<0.001$) than adults (Table 4.3). Under both free-choice and no-choice experiments, about 80% of the larvae and 10% of the adults were consumed.

The consumption of prey larvae by the adult predators was influenced by the density of the prey larvae. The functional response of adults fitted the Type-2 ($Y = 2.10X^{0.49}$, $R^2 = 0.98$) much better than the Type-1 ($Y = 1.98 + 0.33X$, $R^2 = 0.77$). At lower prey densities, the proportion of larvae consumed was found to be higher. The maximum number consumed per day was 30 larvae. Predators failed to respond to further increases in prey density and a plateau was reached between 10 and 15 third instar larvae per day (Fig. 4.2). The daily consumption of last instar nymphs was highly variable and depended on the number of days from the last moult. The largest number of prey was consumed two to three days after the fourth moult and then voracity declined to zero one day before moulting into the adult stage (Fig. 4.3). In the field, *G. conspicuus* was also observed preying on three lepidopteran species (Table 4.4).

Macrorhaphis acuta Dallas

M. acuta was the second most abundant heteropteran predator of the beetle (Table 4.1). Populations of this bug increased from February to May, reaching peak in April (Fig. 4.1). Females laid eggs in masses of 15 to 83 (39.3±3.2) on sesbania leaves and twigs in the field. In the field *M. acuta* eggs suffered heavy parasitism by *Telonomus* sp. and *Trisolcus sipiodes* Johnson

(Scelionidae: Hymenoptera) which together caused over 60% parasitism in May and June. The nymphal development passed through five instars. The duration of the different life stages is given in Table 4.2.

The adults and all the nymphal stages of the predator attacked the eggs, larvae and adults of *M. ochroptera*. In the insectary, adult *M. acuta* consumed more larvae ($P<0.001$) than adults under both free-choice and no choice conditions (Table 4.3). The daily consumption of larvae by *M. acuta* followed the same pattern as that of *G. conspicuus*, but had a higher upper threshold before the response curve reached a plateau (Fig 4.2). The response curve fitted the Type-2 ($Y = 2.14X^{0.53}$, $R^2 = 0.98$) much better than the Type-1 model ($Y = 2.06+ 0.39X$, $R^2 = 0.86$). The daily consumption of last instar nymph was variable and peak consumption was observed two to three days after the fourth moult (Fig. 4.4). In addition to *M. ochroptera, M. acuta* preyed on many species of insect pests attacking various plants at Msekera (Table 4.4).

Mecosoma mensor Germar

M. mensor was the third most common predator of the beetle (Table 4.1). Populations of this bug followed the same pattern as those of *G. conspicuus* and *M. acuta* (Fig. 4.1). The eggs were laid in masses of 14-52 (30.7±1.9) and the incubation period was 9.4 days (±0.2) in the laboratory. In the field, *M. mensor* eggs suffered heavy parasitism (up to 75%) by *Trisolcus* *sipiodes* Johnson (Scelionidae: Hymenoptera). The nymphal development passed through five instars. The duration of the different life stages is given in Table 4.2.

M. mensor nymphs and adults preyed on the eggs, larvae and adults of *M. ochroptera*. As for the two other species discussed above, *M. mensor* consumed significantly higher numbers of larvae ($P<0.001$) compared to adults under both free-choice and no choice conditions (Table 4.3). The daily consumption pattern of adults was similar to those of *G. conspicuus* and *M. acuta*, but had a lower plateau (Fig 4.2). The response curve fitted the Type-2 ($Y = 1.25X^{0.56}$, $R^2 = 0.98$) much better than the Type-1 model ($Y = 1.17 + 0.26X$, $R^2 = 0.82$). In addition to *M. ochroptera, M. mensor* preyed on many insects in sesbania fallows (Table 4.4).

Afrius yolofa (Guérin-Ménville)

This was a very variable pentatomid species observed less frequently in the sesbania fallows and its life cycle was not known. It attacked larvae and adults of *M. ochroptera*, larvae of *Euproctis rubricosta* Fawc. and *Helicoverpa armigera* (Hubn.) in the fallows (Table 4.4).

Deraeocoris ostentans (Stål)

Adults and nymphs of the mirid bug *D. ostentans* preyed on only eggs of *M. ochroptera*. They also attacked many other insects on different crop and tree species at Msekera (Table 4.4). The population of *D. ostentans* was generally higher during the 1997-98 rainy season compared to the 1999 rainy season. During the 1997-98 rainy season, the numbers built up rapidly beginning from the last week of March and the peak was recorded in May. The percentage egg loss due to predation by the bugs was 15.2% in mid-March and it rose to 73.2% mid-May 1998. During the 1998-99 rainy season, sufficiently large numbers were observed from May onwards. By this time *M. ochroptera* populations had drastically declined and predation of eggs could not be assessed.

Rhinocoris segmentarius (Germar)

In the field both adults and nymphs of the reduviid bug *R. segmentarius* preyed on adults and larvae of *M. ochroptera*. This species was found throughout the rainy season in small numbers. In addition to *M. ochroptera*, it was seen to attack *E. rubricosta*, *H. armigera* and an unidentified lepidopteran larva on sesbania.

Cyaneodinodes fasciger (Chaudoir)

All larval stages and adults of the carabid *C. fasciger* preyed on larvae and eggs of *M. ochroptera*. The adult beetles dwell in the soil and these were seen frequently in weed infested sesbania fallows. The larvae of *C. fasciger* mimic those of *M. ochroptera* Except for their fast movement, *C. fasciger* could easily be mistaken for *M. ochroptera* larvae because of their similarity in colour, shape and size. Both adults and larvae of this species were found to be active climbers and were seen attacking *M. ochroptera* larvae and eggs on tree branches as well as on the soil surface. The larvae are fosorial and dig into the soil for pupation. Though this was one of the commonest predators in weedy fields, its impact could not be assessed in the conventional clean-weeded fallows because most of the attacks occurred in weedy fallows.

Tetramorium sericeiventre Emery and *Pheidole* sp.

The ant species *Tetramorium sericeiventre* Emery and *Pheidole* sp. were observed attacking larvae of *M. ochroptera*. Both species collected larvae crawling on the soil surface and carried them to their nest. I have not attempted to quantify their impact on *M. ochroptera* populations, but qualitative observations around ant nest sites confirmed heavy predation especially of the small larvae of the beetle. The ants were abundant towards the end of the rainy season (March-April) in sesbania fallows.

Mallada sp.

The larvae of the lacewing *Mallada* sp. were frequently observed preying on larvae and eggs of *M. ochroptera*. Assessment of their population could not be made reliably because the larvae cover themselves with pieces of dry leaves and could not be readily distinguished from weathered sesbania leaves. Preliminary data showed that their population was higher during the 1998-99 and 1999-2000 rainy season compared to the 1997-98.

4.3.2 Parasites of *M. ochroptera*

Perilitus larvicida van Achterberg (Braconidae: Hymenoptera) and an entomoparasitic nematode, *Hexamermis* sp. (Mermithidae: Nematoda) were recorded for the first time parasitizing the larvae and adults of *M. ochroptera*. No parasites were found in over 2000 egg masses and 1300 pupa collected from the fallows during the study period.

Perilitus larvicida van Achterberg

P. larvicida completed its life cycle both as an imaginal and as a larval koinobiont (where the host continues to develop after oviposition by parasitoid) endoparasite of *M. ochroptera*. All parasitized larvae and adults of *M. ochroptera* died at parasitoid emergence. Apparent parasitism was usually very low in all the areas surveyed during the peak population of *M. ochroptera* (Table 4.6 and 4.7). In total, parasitism by *P. larvicida* was only 5.2% in third instar larvae (n=2119) and 6.7% in adults (n=1712) at Msekera. Four of the 5 collection sites in natural stands of *S. sesban* and *S. leptocarpa* (in *dambos*) provided parasitism by *P. larvicida* (mean parasitism 4.7%, n=485 in larvae and 9.6% (n=479) in adults (Table 4.7). Only one out of the 11 farms had *P.*

larvicida. Parasitism by *P. larvicida* was lower at Msekera during the rainy season but showed increase during the dry season (Table 4.6).

Hexamermis sp.

Hexamermis sp. parasitized both larvae and adults of *M. ochroptera*, but larval parasitism (15.6%, n=2119) was higher compared to adult parasitism (0.4%, n=1712) at Msekera. *Hexamermis* sp. kills exclusively the last instar larvae, with up to 11 juvenile nematodes emerging from a single host larva. The size of the emerging nematodes (post-parasitic juveniles) varied from over 10 cm for specimens developing singly to less than 2 cm in the case of super parasitism. The nematodes developed into the adult stage in the soil.

Hexamermis was very rare in natural stands of sesbania, but more abundant at the sites situated in the Msekera Research Station (Table 4.6 and 4.7). Parasitism by *Hexamermis* was observed only during the rainy season, mainly in January-April (Table 4.6.). Parasitism by this species was recorded only in two out of the four natural stands and two out of the 11 farms surveyed.

4.4 DISCUSSION

4.4.1 Predation

Insects in the families Pentatomidae, Reduvidae, Miridae, Carabidae, Formicidae and Chrysopidae were found to prey on different life stages of *M. ochroptera*. Members of these families of insects have also been used in the bio-control of pest chrysomelid beetles such as *Leptinotarsa decemilineata* (Cox, 1996b). The commonest predators of *M. ochroptera* were the heteropteran bugs. *G. conspicuus* and *M. acuta* accounted for over 80% of the heteropteran predators. These species were found in the fallows only during the rainy season. It is not yet known how they survive during the dry season (May-November). It is probable that the adults hibernate during the winter (Mossop, 1927).

Though *G. conspicuus*, *M. acuta*, and *M. mensor* could prey on the eggs, larvae and adults of *M. ochroptera*, larvae constituted the biggest proportion (>65) of their diet. These species have also been reported to attack other pest species on different kinds of plants in Africa (Table 4.5). However, little was known about their biology except the descriptions of stages of *G. conspicuus* (Mossop, 1927). According to Mossop (1927), *G. conspicuus* laid eggs in masses of 12 to 59 and one female laid 119 eggs in four masses during two and half months in captivity. These were fewer than eggs laid in just one big sized mass at Msekera. The incubation period of eggs was also much shorter than the 18 to 20 days reported by Mossop (1927) in South Africa.

First instar nymphs of *G. conspicuus*, *M. acuta* and *M. mensor* appeared not to feed and Mossop (1927) reported similar observations on *G. conspicuus*. The second to fourth instar nymphs attacked the prey as a group and so it was difficult to determine voracity of individual nymphs. The fifth instar nymphs also showed variations in daily consumption, the peak voracity being 3 to 4 days after the fourth moult and feeding very little 2 to 3 days before moulting into adulthood. This behaviour, termed the "developmental response" has also been reported in other predatory insects (Murdoch, 1971; Hassell *et al.*, 1976).

Deraeocoris ostentans has been reported as a pest on cotton in Uganda (Hargreaves, 1929) and coffee in Kenya (Anderson, 1934). However, this bug was not observed feeding on sesbania. So far, most of the *Deraeocoris* spp. reported are well known predators of many insects (Villacarlos, 1993; Ulubilir *et al.*, 1997) and their potential as sap-sucking pests has been experimentally disproved at least in one species (Chinajariyawong and Harris, 1987).

The biology of *C. fasciger* is virtually unknown. Generally, *Cyaneodinodes* (=*Chlaenius* spp.) are known to lay their eggs singly in the soil (David *et al.*, 1973). The larvae move up and down the plant in search of prey and feed on larvae of Noctuidae (Katiyar *et al.*, 1976). The mimicry shown by *C. fasciger* is worth noting here. Another carabid, *Cyaneodinodes ammon* Fab. was similarly reported to mimic *Mesoplatys cincta* (Jolivet and Van Parys, 1977), but there has been a controversy over the type of mimicry. Balsbaugh (1988) argued that both species are toxic to potential predators due to poisons in their haemolymph and interpreted it as a case of Mullerian mimicry; mimicry to protect both species against vertebrate predators. But because of the predaceous nature of the carabid, its mimicry was complicated, and Jolivet and Van Parys (1977) interpreted it as a case of Peckhamian mimicry. The similarity between *C. fasciger* and *M. ochroptera* appears to conforms to the Batesian-Wallacian mimicry complex of Pasteur (1982) that allows the predaceous carabid to more easily approach its prey. The adaptive significance of this association needs to be further studied.

The results of this study suggest that predators play an important role in regulating the beetle population. These predators may also exert some control on other pests of sesbania and crop plants such as pigeon pea. This may be particularly relevant to areas like southern Malawi where sesbania is relay intercropped with pigeon pea and maize. Generalist predators can feed on any pest that is in abundance, acting as a balancing factor in the ecosystem. Even in low numbers they can slowly reduce pest populations, when specific predators may not be efficient (DeBach, 1951).

The role of *Mallada* and *Deraeocoris* species in the biological control of serious pests such as *H. armigera*, aphids, psyllids and white flies have been demonstrated elsewhere (Villacarlos, 1993; Mani and Krishnamoorthy, 1995; Kabissa *et al.*, 1996; Ulubilir *et al.*, 1997). Artificial diets and methods for mass rearing of *Mallada* species have been also developed (Yazlovetskii *et al.*, 1992; Gautam, 1994; Lee *et al.*, 1994). Nymphal stages of the Pentatomidae also appear to derive some nutrients from plants and the role of plant food in their development should be further investigated so that practical methods of mass-production could be developed.

There are also opportunities for manipulation of predator activity and augmentation of their populations. Naturally occurring populations of predators have been successfully concentrated and their oviposition increased by spraying solutions of attractants such as sucrose, molasses (Schiefelbein and Chiang, 1966; Carlson and Chiang, 1973; Ben Saad and Bishop, 1976), caryophyllene (Flint *et al.*, 1979), brewers yeast and tryptophan (Hagen *et al.*, 1976; Liber and Niccoli, 1988) on the crop. Where the habitat preferences of the predators is known, cultural practices may also be manipulated to favour the activity of predators such as *C. fasciger*. Most Carabidae including the genus *Cyaneodinodes* are known to show affinity to thick vegetation and forests (Bhat and Rajagopal, 1993). The current practice of spraying insecticides for control of *M. ochroptera* should also be discouraged in order to conserve these natural enemies.

Many biotic and abiotic factors are known to influence the activity of natural enemies. Parasites are probably the most important biotic factors which may reduce the efficiency of bio-control agents (Sileshi, 1997c). The heavy egg parasitism observed on *M. acuta* and *M. mensor* by *T. sipiodus* and *Telonomus* sp. during this study, *Trisolcus basalis* (Woll.) on *M. acuta* reported by Lee (1971), *Asolcus aloysiisabaudiae* (Foutts) and *Asolcus seychelensis* (Kieff) on *G. conspicuus* reported by Bullock and Smith (1968) certainly limit their effectiveness. Another limitation may be that the predator populations build up much later than that of *M. ochroptera*. A third limitation of such general predators may be sudden changes in the predator's preference between various prey species that may influence their efficiency in control of the target pest. Therefore, predation must not be viewed as the ultimate solution to the beetle problem in fallows, but as an adjunct to other biological control methods and cultural practices.

4.4.2 Parasitism

During the three seasons of the study, only two parasitic organisms were recorded from *M. ochroptera*. This is unusual for an insect whose different stages occur in large numbers on the same plant. Insects that have exposed imaginal, egg and larval stages, and that feed externally on foliage are usually attacked during most of their developmental stages by a wide range of parasitoids (Hawkins, 1994). The eggs, larvae and pupae of the Chrysomelidae are also known to be attacked by a variety of parasitic insects (Cox, 1994b) and *M. ochroptera* cannot be an exception. This study was conducted over a relatively short period and in a limited area. That is probably why I failed to observe the complete spectrum of parasites of *M. ochroptera*.

P. larvicida belongs to the sub-family Euphorinae (Braconidae: Hymenoptera), that has been associated with adult parasitism (Achterberg *et al.*, 2000). Parasitism of adult insects is a peculiar and rather rare phenomenon among parasitic Hymenoptera (Tobias, 1966; Shaw, 1988). Among the Euphorinae, *Perilitus* and *Microctonus* species are known to oviposit in both adults and immature stages of the same holometabolous insect (Waloff, 1961; Loan, 1969; Semyanov, 1979; Obrycki *et al.*, 1985).

Perilitus species are recorded from Curculionidae, Coccinelidae and Chrysomelidae. Elsewhere, *Perilitus dubius* (Wesmael) was reported to parasitized adult *Gonioctena olivacea* (Forster) (Richards, 1960; Waloff, 1961), *P. sicheli* (Giard) and *P. falciger* (Ruthe) parasitized adult *Timarcha* spp. (Jolivet, 1950; Richards, 1960). *P. aethiops* Nees and *P. brevicollis* Halliday were reported to parasitize larvae of *Phyllotreta nemorum* L. (Newton, 1931) and *Altica ampelophaga* (Guérin-Ménville) (Künkel d'Herculais and Langlois, 1891), respectively. *P. brevicollis* has been noted ovipositing on adult *A. ampelophaga* (Künkel d'Herculais and Langlois, 1891). However, in all reported cases the percentage of successful parasitization occurred when adults were attacked (Shaw, 1988). When larvae are attacked, development of the parasitoid is delayed until the host becomes adult (Shaw and Huddleston, 1991; Cox, 1994b). The species reported here is probably the first well-documented case of a parasitic Hymenoptera attacking and successfully emerging from both adults and larvae of the same host.

Several species of *Hexamermis* are reported from chrysomelid beetles (Poinar, 1988) but little is known on their biology. The best known example is *Hexamermis albicans* Siebold, a parasite of the Colorado potato beetle (Myshachkov, 1990). Infectious stages of *Hexamermis* species are capable of climbing several metres up trees to reach their hosts (Poinar, 1979; Akanbi and

Ashiru, 1991). Generally, Mermithidae are parasites of aquatic or terrestrial insects and enter their insect host, usually an early instar larva, by being ingested or by penetrating the integument to gain entry to the body cavity (Poinar, 1979; Kaiser, 1991; Popiel and Hominick, 1992). They are usually specific to a single species or to one or two families of insects and are almost always lethal to their hosts (Petersen, 1985). In the present study, it was not possible to investigate the mechanisms of infection and development of *Hexamermis* in *M. ochroptera*. Future studies should focus on the study of the biology of *P. larvicida* and *Hexamermis* sp.

Populations of *M. ochroptera* suffer from very low levels of parasitism, which is probably one of the contributing factors to the development of outbreaks in agroforestry systems. Considering the very low rates of parasitism, at present it would be difficult to recommend control strategies using parasites. Two areas, however, merit further investigation. Firstly, *Hexamermis* sp. was abundant at various sites at Msekera, where *S. sesban* fallows have been planted for more than ten years. The control exerted by *Hexamermis* sp. is by no means satisfactory, but the nematode populations have been increasing between 1998 and 2000. It is desirable to monitor its impact at Msekera and in farmers' fields where *S. sesban* fallows have been planted for a long time. Secondly, the low rate of parasitism and the outbreak populations observed every year suggest that the parasitoid complex of *M. ochroptera* is incomplete or the beetle is not endemic to eastern Zambia.

Therefore, it would be highly desirable to explore for parasitoids of *M. ochroptera* in other parts of Africa where many species of *Sesbania* are reported to grow naturally and *M. ochroptera* is endemic. Potential areas include parts of Ethiopia (the Rift Valley Lakes and Lake Tana region), Kenya (parts of Western and Nyanza Provinces especially along Lake Victoria), Tanzania and Malawi (Lake Malawi and Malombe).

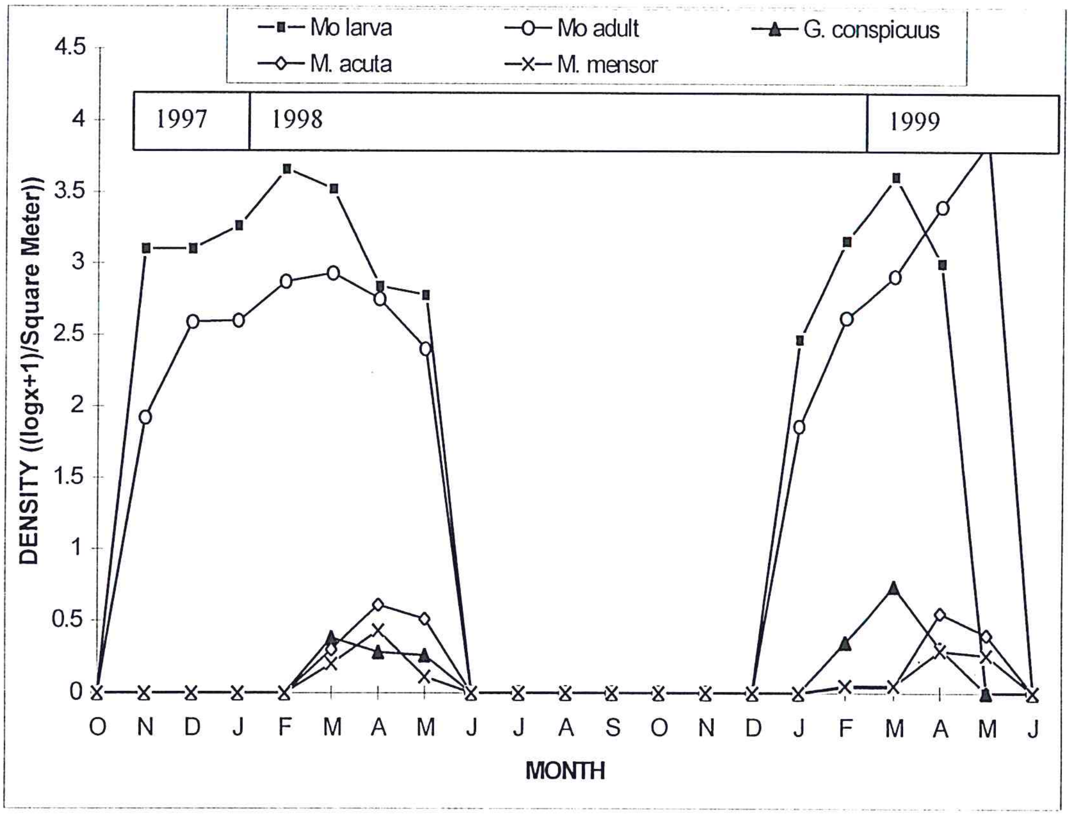

Fig.4.1. Seasonal population fluctuations of *M. ochroptera* (Mo) and its predators, *G. conspicuus* (GC), *M. acuta* (Ma) and *M. mensor* (Mm) in sesbania planted fallows at Msekera, Eastern Zambia, from October 1997 to June 1999. The density in y-axis is numbers per square meter

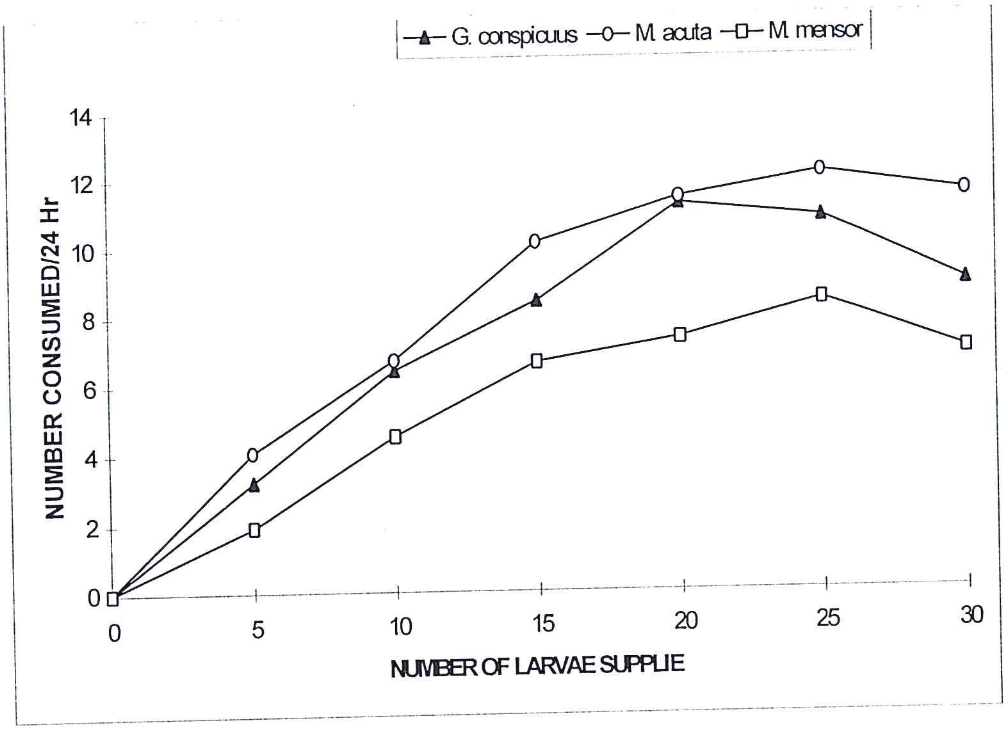

Fig.4.2. Daily consumption of third instar larvae of *M. ochroptera* by adult *G. conspicuus*, *M. acuta* and *M. mensor* at different densities in the insectary at Msekera, Eastern Zambia.

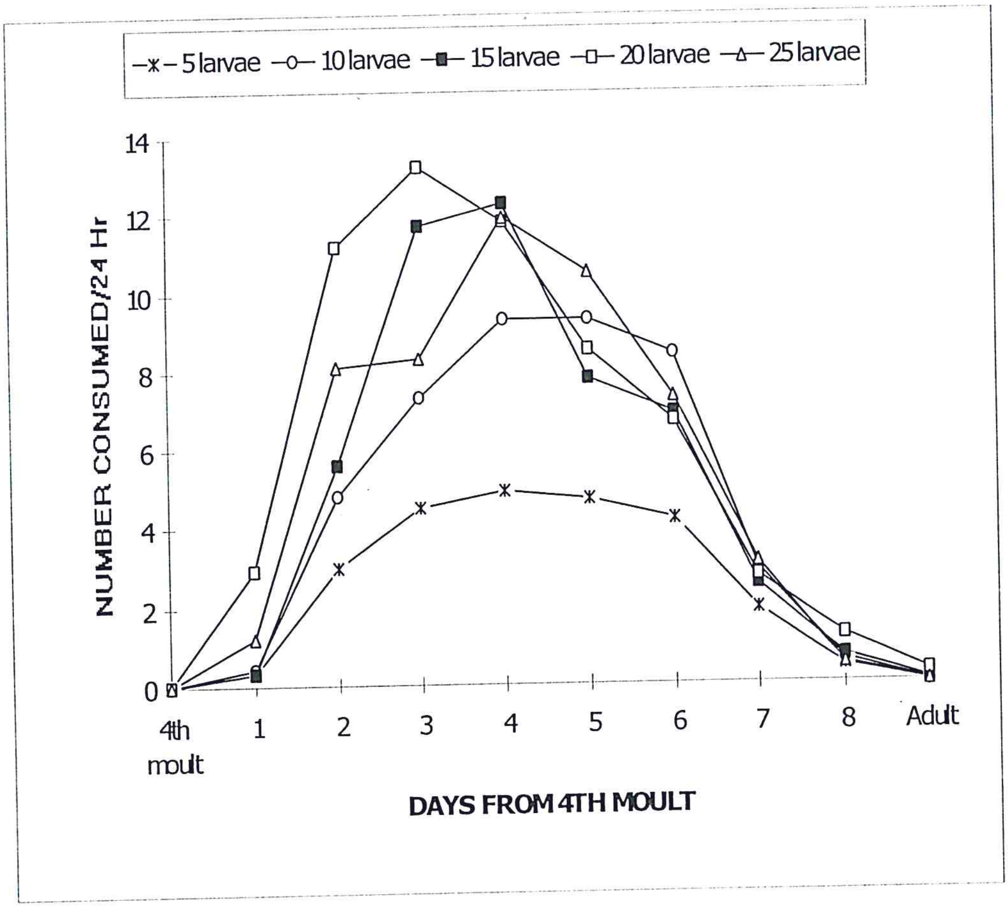

Fig.4.3. Daily consumption of third instar larvae of *M. ochroptera* by fifth instar nymphs of *G. conspicuus* at different prey densities in the insectary at Msekera, Eastern Zambia

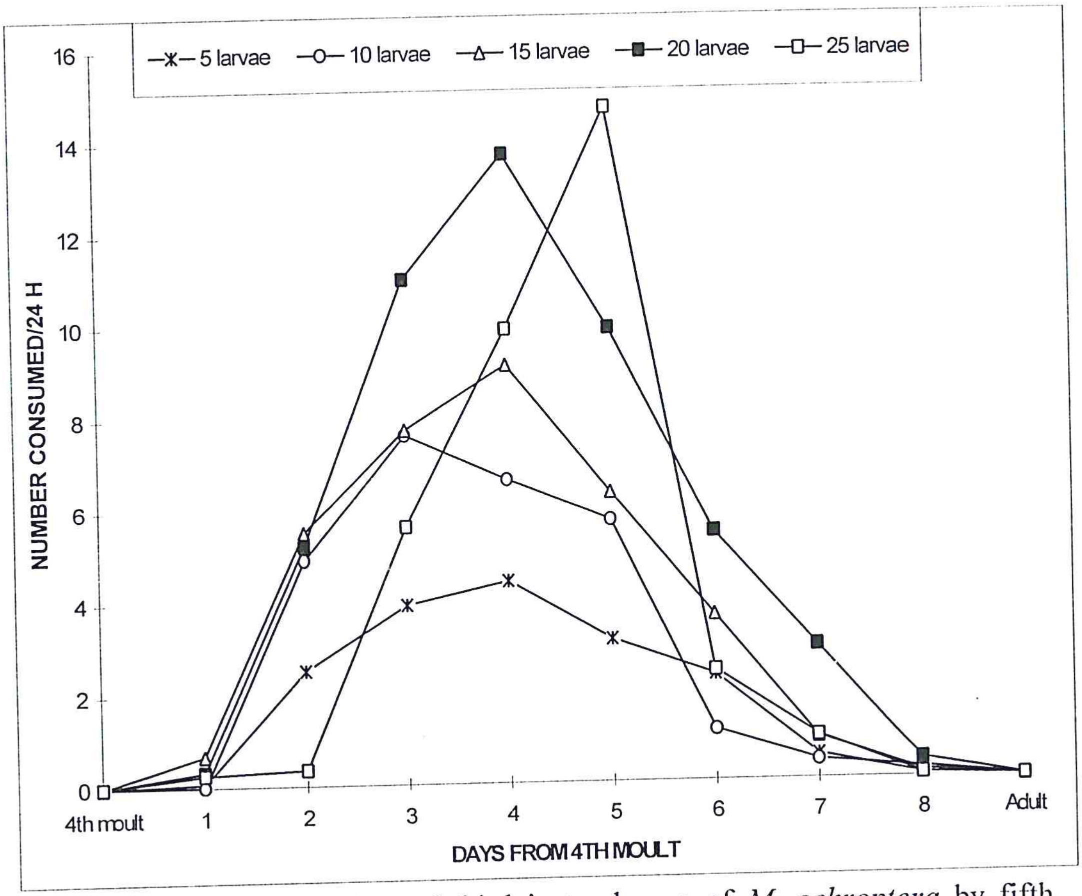

Fig.4.4. Daily consumption of third instar larvae of *M. ochroptera* by fifth instar nymphs of *M. acuta* at different prey densities in the insectary at Msekera, Eastern Zambia

Table 4.1. Distribution and occurrence (% of samples taken in each area) of heteropteran predators of *M. ochroptera* in sesbania fallows in eastern Zambia, 1999

Predator	Msekera			Kalunga		Chadiza	Kagoro
Species	29.3.99	25.4.99	25.5.99	26.2.99	28.4.99	17.5.99	3.5.99
G. conspicuus	58.1*	68.8	62.3	60.1	51.1	39.7	63.8
M. acuta	31.5	21.7	28.6	31.3	25.5	52.9	19.6
M. mensor	6.3	4.4	3.9	5.2	10.6	4.4	9.1
A. yolofa	2.9	3.1	2.2	3.4	10.7	0.7	4.2
R. segmentarius	1.2	2.0	3.0	0.0	2.1	2.2	3.3
Total number	734	1293	1556	132	478	680	872

* Percentage of each species in the sample

Table 4.2. Duration of the developmental stages of the three most common pentatomid predators of *M. ochroptera* in the laboratory at Msekera, eastern Zambia

Development	*G. conspicuus*	*M. acuta*	*M. mensor*
Eggs	12.4±0.2 (11-13)[a]	9.3±0.2 (8-11)	9.4±0.2 (7-12)
Nymphal			
First instar nymph	3.3±0.2 (2-6)	2.2±0.1 (1-3)	3.0±0.2 (2-5)
Second instar nymph	4.3±0.2 (3-7)	5.6±0.2 (4-8)	2.7±0.1 (2-4)
Third instar nymph	5.8±0.2 (5-8)	3.2±0.2 (2-4)	3.4±0.1 (2-5)
Fourth instar nymph	6.3±0.2 (4-9)	6.5±0.2 (5-8)	5.4±0.2 (4-8)
Fifth instar nymph	9.1±0.2 (6-10)	8.6±0.2 (7-11)	8.0±0.2 (6-11)
Egg-Adult	43.2±0.5 (38-47)	35.4±0.4 (30-40)	31.9±0.6 (26-39)
Adult life span	29.9±1.1 (15-41)	26.9±1.3 (14-36)	21.0±1.4 (10-35)

[a] Mean number of days ± standard error and range in parenthesis; n= 30

Table 4.3. Mean number of adults and larvae of *M. ochroptera* consumed by the adults of *G. conspicuus*, *M. acuta* and *M. mensor* under free-choice and no-choice conditions in the insectary at Msekera

Test Condition and Prey supplied	*G. conspicuus*			*M. acuta*			*M. mensor*		
	Adult	Larvae	t value	Adult	Larvae	t value	Adult	Larvae	t value
Free-choice condition									
5 Adults + 5 Larvae	0.6±0.2[a]	4.1±0.4	8.7***	0.3±0.1	4.3±0.3	16.1***	0.8±0.3	3.4±	6.6***
10 Adult + 10 Larvae	0.3±0.1	7.8±0.6	13.0***	0.5±0.2	9.4±0.2	34.0***	1.8±0.6	7.7±0.5	8.0***
No-choice condition									
5 Adults or 5 Larvae	1.1±0.3	4.4±0.2	8.1***	1.1±0.3	4.7±0.2	11.5***	1.1±0.3	3.6±0.3	6.2***
5 Adults or 10 Larvae	1.1±0.3	8.6±0.4	15.2***	1.1±0.3	9.4±0.2	24.5***	1.1±0.3	6.8±0.4	10.8***
10 Adults or 5 Larvae	1.2±0.3	4.4±0.2	7.9***	1.4±0.4	4.7±0.2	7.6***	1.6±0.5	3.6±0.3	3.4**
10 Larvae or 10 Adults	1.2±0.3	8.6±0.4	15.0***	1.4±0.4	9.4±0.2	17.9***	1.6±0.5	6.8±0.4	7.7***

[a] mean ± standard error, ns = not significant at 0.05 level, ** significant at 0.01 level, *** significant at 0.001 level.

Table 4.4. The prey species of *A. yolofa*, *G. conspicuus*, *M. acuta*, *M. mensor*, *R. segmentarius*, *D. ostentans* and *Mallada* sp. observed in the field at Msekera, eastern Zambia

Predator species	Prey species	Plant specie
A. yolofa	*E. rubricosta* Fawc., *Plusia orichalcea* F.	*S. sesban*
G. conspicuus	*E. rubricosta, H. armigera* (Hub.)	*S. sesban*
	P. orichalcea	*S. sesban*
M. acuta	*E. rubricosta*	*S. sesban*,
	H. armigera	Castor, *S. sesban*, cotton, pigeon pea,
	P. orichalcea	*S. sesban*
	Cosmophila flava (F.)	Cotton
	Spodoptera littoralis (Boisd.)	Cotton
M. mensor	*E. rubricosta, H. armigera, P. orichalcea*	*S. sesban*
D. ostentans	*Lipaleyrodes* sp.	*S. sesban*
	Heteropsylla cubana Craw.	*Leucaena leucocephala*
	Sitobion nigrinectaria	Pigeon pea
	Acanthomia sp.	Pigeon pea
Mallada sp.	*Lipaleyrodes* sp.	*S. sesban*
R. segmentarius	*H. armigera,*	*S. sesban*, cotton, Pigeon pea, sunflower
	C. flava	Cotton
	S. littoralis	Cotton

Table 4.5. Prey species of *A. yolofa*, *G. conspicuus*, *D. ostentans*, *M. acuta*, *M. mensor*, *R. segmentarius*, *C. fasciger* and *Pheidole* spp. reported from elsewhere in Africa

Predator	Species attacked	Country of Report (References)
A. yolofa	*Acreae eponina* (Cram.)	Nigeria (Matanmi & Hassan, 1987
	Mesoplatys cincta Oliv.	Nigeria (Golding, 1931)
G. conspicuus	*Achaea lienardi* Boisd.	South Africa (Taylor, 1965)
	Argyrostagma niobe (W.)	Kenya (Bullock & Smith, 1968)
	Dasychira georgiana Fawc.	Kenya (Bullock & Smith, 1968)
	Earias biplaga Walk.	Uganda (Nyiira, 1970)
	Earias insulana Boisd.	Uganda (Nyiira, 1970)
	Epicerura pulverulenta H.	Nigeria (Akanbi & Ashiru, 1991)
	Helicoverpa armigera (Hub.)	Uganda (Nyiira, 1970); Tanzania (Reed, 1965)
	Diparopsis castanea Hamps.	S. Africa (Smith, 1933)
	Bombycomorpha pallida Dist.	S. Africa (Gunn, 1916)
	Gonipterus scutellatus Gyll.	S. Africa (Mossop,1927)
	Mesoplatys cincta Oliv.	Nigeria (Golding, 1931)
D. ostentans	*Megalurothrips sjostedti* Try.	Kenya (Kahuthia-Gathu, 2000)

Table 4.5. Continued

M. acuta	*Achaea lienardi* Boisd.	S. Africa (Taylor, 1965)
	Acreae terpsicore (L.)	Ghana (Duodu & Lawson, 1987)
	Ascotis reciprocaria Wlk	Kenya (Abasa and Mathenge, 1974)
	Cassida jeanneli Spaeth.	Kenya (Poulton, 1925)
	Diparopsis castanea Hamps.	Malawi (King, 1928)
	Earias biplaga Walk.	Malawi (King, 1928)
	Earias insulana Boisd.	Malawi (King, 1928)
	Epicampoptera andersoni (Tams)	Kenya (Abasa, 1975)
	Helicoverpa armigera (Hub.)	Uganda (Nyiira, 1970)
	Latoia vivida Walk.	Malawi (Lee, 1971)
	Leucolema dohertyi	Kenya (Abasa, 1975)
	Niphadolepis alianata Karsch.	Malawi (Lee, 1971)
	Mesoplatys cincta Oliv.	Nigeria (Golding, 1931)
R. segmentarius	*Acreae eponina* (Cram.)	Nigeria (Matanmi & Hassan, 1987)
	Bagrada hilaris (Burm.)	S. Africa (Gunn, 1919)
	Dysdercus spp.	S. Africa (Ullyett, 1930)
	Earias biplaga Walk.	S. Africa (Taylor, 1932)
	Earias insulana Boisd.	S. Africa (Taylor, 1932)
	Helicoverpa armigera (Hub.)	S. Africa (Taylor, 1932)
C. fasciger	*Phaedonia areata* F.	Malawi (Smee, 1935)
Other spp.	*Helicoverpa armigera* (Hub.)	Senegal (Bhatnagar, 1987)
Pheidole spp.	*Helicoverpa armigera* (Hub.)	Kenya (Berg *et al.*, 1997)

Table 4.6. Apparent parasitism[#] of larvae and adults of *M. ochroptera* by *Perilitus larvicida* and *Hexamermis* sp. at Msekera Research Station, eastern Zambia

Date of Collection	*Parasitism (%) by* Perilitus larvicida		Parasitism (%) by *Hexamermis* sp.	
	Adult	Larva	Adult	Larva
April 1998	5.4 (186)	1.2 (82)	13.0 (186)	1.2 (82)
January 1999	NA	0.0 (87)	NA	42.8 (87)
February 1999	0.0 (55)*	0.0 (30)	0.0 (55)	30.0 (30)
March 1999	0.6 (163)	0.97 (724)	1.2 (163)	19.4 (724)
April 1999	4.8 (105)	2.1 (146)	0.0 (105)	8.9 (146)
May-June 1999[⊕]	11.6 (138)	10.3 (155)	0.0 (138)	0.0 (155)
July-August 1999[⊕]	80.0 (10)	NA	0.0 (80)	NA
November 1999	10.8 (111)	NA	0.0 (111)	NA
December 1999	0.6 (168)	3.6 (140)	0.0 (168)	0.0 (140)
January 2000	1.7 (120)	0.8 (122)	0.8 (120)	55.7 (122)
February 2000	2.5 (282)	2.9 (175)	0.4 (282)	30.9 (175)
March 2000	10.0 (340)	11.3 (320)	0.6 (340)	2.8 (320)
April 2000	12.7 (220)	17.7 (220)	0.0 (220)	0.0 (220)
Total	6.7 (1712)	5.2 (2119)	0.4 (1712)	15.6 (2119)

[#] Data for different fields and dates of collection were combined for each month

[⊕] When too few insects were collected data were combined for two months

* Figures in parenthesis indicate total number of adults or larvae of *M. ochroptera* collected

NA= Insects were not available or very rare to make any valid comparison

Table 4.7. Apparent parasitism of larvae and adults of *M. ochroptera* by *Perilitus larvicida* and *Hexamermis* sp. in natural stands (*dambos*) and farmers fields in eastern Zambia

Collection sites	Date	% *M. ochroptera* Defoliation	Parasitism (%) by *Perilitus larvicida*		Parasitism (%) by *Hexamermis* sp.	
			Adult	Larva	Adult	Larvae
Natural stands						
Chipata	17.3.99	<5 (on Ss)$^{\Theta}$	4.1 (49)*	0.0 (7)$^{@}$	0.0 (49)	0.0 (7)
Msekera	17.3.99	50-70(on Sl)	0.9 (105)	2.3 (177)	0.9 (105)	0.0 (177)
Eswelo	18.3.99	50-70 (on Sl)	18.8 (207)	6.9 (231)	1.0 (207)	2.2 (231)
Kapata	28.3.99	50-70 (on Sl)	3.4 (118)	4.3 (70)	0.0 (118)	0.0 (70)
Chiminya	15.3.99	5-10 (on Ss)	0.0 (58)	0.0 (52)	0.0 (58)	0.0 (52)
Farms						
Kalichero (4)	18.3.99	5-50 (on Ss)	0.7 (148)	0.8 (353)	0.0 (148)	2.0 (353)
Kalunga (3)	15.3.99	5-50 (on Ss)	0.0 (76)	0.0 (135)	0.0 (76)	0.0 (135)
Chadiza (1)	17.3.99	10-30 (on Ss)	0.0 (50)	0.0 (50)	0.0 (50)	0.0 (50)
Katete (2)	19.3.99	<5 (on Ss)	0.0 (41)	NA	0.0 (41)	NA

$^{\Theta}$Host plants: Ss = *Sesbania sesban*, Sl= *Sesbania leptocarpa*

* Figures in parenthesis indicate total number of adult or larvae of *M. ochroptera* collected

$^{@}$All insects found were collected

NA= Insects were not available

CHAPTER 5

5.0 RESISTANCE OF SESBANIA TO *Mesoplatys ochroptera*[†]

5.1 INTRODUCTION

Sesbania is a highly variable genus with its greatest species diversity in Africa (Gillett, 1963). Between-species and within-species variations have been reported in growth and biomass production (Otieno *et al.*, 1991; Maghembe and Prins, 1992; Karachi *et al.*, 1994; Heering *et al.*, 1996), longevity, coppicing and hedge formation (Maghembe and Prins, 1992), nitrogen fixation and nutrient mobilisation (Rao and Gill, 1993).

Differences in response to *M. ochroptera* damage have also been noted between *Sesbania* accessions (Steinmüller, 1995). However, systematic studies evaluating a wide range of genotypes have not been conducted to identify accessions that are resistant/tolerant to *M. ochroptera* in southern Africa. Three modalities of resistance to herbivore insects—antixenosis, antibiosis and tolerance—are known in plants (Painter 1951; Kogan and Ortman, 1978; Speight *et al.*, 1999). Antixenosis is commonly measured by comparing the number of insects alighting, the number leaving or their oviposition response on a range of genotypes (Müller, 1958; Gibson, 1971; Sileshi, 1994; 1995b). Tests of antibiosis usually assess the fitness of pest individuals in terms of

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feeding, development, reproduction and survival (Beland and Hatchett, 1976; Beach *et al.*, 1985).

Tolerance is defined as the ability of plants to compensate, in part, for the effect of defoliation on plant fitness (Speight *et al.*, 1999). In other words, a plant with high tolerance maintains high levels of growth or reproduction for a given level of defoliation than a plant with low tolerance. Therefore, recovery from damage (e.g. seedling survival) and the amount of compensatory growth in the form of productive tillers, additional branches, etc. after insect attack are commonly used as measures of tolerance (Dent, 1991; Sileshi, 1994; 1995b).

The objectives of this study were (1) to determine the mechanisms of resistance of *Sesbania* to *M. ochroptera* and (2) to select accessions of *Sesbania* that possess a reasonable level of resistance and desirable agronomic characteristics such as fast growth and biomass production.

5.2 MATERIALS AND METHODS

5.2.1 Growth and survival

The study was conducted at the Msekera Research Station in Eastern Province of Zambia. Detailed description of the study site is given in Chapter 2. A total of 32 accessions of *Sesbania* were obtained from the International Livestock Research Institute (ILRI), the International Centre for Research in Agroforestry (ICRAF) and local collections (Table 5.1). The accessions were planted in the nursery at Msekera on December 1, 1998. The seeds of each accession were pre-treated by soaking overnight in hot water about five times the volume of seed (Kwesiga and Beniest, 1998). Planting was done in a raised-bed nursery with miombo soil as a source of local rhizobium inoculum. Height of seedlings was measured at two, four and five weeks after planting. The number of leaves per seedling was counted at transplanting in the field.

The accession ILCA 17373 had very poor germination in the nursery. The remaining 31 accessions were transplanted in field plots on January 8, 1999. The soils of the field consisted of ferric luvisols (FAO classification) characterised by low organic matter content and macro-nutrients (Matungulu, 1994; Table 5.2). The individual accessions formed the plot unit. The plot size was 3 m x 6 m and net plot was 1 m x 4 m. The planting pattern was three rows of sesbania at 1 m within and between rows making a total of 18 plants per plot. The treatments were arranged in a randomised complete block design with three replicates. To ensure a uniform stand, gaps if any were filled in two weeks after transplanting (Kwesiga and Beniest, 1998). The field was also kept weed-free by weeding when necessary.

To select accessions that possessed the desirable characteristics, data were collected on plant height, branch number, basal (collar) diameter, and leaf and stem weight. Growth in height is considered a principal indicator of the performance of crops and trees. However, the correlation between tree height and biomass is often poor for multi-stemmed trees such as sesbania (Stewart and Salazar, 1992). Stem height was defined as the total length of the tallest stem in multi-stemmed plants (Stewart and Salazar, 1992). Therefore, height was measured from the ground to the highest growing point of the tallest stem. Height was measured at one, two, five and 15 months after transplanting (MAP).

Stem diameter at 15 cm aboveground is known to provide a reliable estimation of biomass in *Sesbania* provenances (Oduol, 1994). Therefore, basal diameter (BD), defined as the average of three diameter measurements made at a point between 10-15 cm above the ground (Stewart and Salazar, 1992) was taken at 5 and 15 MAP. The number of primary branches and percentage survival of plants was assessed at 5 and 15 MAP. All surviving plants were cut down and separated into leaf and stem portions and fresh weights were taken at 15 MAP. Oven dry weight was not used due to limitations in facilities.

5.2.2 Tests for resistance

In order to determine the nature of resistance of *Sesbania* accessions to *M. ochroptera*, both field and laboratory experiments were conducted. For the test of antixenosis, two free-choice experiments were set up. The first one was a field experiment set up in December-January 1999. The second one was a nursery experiment set up in January 2000. Antibiosis was studied using a single-choice experiment in the laboratory.

5.2.2.1 Field experiment

The 31 accessions planted in the field were used for this study. Since *M. ochroptera* numbers were low at the beginning of the assessments, artificial infestation with laboratory reared beetles was needed to ensure uniform infestation. Three mating pairs of *M. ochroptera* (aged 4 days) were introduced into each plot at two MAP. Preference of each accession by adults for feeding and oviposition was judged by counting adults and egg masses per plot four days after infestation. A second count of adults was taken three months after planting, but egg masses were not counted since the plants were too tall at this time.

The percentage of plants infested with adults and larvae was assessed ten weeks after planting (2.5 MAP). A visual scale (1-5) developed for evaluation of the Colorado beetle damage (Janson and Smilowitz, 1985) was slightly modified to score leaf damage. Scoring was done as follows: 1= no feeding symptom; 2 = up to 25% of the leaflets consumed, but no terminal shoots damage; 3 = up to 50% of the leaflets consumed, but no terminal shoot damage; 4 = up to 75% of the leaflets consumed, slight damage to terminal shoots; 5= more than 75% of the fully expanded leaves consumed, terminal buds chewed, and the stem debarked. The scoring was done 2.5 and 3 MAP on the three central plants in each plot. The dates of assessment were adjusted to coincide with the period when seedlings were most prone to damage and the field population of *M. ochroptera* was at its peak (see Chapter 3).

5.2.2.2 Nursery experiment

Eleven accessions were selected for this experiment based on their performance in the field experiment and other field trials (see Chapter 2.). *Sesbania macrantha* and ILCA 17393 (*Sesbania bispinosa*) were judged as highly susceptible, Tumbi and Lamuria as moderately susceptible, ZAM-03-97, Zalewa, Nkope and ILCA 1178 as moderately resistant and ILCA 17407 (*Sesbania rostrata*) as resistant. The popular *S. sesban* accessions Vihiga Kak6 and Chipata Dam (Kwesiga and Coe, 1994) were moderately susceptible. The common weed *Sesbania leptocarpa*, a highly susceptible species, was used as a local check.

Since *M. ochroptera* has limited mobility (see Chapter 3), uniform infestations cannot be easily achieved in field plots. The differences in soil fertility across blocks, differences in seedling establishment and survival in field plots were also suspected to introduce systematic errors and reduce the efficiency of the tests. In order to minimise such errors and to ensure uniform exposure of all accessions to the pest, the nursery experiment was established. A raised-bed nursery with miombo soil as a source of local rhizobium inoculum was used. A modified method used by Gibson (1971) for screening *Solanum* species against aphids was used. The plots (1 m row of each accession equidistant from each other) were arranged side by side in a circular block (radius = 1.3 m). Each row radiated from an inner circle with a radius of

0.3 m. Three such blocks were used as replicates. The seedlings were thinned to one plant per hill with 10 cm spacing between plants. Five weeks after planting, 13 pairs of healthy adults were introduced in the centre of the inner circle. Four days after infestation, the number of adults and egg masses was recorded for each accession. Height and number of leaves was recorded on ten seedlings for each accession per replicate (n = 30).

After counting egg masses and adults, the middle leaf was cut from each of four seedlings per accession for each of the three replicates (n = 12). The leaf hairs on the lower surface of leaflets (Steinmüller, 1995) were counted under a Leica GZ6 binocular microscope (40x). In addition, the hairs on the rachis between two successive leaflets were recorded because *M. ochroptera* lays eggs along the rachis rather than on the leaflets (see Chapter 3). It was assumed that the hairs on the rachis were the ones most likely to influence oviposition while the ones on the leaflets influenced adult feeding. Since some accessions had very low density of hairs, the latter were counted on the entire leaflet for all accessions. Leaflet size was assumed to be uniform within a species.

For the antibiosis tests, the 12 accessions evaluated for antixenosis were used. Several fitness parameters including development, survivorship, foliage consumption and weight gain were used to measure the success of *M. ochroptera* on each accession. The mean estimates of development and survival of larvae and pupae were obtained as follows. One egg mass was placed in a plastic Petri dish containing moist tissue paper (Wade, 1994). The emerging larvae were confined in a group of 15 in each Petri dish and supplied with fresh cut leaves of each accession. This was replicated six times. The leaves were changed every 24-h until the larvae developed into the pupal stage. Larvae were checked daily and moulting or mortality recorded. When larvae reached the prepupal stage, they were transferred into plastic Petri dishes containing moist soil for pupation. These were monitored and adult emergence recorded. Then the percentage survival of the larvae and pupae was computed.

For determination of leaf consumption and weight gain on each accession, cultures of larvae were raised on *Sesbania leptocarpa* as above. When the larvae reached the third instar, groups moulted within 24 h were weighed using a Mettler balance (precision ±0.001 g) and placed individually into plastic Petri dishes. The larvae were provided with a weighed amount of fresh foliage of one of the sesbania accessions. The same weight of foliage was also kept as a blank. The weight of larvae was taken for each subsequent 24-h period until the completion of each development stage or mortality observed. Unconsumed foliage was removed from each dish after 48 h and weighed. The blank was used to correct for reduction in foliage weight due to moisture loss. Leaf weight was used in preference to leaf area consumed because it is assumed to be a more accurate measure of total larval consumption, especially when comparing genotypes that have different leaf thickness (Beach *et al.*, 1985). The weight of consumed foliage was obtained as the difference of the weight of the blank and the weight of unconsumed foliage every 24-h. All surviving larvae were collected and placed in a Petri dish containing moist soil for pupation. A completely random design with four replicates (each replicate with 10 larvae) was used. Adult weight was recorded at emergence. The data collected for each larvae included initial weight (W_0), pre-pupal live weight (W_1) and total leaf weight consumed (L). Weight gain (G) was obtained as (W_1)-(W_0) and feeding efficiency (FE) (Wade, 1994) computed as (100G/L).

Percentage seedling survival after heavy beetle infestation was used as the main criterion for tolerance. Relating the initial level of infestation and defoliation with plant growth and biomass production also gave a measure of tolerance.

5.2.3 Statistical analyses

All insect and leaf-hair counts were transformed into $log_{10}\ (x+1)$ and subjected to ANOVA. Insect damage-scores were subjected to non-parametric Kruscal-Wallis one-way analysis of variance (NANOVA) using the SAS Statistical package. Percentile data were transformed using the inverse sine (arcsine $\sqrt{\%}$) function. When ANOVA showed significant F values, least significant differences (LSDs) were calculated using transformed data and means separated using Student-Newman-Keuls test. Since calculated LSD values are only appropriate for the transformed data, they are not indicated in the Tables. Differences among means were expressed by letters derived from analyses of transformed percentile and count data. Simple correlation analyses were conducted between beetle infestation (density, defoliation, etc.) and plant characteristics to establish relationships between *M. ochroptera* damage and plant growth.

5.3 RESULTS

5.3.1 Growth and survival

Seedling characteristics showed that nine accessions were wrongly identified as *Sesbania sesban* while actually they were *S. bispinosa* or *S. rostrata*. Accessions ILCA 17372, ILCA 17373, ILCA 17377, ILCA 17379, ILCA 17388, ILCA 17391, ILCA 17393 were found to be *Sesbania bispinosa* whereas ILCA 17407 was *Sesbania rostrata* and ILCA 17398 was *Sesbania brevipeduncula* (Table 5.3).

There were variations in growth rate and number of leaves within and between species in the nursery (Table 5.3). Except ILCA 17398, all accessions of *S. macrantha*, *S. bispinosa* and *S. rostrata* grew faster than *S. sesban* accessions and attained 0.5m at transplanting in 6 weeks. In addition to severe damage by *M. ochroptera*, ILCA 17398 was frequently browsed by rabbits and completely lost within the first two months after planting. Variations were also noted within the *S. sesban* accessions with respect to stem colour and hairiness in the nursery. Two varieties of *S. sesban* (*zambeziaca* and *nubica*) were provisionally identified based on Kwesiga and Beniest (1998). Accessions of the variety *zambeziaca* had green stems and smaller leaves with fewer hairs where as the *nubica* accessions had reddish and rough stems and bigger leaves densely covered with hairs.

In the field, *Sesbania* species significantly differed in growth rate and maturity (Table 5.4, 5.5, 5.6). *S. macrantha*, *S. bispinosa* and *S. rostrata* accessions generally grew faster than *S. sesban*. There was no significant difference in height growth between *S. sesban* accessions at 2 and 5 MAP (Table 5.4). At 15 MAP, only Kakamega significantly (P<0.05) differed from Chipata Dam in height among the *S. sesban* accessions. Kakamega also had a significantly higher basal diameter compared to four *S. sesban* accessions at 15 MAP. Little difference was observed between *S. sesban* accessions in the number of primary branches (Table 5.5). Except *S. sesban* and *S. macrantha*, all the other *Sesbania* species matured and died by the end of five months (Table 5.6).

Significant differences (P<0.05) were also observed among *Sesbania* accessions in percentage survival (Table 5.6). At 2 15 MAP, a significantly higher survival was observed in Kakamega than in Naivasha 2 and ILCA 17367 (Table 5.6). The highest fresh aboveground biomass (69.5-kg/plot) was also recorded in Kakamega. There was no difference (P>0.05) between the other *Sesbania* species in survival at 2 MAP. None of the *S. bispinosa* accessions survived beyond 5 MAP due to the heavy defoliation by beetles

(Table 5.7) and ageing (Table 5.6). Therefore, no biomass data was collected for these accessions.

5.3.2. Mechanisms of resistance

5.3.2.1. Antixenosis

In the field experiment, significant differences ($P<0.05$) were observed between accessions of *S. sesban* in the density of adults and egg masses per plot four days after infestation (Table 5.7). The largest number of adults (11.7) and egg masses (35.3) per plot was recorded on Lamuria. On the other extreme, ILCA 17367 had the smallest number of adults (0.7) and egg masses (5.7) per plot. In Lamuria and Tumbi 026, the number of adults was more than the original number of six introduced per plot. In this case, it was assumed that the beetles have moved from other accessions such as ILCA 17367, ILCA 17365 and *S. rostrata* (ILCA 17407) to plots of Lamuria and Tumbi 026.

Three months after planting, Kakamega had the largest number of adults per plant (5.6) whereas ILCA 17355 had the smallest (0.9) among the *S. sesban* accessions (Table 5.7). However, adult numbers did not differ significantly ($P>0.05$) between the other accessions. There was also no significant difference ($P>0.05$) between accessions of *S. sesban* in percentage of infested seedlings and defoliation scores (Table 5.7). However, some accessions had up to 100% of infested seedlings, while accessions such as Nkope had smaller proportion (73%) of infested seedlings. Among the other

Sesbania species, ILCA 17372 had the biggest proportion (99%) of infested plants where as ILCA 17407 had the smallest (5%) (Table 5.7).

Significant differences ($P<0.05$) were also observed between accessions in foliar damage by *M. ochroptera*. The Kruscal-Wallis χ^2 approximations were 44.2 ($P=0.035$, $DF=29$) and 60.0 ($P=0.0006$, $DF=29$) for damage scores at 2.5 and 3 MAP, respectively. Irrespective of the beetle density, most accessions of *S. sesban* suffered less than 50% defoliation (score <3) compared to *S. bispinosa* and *S. macrantha* accessions that suffered over 50% (score >3) defoliation. Most *S. bispinosa* accessions were completely defoliated and killed by 3 MAP (Table 5.7). Similarly, at 14 MAP, *S. macrantha* was heavily defoliated while only trace damage (score < 2) was recorded on all *S. sesban* accessions (data not shown).

Simple correlation analysis was used to examine the relationship between plant characteristics and beetle densities (number of adults and egg masses). Correlation analysis showed no linear association between seedling survival and *M. ochroptera* density. However, a significant ($P<0.05$) linear relationship was observed between height growth at different times and infestation by *M. ochroptera* (Table 5.9). The number of adults at three MAP was significantly positively correlated with seedling height at two MAP ($r=0.64$, $P=0.001$, $n=22$). Similarly, the proportion of infested seedlings was significantly correlated with seedling height ($r=0.52$, $P=0.02$, $n=22$) and number of leaves ($r=0.48$, $P=0.02$, $n=22$) at transplanting.

Data from the nursery experiment also showed significant differences among the 12 accessions in growth rate and number of nodes. Accessions of *S. bispinosa*, *S. macrantha*, *S. leptocarpa* and *S. rostrata* grew faster than *S. sesban* confirming results of the field experiment. *S. sesban* and *S. rostrata* accessions had significantly ($P<0.05$) more number of hairs on the rachis and leaflets compared to *S. macrantha*, *S. leptocarpa* and *S. bispinosa* accessions (Table 5.8). However, there were no significant differences ($P>0.05$) between *S. sesban* accessions in leaf-hairs.

The highest density of adults and egg masses was recorded in *S. macrantha* followed by *S. leptocarpa* and *S. bispinosa* while the lowest was in *S. sesban* (Lamuria, ZAM-03-97 and Nkope) and *S. rostrata* accessions. The density of *M. ochroptera* per meter row was significantly ($P<0.05$) positively correlated with number of leaves per seedling. On the other hand, the number of adults and egg masses was negatively correlated with hairiness of the leaf (Table 5.10).

5.3.2.2 Antibiosis

Significant differences ($P<0.001$) were observed between *Sesbania* accessions in cumulative foliage consumption by larvae (Table 5.11). Larvae reared on *S. leptocarpa* consumed significantly more foliage (mg fresh weight) than those reared on *S. bispinosa* (ILCA 17393), *S. macrantha*, *S. sesban* and *S. rostrata* (ILCA 17407). Within the *S. sesban* accessions, the lowest total foliage consumption was recorded on larvae reared on ILCA 1178, but this was not significantly different (P>0.05) from those reared on Zalewa, Vihiga Kak 6, ZAM-03-97 and Chipata Dam. The highest larval weight gain was observed on *S. leptocarpa*. Larvae reared on Chipata Dam and ILCA 1178 dramatically lost weight (Table 5.11). The highest and lowest feeding efficiency was found for larvae feeding on ZAM-03-97 and ILCA 1178, respectively. A significantly positive correlation was found between total foliage consumption (all accessions combined) and larval weight gain (r= 0.64, P= 0.02, n= 12) as well as adult weight at emergence (r= 0.61, P= 0.03, n= 12).

Differences (P<0.001) were also observed between accessions in the developmental period of *M. ochroptera*. Larval and pupal development was faster on *S. leptocarpa*, *S. bispinosa* and *S. macrantha* compared to *S. sesban* accessions. Development from the larval stage to the adult was twice as long in *S. sesban* accessions such as Zalewa and Nkope compared to *S. leptocarpa*, *S. bispinosa* and *S. macrantha* accessions (Table 5.11). Among the *S. sesban* accessions, significant differences were observed only in pupal development. Though larval and larva-adult development took longer in Zalewa and Nkope, the difference between *S. sesban* accessions was not statistically significant.

Larval survivorship was significantly higher (P<0.01) on *S. leptocarpa*, *S. bispinosa* and *S. macrantha* accessions compared to *S. sesban* and *S. rostrata* accessions (Table 5.11). Over 95% of the larvae reared on *S. rostrata* died before the first moult and a mere 3% developed to the pupal stage. Among

S. sesban accessions the highest pupal mortality (66%) was noted in ILCA 1178 while the lowest was in ZAM-03-97.

There were significant differences (P<0.001) in the weight of larvae at pupation and adults developing from larvae reared on different accessions (Table 5.11). Larval weight at pupation was highest when reared on *S. leptocarpa* and lowest on ILCA 1178. Adult weight at emergence was highest for larvae reared on *S. leptocarpa* and *S. bispinosa* compared to those developing from *S. macrantha* and *S. sesban* accessions. However, there was no statistical difference between adults developing on *S. sesban* accessions. A significant correlation was found between adult weight at emergence and larval weight at pupation (r= 0.95, P= 0.000, n= 9).

5.3.2.3. Tolerance and desirable agronomic traits

Accessions that showed better seedling survival, growth and biomass after sustaining higher levels of defoliation were regarded as tolerant to damage. Most *S. sesban* and *S. macrantha* accessions showed better growth and biomass production compared to *S. bispinosa* and *S. rostrata*. Kakamega and Kisii 2 were found to be highly tolerant to defoliation among the *S. sesban* accessions tested in the field. These accessions had the highest defoliation score and adult density at 2.5 and 3 MAP (Table 5.7). At the same time they showed good growth in terms of height, diameter and biomass yield (Table 5.4, 5.5 and 5.6). Correlation analysis showed lack of linear association between the degree of defoliation by *M. ochroptera* and percentage survival of *S. sesban* (all accessions combined) (Table 5.9). A positive correlation was found between defoliation during the seedling stage and most plant characteristics of *S. sesban* accessions. In some cases this correlation was significant ($P<0.05$). The other *Sesbania* species did not appear to tolerate defoliation.

5.4 DISCUSSION

Accessions of *S. sesban* showed better growth and productivity compared to those of *S. bispinosa* and *S. rostrata*. *Sesbania bispinosa* and *S. rostrata* proved to be annual plants of very low productivity. Height growth in *S. sesban* accessions ranged from 1.8 to 3.5 m in 15 months. The growth in height and basal diameter for *S. sesban* accessions is within the range reported by other workers (Karachi *et al.*, 1994; Kwesiga, Personal communication). *S. macrantha* showed comparable growth with *S. sesban*, but it was heavily defoliated by *M. ochroptera*. Similarly, *S. macrantha* accessions were found to be more susceptible to the beetle damage compared to *S. sesban* in western Kenya (Onim *et al.*, 1990). Under the conditions that prevailed during the study period at Msekera, the accessions Kakamega, Kisii 2, Zalewa, Nkope, Zwai 036 and Zwai 090 showed outstanding seedling survival, growth and biomass production.

The difference in *M. ochroptera* densities between species and accessions within species confirmed our earlier field observations (see Chapter

2). Among the species tested, *S. rostrata* had the lowest beetle density and foliar damage. Similarly, in a preliminary study conducted earlier (Kwesiga F., Personal communication), *S. rostrata* had the lowest foliar damage out of 64 accessions of annual *Sesbania* species. The results of the field and nursery experiments were largely confirmatory with regard to preference of accessions for feeding and oviposition. *M. ochroptera* showed clear preference for *S. bispinosa* and *S. macrantha* accessions to *S. sesban*. There is also evidence that accessions of *S. macrantha*, *S. leptocarpa*, *S. tetraptera* and *S. bispinosa* are more preferred to *S. rostrata* and most accessions of *S. sesban* (see Chapter 2). Within *S. sesban*, some accessions such as ILCA 17367, ILCA 17365 and ILCA 1178 were relatively less preferred for adult feeding and oviposition compared to the popular accession Vihiga Kak 6. However non-preference was found to be insufficient to prevent field damage even in the least preferred *S. sesban* accessions such as ILCA 17367. This is probably because of the large number of eggs laid in one batch (see Chapter 3) and the indiscriminate feeding by the hatching larvae. *M. ochroptera* larvae are generally able to feed on any quality of leaves in a stand of *S. sesban* (see Chapter 2).

The preference of a particular accession for feeding and oviposition by adult *M. ochroptera* appeared to be influenced by the hairiness of the leaves, the number of leaves per seedling and the height of the seedling. Generally, hairy accessions were less preferred for adult feeding and oviposition. This agrees with previous studies on *M. ochroptera* (Steinmüller, 1995) and several other species of phytophagous insects attacking legumes such as soybean and cow pea (Turnipseed, 1977; Lambert *et al.*, 1995). The bigger correlation coefficients observed between the number of egg masses and hairs on the rachis probably indicate that hairs on the rachis are more likely to influence oviposition compared to those on leaflets.

Fast growing accessions with large number of leaves were more preferred to slow growing ones. This is consistent with the "plant vigour" hypothesis (Price, 1991; Price *et al.*, 1995) which contends that insect herbivores prefer, and perform well on vigorous plants. If females show strong preference for smaller plant, then resources will be limited (Price, 1992) to support the large number of larvae produced.

Antibiosis was reflected in reduced intake of foliage, weight loss, increase in developmental period and larval mortality. The reduction in intake of foliage appears to be mainly due to low palatability (Steinmüller, 1995). In addition, physical deterrence imposed by leaf-hairs may also reduce intake as can be seen from the negative correlation between leaf consumption and leaf hairs (Table 5.10).

Increase in developmental period in insects feeding on resistant genotypes has been used as a measure of antibiosis (Lambert and Kilen, 1984; Beach *et al.*, 1985). Larval and pupal periods were shorter in the susceptible species *S. macrantha*, *S. leptocarpa* and *S. bispinosa* compared to *S. sesban* accessions. This conforms to the findings by Sekhon and Sajjan (1987) who reported shorter larval and pupal periods in *Chilo partellus* reared on susceptible than resistant maize. The slow larval growth and the increased feed requirement per unit weight gain on some *S. sesban* accessions such as Lamuria, Tumbi and Nkope probably suggests that antibiosis is due to reduced digestibility. The weak correlation between total foliage consumption and larval weight gain also confirms this speculation. Similarly, Steinmüller (1995) found significant reduction in larval growth due to low digestibility of leaves of high-tannin *S. sesban* and *Sesbania goetzii* accessions.

The delay in development of larvae and pupa on some accessions such as Nkope and Zalewa has the potential of reducing the number of generations produced during the rainy season. Predation and parasitism are known to be greater on host plants where the insect's developmental period is longer (Price *et al.*, 1980) as this increases the chances of exposure of smaller and weaker individuals to natural enemies (Singh, 1986). This has been experimentally demonstrated in the chrysomelid beetle *Galerucella lineola* (Haggstrom and Larsson, 1995). The reduction in larval and adult weight at emergence may have subtle ecological consequences on *M. ochroptera* populations. Production of smaller individuals may lead to poor accumulation of food reserves and consequently this would adversely affect fecundity and the survival of the over-wintering adults. On the other hand, the smaller size of prey on resistant varieties can have a knock-on effect with the emergence of smaller parasitoids having reduced fecundity or survivorship (van Emden, 1991).

The low larval survivorship on *S. rostrata* (ILCA 17407) and some accessions of *S. sesban* such as Nkope, ILCA 1178 and Zalewa may also be due to toxicity. Toxicity of *S. sesban* leaves has been documented by Williams (1983). Toxic chemicals such as tannins, canavanines and saponins and other polyphenols common in *S. sesban* (Evans and Rotar, 1987; Mafongoya *et al.*, 1998) could have caused the mortality of larvae. Tannins are known to act more like toxins than digestibility-reducers (Zuker, 1983). The level of larval and pupal mortality on resistant accessions such as ILCA 1178 may sufficiently prohibit the development of large beetle populations during the rainy season. This may also have an adverse effect on the overall population of *M. ochroptera*. The cumulative mortality over the five to six generations produced in the rainy season is most likely to be very high and this could drastically reduce the number of beetles reaching the over-wintering generation.

Some *S. sesban* accessions completely recovered after defoliation showing their tolerance to damage by *M. ochroptera*. Similarly Wale *et al.* (1996) observed full regeneration of completely defoliated *S. sesban* plants. Apparently the observed beetle densities and the degree of defoliation did not significantly influence survival of *S. sesban* accessions. This can be seen from the lack of a significant correlation between the degree of defoliation and percentage survival. The significant positive correlation between percentage defoliation and growth in height, diameter and above ground biomass probably indicates compensatory growth in damaged *S. sesban* accessions. I have also established that defoliation of seedlings during the first two to three months after transplanting promotes compensatory growth in the provenance Vihiga Kak6 (see Chapter 6). When *S. bispinosa*, *S. leptocarpa*, and *S. macrantha* accessions were damaged, chances of recovery were very slim because the larvae consumed the growing point as well as the stem of these species.

As *M. ochroptera* infestation did not lead to reduction in survival, growth and yield of *S. sesban* accessions, very high beetle resistance may not be required. Resistant accessions containing very high levels of allelochemicals such as tannins may not necessarily be ideal because allelochemicals involved in plant resistance can also be toxic to parasitoids and predators (Herzog and Funderburk, 1985) or they may reduce their fitness. A second advantage of partial resistance is that the selection pressure on a pest, which could lead to an adapted biotype in frequency, will be reduced compared with a high level of plant resistance (van Emden, 1991; van Emden, 1999). There is a dynamic, evolutionary arms race between insect herbivores and their hosts and the development of novel plant defences are always followed by adaptations of herbivores to resist these defences (Ehrlich and Raven, 1964; Thompson, 1989). The production of defence is also costly to plants (Speight *et al.*, 1999). Plants with higher levels of resistance grow slowly or are less productive because they heavily invest in materials used for defence (Coley, 1986; Simms and Rausher, 1989; Sager and Coley, 1995). Partial resistance has also a benefit over a high level of resistance of greater compatibility with yield aspirations (van Emden, 1991; van Emden, 1999).

The role of maintaining genetic diversity in forestalling pest and disease problems in fallows has been recognised (Sanchez, 1999). Genetically uniform fallow germplasm has the potential to increase insect and disease problems. Genetic diversity can be achieved by planting a mixture of accessions of sesbania with desirable characteristics such as resistance and higher yield wherever the benefits from fallows are not expected to be negatively affected by the mixture.

Table 5.1. Origin of the *Sesbania* accessions screened for resistance

Accession	Source	Country of origin	Locality of collection			
			District	Lat.	Long.	Alt. (m)
Kakamega	ICRAF	Kenya	Kakamega	No Data	No Data	No Data
Kisii 2	ICRAF	Kenya	Kisii2	34°5'E	0°4'S	1860
Naivasha 2	ICRAF	Kenya	No Data	No Data	No Data	No Data
Vihiga Kak 6	ICRAF	Kenya	Kakamega	34°5'E	0°1'N	1580
Lamuria	ICRAF	Kenya	No Data	No Data	No Data	No Data
Zwai 022	ILRI	Ethiopia	Zwai	38°5'E	8°0'N	1650
Zwai 090	ILRI	Ethiopia	Zwai	38°5'E	8°0'N	1650
Zwai 036	ILRI	Ethiopia	Zwai	38°5'E	8°0'N	1650
Nkope	ICRAF	Malawi	Mangochi	35°0'E	14°1'S	440
Rumphi	ICRAF	Malawi	Rumphi	33°8'E	11°2'S	900
Zalewa	ICRAF	Malawi	Ncheu	34°5'E	15°3'S	400
Kadawere	ICRAF	Malawi	Mangochi	35°2'E	14°4'S	472
ILCA 17355	ILRI	Malawi	Mangochi	35°1'E	14°2'S	474
ILCA 17363	ILRI	Malawi	Dedza	34°1'E	14°2'S	1400
ILCA 17365	ILRI	Malawi	Salima	34°4'E	13°4'S	415
ILCA 17367	ILRI	Malawi	Chinteche	34°1'E	11°5'S	474
Tumbi 026	ICRAF	Tanzania	Tabora	30°4'E	50°0'S	No Data
ILCA 1178	ILRI	Tanzania	Kilosa	37°2'E	6°2'S	430
ILCA 1198	ILRI	Tanzania	Mbozi	No Data	No Data	1380
ZAM-04-97	ICRAF	Zambia	Mambwe	31°6'E	13°2'S	570
ZAM-03-97	ICRAF	Zambia	Chama	33°3'E	11°3'S	570
Chipata dam	ICRAF	Zambia	Chipata	32°4'E	13°3'S	1032
S. macrantha	ICRAF	Zambia	Chipata	32°3'E	13°4'S	1032
ILCA 17372	ILRI	Zimbabwe	Kariba	28°5'E	16°3'S	450
ILCA 17373	ILRI	Zimbabwe	Kariba	28°5'E	16°3'S	450
ILCA 17377	ILRI	Zimbabwe	Mt. Darwin	31°4'E	16°5'S	1050
ILCA 17379	ILRI	Zimbabwe	U.M.P.	32°2'E	16°5'S	750
ILCA 17388	ILRI	Zimbabwe	Chiredzi	31°5'E	20°6'S	450
ILCA 17391	ILRI	Zimbabwe	Mwenezi	31°3'E	21°6'S	450
ILCA 17393	ILRI	Zimbabwe	Mwenezi	30°5'E	21°1'S	450
ILCA 17398	ILRI	Zimbabwe	Hwange	26°3'E	18°2'S	650
ILCA 17407	ILRI	Botswana	Ngami land	23°1'E	19°1'S	925

Table 5.2. Some chemical and physical properties of soils (0-20 cm) of the trial site at Msekera, Zambia

Chemical properties		Physical properties	
Variable	Quantity	Texture class	%
pH (KCl)	4.20	Sand	58
Organic carbon (%)	0.50	Silt	17
Total Nitrogen (%)	0.17	Clay	25
Phosphorus (Bray I, ppm)	2.02		
Exchangeable cations (cmol/l)			
Calcium (Ca)	0.50		
Magnesium (Mg)	0.63		
Potassium (K)	0.19		
Cathion exchange capacity (cmol/Kg)	1.32		

Table 5.3. Seedling characteristics of *Sesbania* accessions in the nursery at Msekera, Zambia, 1998/99

Accessions	Species and variety	Height (m)		Leaves/ seedling at 5 weeks
		4 weeks	5 weeks	
Tumbi 026	*S. sesban* var nubica	0.3	0.6	15.7
Kakamega	*S. sesban* var nubica	0.3	0.5	12.0
ZAM-04-97	*S. sesban* var nubica	0.3	0.4	9.3
Kisii 2	*S. sesban* var nubica	0.2	0.4	9.3*
Zwai 090	*S. sesban* var nubica	0.2	0.4	13.0
Chipata Dam	*S. sesban* var nubica	0.2	0.4	13.3
Naivasha 2	*S. sesban* var nubica	0.2	0.4	11.0*
Vihiga Kak 6	*S. sesban* var nubica	0.3	0.3	12.0*
Zwai 036	*S. sesban* var nubica	0.2	0.3	14.0
ILCA 17363	*S. sesban* var nubica	0.2	0.3	8.7
Zwai 022	*S. sesban* var nubica	0.2	0.4	12.3
Lamuria	*S. sesban* var nubica	0.2	0.4	12.3*
ILCA 1178	*S. sesban* var nubica	0.2	0.2	12.3
ILCA 1198	*S. sesban* var zambeziaca	0.2	0.4	16.3
ZAM-03-97	*S. sesban* var zambeziaca	0.2	0.4	13.7
Rumphi	*S. sesban* var zambeziaca	0.2	0.4	7.7
Kadawere	*S. sesban* var zambeziaca	0.2	0.3	8.0
Zalewa	*S. sesban* var zambeziaca	0.2	0.2	5.3
Nkope	*S. sesban* var zambeziaca	0.2	0.2	6.3
ILCA 17365	*S. sesban* var zambeziaca	0.1	0.2	6.3
ILCA 17355	*S. sesban* var zambeziaca	0.1	0.2	8.3
ILCA 17367	*S. sesban* var zambeziaca	0.1	0.2	6.0
ILCA 17377	*Sesbania bispinosa*	0.4	0.5	13.0
ILCA 17407	*Sesbania rostrata*	0.4	0.7	15.0
ILCA 17391	*Sesbania bispinosa*	0.4	0.6	17.0
ILCA 17379	*Sesbania bispinosa*	0.4	0.6	13.3
ILCA 17393	*Sesbania bispinosa*	0.4	0.6	17.0
ILCA 17372	*Sesbania bispinosa*	0.4	0.6	17.7
---^	*Sesbania macrantha*	0.3	0.7	17.0
ILCA 17388	*Sesbania bispinosa*	0.3	0.5	14.0
ILCA 17398	*Sesbania brevipeduncula*	0.2	0.3	5.3

*Damaged by a seedling disease in the nursery; ^No Accession number attached

Table 5.4. Height growth of *Sesbania* accessions in the field at Msekera, Zambia, 1999/2000

Accessions	Height (m)			Height Increment (m)		
	2 MAP	5 MAP	15 MAP	2 to 5 MAP	5 to 15 MAP	2 to 15 MAP
S. sesban						
Kakamega	0.9 abc	2.3 bc	3.5 ab	1.4 b	1.2 ab	2.6 ab
Tumbi 026	0.9 abc	2.1 bcd	2.8 abc	1.3 b	0.7 ab	1.9 abc
ILCA 1198	0.8 abc	2.1 bcd	2.7 abc	1.3 b	0.6 ab	1.9 abc
Zwai 022	0.8 abc	1.9 b-e	2.0 abc	1.1 b	0.1 ab	1.2 bc
Zwai 090	0.8 abc	2.2 bc	3.0 abc	1.4 ab	0.8 ab	2.1 abc
Kisii2	0.8 abc	2.0 b-e	3.1 abc	1.2 b	1.0 ab	2.2 abc
Chipata Dam	0.8 abc	1.7 b-e	1.7 c	0.9 b	0.0 b	0.9 c
ILCA 17363	0.7 bc	2.2 b-d	2.8 abc	1.5 b	0.6 ab	2.1 abc
Rumphi	0.7 bc	2.2 bc	3.0 abc	1.5 b	0.8 ab	2.3 abc
Zwai 036	0.7 bc	2.1 bcd	3.0 abc	1.5 b	0.9 ab	2.4 abc
ZAM-03-97	0.7 bc	1.9 b-e	1.8 bc	1.2 b	0.0 b	1.2 bc
Vihiga Kak6	0.7 bc	1.8 b-e	2.0 abc	1.1 b	0.2 ab	1.3 abc
ZAM-04-97	0.7 bc	1.6 b-e	2.4 abc	0.9 b	0.8 ab	1.7 abc
Nkope	0.6 bc	2.3 bc	2.9 abc	1.7 b	0.6 ab	2.4 abc
Zalewa	0.6 bc	2.0 b-e	3.1 abc	1.4 b	1.1 ab	2.6 ab
Naivasha2	0.6 bc	2.0 b-e	2.7 abc	1.3 b	0.7 ab	2.1 abc
ILCA 17365	0.6 bc	1.8 b-e	2.6 abc	1.2 b	0.8 ab	2.0 abc
Kadawere	0.6 bc	1.7 b-e	2.3 abc	1.1 b	0.6 ab	1.7 abc
Lamuria	0.6 bc	1.6 b-e	2.6 abc	1.0 b	1.0 ab	2.0 abc
ILCA 1178	0.5 bc	1.7 b-e	2.3 abc	1.2 b	0.6 ab	1.8 abc
ILCA 17355	0.4 c	1.7 b-e	3.0 abc	1.2 b	1.4 a	2.6 ab
ILCA 17367	0.4 c	1.4 b-e	2.5 ab	1.0 b	1.1 ab	2.1 abc
Sesbania spp.						
S. macrantha	0.8 abc	3.1 a	3.7 a	2.4 a	0.5 ab	2.8 a
*Sb (ILCA 17393)	1.2 a	1.5 b-e	ND	0.3 c	ND	ND
Sb (ILCA 17388)	1.0 ab	1.4 b-e	ND	0.4 c	ND	ND
Sb (ILCA 17391)	0.9 abc	1.2 cde	ND	0.3 c	ND	ND
Sb (ILCA 17377)	0.9 abc	1.3 cde	ND	0.4 c	ND	ND
Sr (ILCA 17407)	0.9 abc	1.0 de	ND	0.1 c	ND	ND
Sb (ILCA 17372)	0.8 abc	0.9 e	ND	0.1 c	ND	ND
Sb (ILCA 17379)	0.7 abc	1.0 e	ND	0.3 c	ND	ND

*Sb = *Sesbania bispinosa*; Sr = *S. rostrata;* ND = no data available

Means followed by the same letters within a column are not significantly different from each other according to the Student-Newman-Keuls test

Table 5.5. Basal diameter and branching pattern of *Sesbania* accessions at Msekera, Zambia, 1999/2000

Provenance	Basal Diameter (cm)			Number of Primary Branches		
	5 MAP	15 MAP	Increment	5 MAP	15 MAP	Increment
S. sesban						
Kakamega	2.4 a	4.1 a	1.8 abc	36.8 a	40.8 a	4.0 a
ILCA 1198	2.3 ab	3.4 ab	1.1a-f	37.4 a	32.3 a	0.0 a
Nkope	2.3 ab	3.8 ab	1.6 a-e	34.9 ab	35.5 a	0.7 a
Kisii2	2.1 abc	3.9 ab	1.8 ab	31.7 ab	34.7 a	3.0 a
Zwai 036	2.1 abc	3.4 ab	1.3 a-f	33.4 ab	41.9 a	8.5 a
Zwai 090	2.1 abc	3.3 ab	1.2 a-f	34.1 ab	37.2 a	3.1 a
ILCA 17363	2.1 abc	3.2 ab	1.2 a-f	31.5 ab	32.3 a	0.8 a
Tumbi 026	2.0 a-d	3.3 ab	1.3 a-f	34.6 ab	34.7 a	0.1 a
Rumphi	2.0 a-d	3.3 ab	1.3 a-f	29.2 a-c	36.5 a	7.3 a
Naivasha2	1.9 a-e	3.5 ab	1.6 a-d	34.1 ab	35.8 a	1.7 a
ILCA 17365	1.9 a-e	2.8 ab	0.9 c-f	29.5 a-c	24.3 a	0.0 a
Vihiga Kak6	1.9 a-e	2.6 ab	0.7 ef	27.1 a-d	28.9 a	1.8 a
Zalewa	1.7 a-e	3.6 ab	1.9 a	26.8 a-d	27.8 a	1.0 a
ZAM-04-97	1.7 a-e	3.0 ab	1.3 a-f	23.8 a-e	24.0 a	0.2 a
ZAM-03-97	1.7 a-e	2.5 b	0.8 def	21.6 a-e	22.0 a	0.4 a
Zwai 022	1.7 a-e	2.3 b	0.6 f	29.1 a-c	30.1 a	1.0 a
Lamuria	1.6 a-e	3.1 ab	1.5 a-e	25.0 a-e	32.8 a	7.7 a
ILCA 1178	1.6 a-e	2.8 ab	1.2 a-f	25.2 a-e	28.9 a	3.7 a
Chipata Dam	1.6 a-e	2.3 b	0.7 ef	23.3 a-e	26.2 a	2.9 a
ILCA 17355	1.5 a-e	2.6 ab	1.1 b-f	25.3 a-e	30.5 a	5.2 a
Kadawere	1.4 a-e	3.0 ab	1.6 a-d	25.3 a-e	25.1 a	0.0 a
ILCA 17367	1.4 a-e	2.3 b	1.0 b-f	24.7 a-e	26.5 a	1.8 a
Sesbania spp.						
S. macrantha	2.3 ab	3.7 ab	1.4 a-f	18.2 a-e	24.0 a	5.8 a
*Sb (ILCA 17393)	1.1 b-e	ND	ND	15.8 b-e	ND	ND
Sb (ILCA 17391)	0.8 c-e	ND	ND	9.9 c-e	ND	ND
Sb (ILCA 17388)	0.8 c-e	ND	ND	8.6 de	ND	ND
Sr (ILCA 17407)	0.8 c-e	ND	ND	7.9 de	ND	ND
Sb (ILCA 17377)	0.7 de	ND	ND	10.5 c-e	ND	ND
Sb (ILCA 17379)	0.7 de	ND	ND	8.7 de	ND	ND
Sb (ILCA 17372)	0.6 e	ND	ND	5.9e	ND	ND

*Sb = *Sesbania bispinosa*; Sr = *S. rostrata*

ND = no data available

Figures followed by the same letters in a column are not significantly different from each other according to the Student-Newman-Keuls test

Table 5.6. Survival, fresh above-ground biomass and days to flowering of *Sesbania* accessions at Msekera, Zambia, 1999/2000

Provenance	%survival**		Biomass (kg/plot)[§]			Days to 50%[†] Flowering
	2 MAP	15 MAP	Leaf	Stem	Total	
S. sesban						
Kakamega	99.0 a	65.7 a	29.0 a	40.1 a	69.5 a	210
ZAM-03-97	97.2 ab	41.4 ab	8.0 ab	13.6 a	21.4 a	210
Lamuria	97.1 ab	52.1 ab	13.2 ab	18.3 a	31.6 a	180
ILCA 1198	97.1 ab	56.9 ab	15.4 ab	23.9 a	42.9 a	210
Zwai 022	96.6 ab	52.0 ab	7.7 ab	10.0 a	17.8 a	210
Rumphi	96.0 ab	59.5 ab	14.6 ab	22.6 a	37.6 a	210
Zwai 090	96.0 ab	54.3 ab	20.2 ab	37.0 a	57.3 a	210
Tumbi 026	94.5 ab	52.3 ab	18.4 ab	26.5 a	45.1 a	210
ILCA 17355	94.5 ab	60.7 ab	0.8 b	5.6 a	6.8 a	180
ILCA 17365	93.7 ab	55.6 ab	3.4 ab	6.1 a	9.6 a	180
Nkope	93.2 ab	44.7 ab	17.2 ab	35.3 a	52.5 a	180
Zwai 036	93.2 ab	56.0 ab	17.9 ab	27.7 a	45.8 a	180
Chipata Dam	89.7 abc	42.1 ab	15.9 ab	25.6 a	41.0 a	210
ZAM-04-97	87.8 abc	45.3 ab	16.9 ab	22.3 a	39.2 a	210
Zalewa	86.3 abc	47.4 ab	16.8 ab	27.3 a	44.1 a	180
ILCA 17367	83.3 abc	52.7 ab	2.8 b	2.9 a	5.8 a	180
ILCA 1178	83.3 abc	41.7 ab	12.0 ab	17.1 a	29.0 a	210
Vihiga Kak6	80.4 abc	42.7 ab	9.3 ab	12.0 a	21.1 a	180
Kadawere	75.0 abc	44.0 ab	16.5 ab	27.4 a	43.8 a	180
Kisii2	65.0 abc	36.0 ab	22.2 ab	35.3 a	60.5 a	210
Naivasha2	50.2 bc	41.4 ab	15.9 ab	24.3 a	40.0 a	210
ILCA 17363	38.8 c	36.5 ab	16.3 ab	22.7 a	38.6 a	180
Sesbania spp.						
S. macrantha	92.8 ab	33.5 b	11.1 ab	43.6 a	54.3 a	90
*Sr (ILCA 17407)	99.9 a	ND	ND	ND	ND	40
Sb (ILCA 17393)	99.0 a	ND	ND	ND	ND	40
Sb (ILCA 17377)	95.8 ab	ND	ND	ND	ND	40
Sb (ILCA 17379)	91.7 ab	ND	ND	ND	ND	40
Sb (ILCA 17372)	89.9 abc	ND	ND	ND	ND	40
Sb (ILCA 17391)	86.0 abc	ND	ND	ND	ND	40
Sb ILCA 17388)	75.0 abc	ND	ND	ND	ND	40

*Sb = *Sesbania bispinosa*; Sr = *S. rostrata*

** % Survival values are given in the original back scale

[§] Analysis was done using % survival as a co-variate

[†] Estimated from the day planted in nursery,

Treatment means followed by the same letters in a column are not significantly different from each other according to the Student-Newman-Keuls test

ND= no data available

Table 5.7. Incidence of *Mesoplatys ochroptera* in *Sesbania* accessions in the field at Msekera, Zambia, 1999/2000

Accession	Adult per plant		Egg masses 2 MAP	% Plants Infested** 2.5 MAP	Defoliation score	
	2 MAP	3 MAP			2.5 MAP	3 MAP
S. sesban						
Lamuria	11.7 a	3.9 a-d	35.3 a	99.9 a	2.8 a	2.6 bcd
Tumbi 026	9.3 ab	3.3 a-d	30.0 ab	98.9 a	2.8 a	2.5 b-e
Zwai 022	6.7 ab	4.7 abc	15.7 abc	82.6 a	2.2 ab	2.3 b-e
Zwai 090	6.7 ab	5.3 ab	20.3 abc	89.8 a	2.2 ab	2.2 b-e
Kakamega	5.7 ab	5.6 a	18.0 abc	89.1 a	2.9 a	3.3 a-d
Naivasha 2	5.0 ab	3.0 a-d	16.3 abc	97.6 a	2.8 a	3.2 a-d
Nkope	5.0 ab	2.4 a-d	20.3 abc	73.3 a	2.6 ab	2.3 b-e
Chipata dam	5.0 ab	1.6 a-d	9.7 bc	77.5 a	2.1 ab	2.4 b-e
Kadawere	4.7 ab	2.8 a-d	13.7 abc	81.2 a	2.5 ab	1.9 c-e
Zalewa	4.3 ab	2.3 a-d	17.3 abc	92.8 a	2.8 a	2.0 c-e
ZAM-04-97	4.3 ab	1.4 a-d	13.7 abc	82.8 a	2.3 ab	2.7 bcd
Rumphi	4.0 ab	5.0 ab	16.7 abc	99.9 a	2.9 a	2.4 b-e
ZAM-03-97	3.3 ab	2.8 a-d	10.0 bc	99.9 a	2.6 ab	1.8 de
Kisii2	3.3 ab	3.1 a-d	11.0 bc	98.6 a	3.0 a	2.9 bcd
ILCA 1198	3.0 ab	2.6 a-d	14.0 abc	97.1 a	2.4 ab	2.5 b-e
Zwai 036	3.0 ab	3.3 a-d	12.0 abc	97.5 a	2.3 ab	2.3 b-e
ILCA 17355	2.3 ab	0.9 a-d	10.0 bc	76.8 a	2.4 ab	2.4 b-e
Vihiga Kak6	2.3 ab	3.8 abc	11.7 abc	99.9 a	2.7 a	2.5 b-e
ILCA 1178	2.0 ab	1.6 a-d	12.3 abc	88.0 a	2.4 ab	2.2 b-e
ILCA 17363	1.7 ab	3.1 a-d	11.3 abc	96.2 a	2.8 a	2.9 b-d
ILCA 17365	1.0 ab	2.7 a-d	8.3 bc	76.8 a	2.1 ab	2.2 b-e
ILCA 17367	0.7 b	1.4 a-d	5.7 bc	76.2 a	2.6 ab	1.9 cde
Sesbania spp.						
*Sb (ILCA 17393)	6.7 ab	1.6 a-d	19.7 abc	98.2 a	3.3 a	3.6 abc
S. macrantha	16.7 ab	2.9 a-d	18.6 abc	92.8 a	3.1 a	3.1 bcd
Sb (ILCA 17377)	6.3 ab	2.6 a-d	16.0 abc	94.6 a	2.9 a	3.3 a-d
Sb (ILCA 17379)	6.0 ab	0.4 bcd	12.3 abc	94.5 a	3.5 a	3.8 ab
Sb (ILCA 17372)	4.7 ab	0.3 a-d	14.7 abc	98.9 a	3.5 a	4.5 a
Sb (ILCA 17391)	5.7 ab	1.3 a-d	17.7 abc	98.1 a	3.0 a	3.3 a-d
Sb (ILCA 17388)	3.0 ab	1.0 a-d	20.3 abc	92.6 a	3.3 a	3.2 a-d
Sr (ILCA 17407)	0.0 b	0.1 d	0.3 c	4.8 b	1.0 b	1.0 e

*Sb = *Sesbania bispinosa*; Sr = *S. rostrata*

** % Infestation values are given in the original (untransformed scale)

Treatment means followed by the same letters in a column are not significantly different from each other according to the Student-Newman-Keuls test

Table 5.8. The density of adults and egg masses of *M. ochroptera*, leaf hairs, seedling height and number of nodes in selected accessions of *Sesbania* at five weeks after planting in the nursery at Msekera, Zambia; February 2000

Provenance	*M. ochroptera*/m		Leaf hairs on		Height	No. of leaves
	Adult	Egg mass	Rachis	Leaflet	(m)	per seedling
S. macrantha	10.7 a	12.3 a	4.1 c	4.4 b	0.3 a	15.3 a
S. leptocarpa	7.3 ab	9.7 a	4.8 c	34.8 a	0.3 a	14.7 a
ILCA 17393	6.7 ab	7.3 ab	1.6 d	4.0 b	0.2 b	11.0 b
Chipata dam	4.0 ab	1.7 bc	29.9 ab	72.6 a	0.2 b	9.1 b
Zalewa	1.7 ab	2.0 bc	25.5 b	28.6 a	0.2 b	9.5 b
Vihiga Kak6	1.0 ab	1.7 bc	38.0 ab	103.7 a	0.2 b	10.5 b
Tumbi 026	0.3 b	2.7 bc	34.5 ab	36.5 a	0.2 b	10.3 b
ILCA 1178	0.3 b	0.3 c	33.4 ab	30.6 a	0.2 b	9.4 b
Lamuria	0.0 b	2.3 bc	41.1 ab	70.9 a	0.2 b	10.3 b
ZAM-03-97	0.0 b	2.3 bc	34.4 ab	53.6 a	0.2 b	7.9 b
Nkope	0.0 b	2.0 bc	25.6 b	35.0 a	0.2 b	8.5 b
ILCA 17407	0.0 b	1.7 bc	61.5 a	70.9 a	0.3 a	10.7 b

ILCA 17393 = *S. bispinosa*, ILCA 17407 = *S. rostrata*

Figures followed by the same letters in a column are not significantly different from each other according to the Student-Newman-Keuls test

Table 5.9. Pearson's correlation coefficients between *M. ochroptera* infestation and plant variables of 22 accessions of *S. sesban* at Msekera, eastern Zambia

Variable	Adult density[✝]		Egg density	Defoliation	
	2 MAP	3 MAP	2 MAP	2.5 MAP	3 MAP
No. leaves (5 wks)	0.43*	NA	0.31	NA	NA
Height (5 wks)	0.66***	NA	0.52*	NA	NA
Height (2 MAP)	0.54**	0.64***	0.40*	NA	NA
Height (5 MAP)	0.18ns	0.61**	0.30	0.35	0.33
Height (15 MAP)	0.06ns	0.29	0.27	0.42*	0.43*
Height increase (2-15 MAP)	-0.06ns	0.10	0.18	0.49*	0.26
Basal diameter (5 MAP)	0.04ns	0.54**	0.18	0.24	0.41
Basal diameter (15 MAP)	0.21ns	0.38	0.38	0.56**	0.56**
Basal diameter increase	0.26ns	0.12	0.39	0.58***	0.48*
Branch No. (5 MAP)	0.15ns	0.49	0.28	0.22	0.48*
Branch No. (15 MAP)	0.30ns	0.59**	0.41	0.35	0.45*
Branch number increase	0.28ns	0.26	0.25	0.32	0.13
Survival (2 MAP)	0.26ns	NA	0.22	NA	NA
Survival (15 MAP)	0.16ns	0.38	0.20	-0.12	0.39
Leaf weight	0.39ns	0.47*	0.39	0.37	0.66***
Stem weight	0.37ns	0.41	0.37	0.30	0.56**
Total Weight	0.37ns	0.43*	0.37	0.34	0.61**

[✝] Data analysed after transformation to $\log(x+1)$; NA= Not applicable;

*, **, ***: Significant at $p<0.05$, 0.01 and 0.001, respectively; ns: non significant ($p>0.05$), Degrees of freedom = 21

Table 5.10. Pearson's correlation coefficients for adult and egg mass densities, larval leaf consumption, and leaf-hair density and seedling height in 12 accessions of *Sesbania* in a nursery experiment at Msekera, eastern Zambia

Variable	Adult Density[✞]	Egg mass density[✞]	Leaf consumption by larvae
Hairs on rachis[✞]	-0.84***	-0.84***	-0.52ns
Hairs on leaflets[✞]	-0.65*	-0.67*	-0.35ns
Leaves/seedling	0.73**	0.81**	NA
Seedling height	0.43ns	0.64*	NA

[✞], Data analysed after transformation to *log (x+1)*; NA= Not Applicable

*, **, ***: Significant at $p<0.05$, 0.01 and 0.001, respectively; ns: non significant ($p>0.05$); Degrees of freedom = 10

Table 5.11. Fitness of *M. ochroptera* on 12 accessions of *Sesbania* at Msekera, eastern Zambia

Accession	Total Foliage Consumed (mg)	Larval weight (mg)		Feeding Efficiency (%) (FE =100G/L)	Percent survival*		Duration of development (Days)			Adult Weight at Emergence (in mg)
		Gain ($G=W_1-W_0$)	Pre-pupal weight (W_1)$^{\#}$		Larval	Pupal	Larval	Pupal	Larva to adult	
S. leptocarpa	0.48 a	0.12 a	0.25 a	25.8 ab	99.2 a	75.6 ab	8.3 b	6.1 c	14.4 b	0.20 a
Nkope	0.37 b	0.03 b	0.16 c	7.5 ab	21.8 cd	45.9 ab	21.0 a	10.9 ab	31.9 a	0.12 c
Lamuria	0.32 b	0.00 cd	0.14 cd	0.0 ab	43.9 cd	50.0 ab	16.8 a	9.0b	25.7 a	0.11 c
ILCA 17393	0.30 bc	0.10 a	0.24 a	31.8 ab	96.7 a	77.8 a	8.4 b	6.5 c	15.0 b	0.21 a
S. macrantha	0.30 bc	0.05 b	0.20 b	15.8 ab	90.6 ab	64.5 ab	9.6 b	7.1 c	16.6 b	0.16 b
Tumbi 026	0.26 bc	0.01 bcd	0.15 cd	4.3 ab	48.0 c	44.5 ab	17.7 a	9.7 ab	26.5 a	0.11 c
ILCA 17407	0.19 c	0.003 bcd	0.15 cd	-0.75 ab	3.3 d	----‡	----‡	----‡	----‡	0.12 c
Zalewa	0.09 d	0.05 bc	0.17 c	134.0 ab	30.8 cd	52.3 ab	20.9 a	11.3 a	32.2 a	0.12 c
Vihiga Kak6	0.07 d	0.008 bcd	0.16 c	10.3 ab	52.1 bc	64.1 ab	16.8 a	9.2 ab	26.1 a	0.14 bc
ZAM-03-97	0.04 d	0.04 bc	0.16 c	258.3 a	61.0 abc	65.6 ab	15.2 a	8.9 b	24.9 a	0.11 c
Chipata dam	0.03 d	-0.02 d	0.12 de	-141.8 b	54.6 bc	51.6 ab	16.0 a	9.5 ab	25.6 a	0.11 c
ILCA 1178	0.01 d	-0.05 e	0.10 e	-437.5 c	34.3 cd	33.2 b	16.3 a	9.5 ab	25.8 a	0.11 c

ILCA 17393 = *S. bispinosa*, ILCA 17407 = *S. rostrata*

$^{\#}$ Analysis was done using the initial larval weight (W_0) as a co-variate; *Percent Survival values are given in the back-transformed scale

‡ Missing values; Figures followed by the same letters in a column are not significantly different from each other according to the Student-Newman-Keuls test

CHAPTER 6

6.0 EFFECT OF *M. ochroptera* DAMAGE ON *S. sesban*

6.1 INTRODUCTION

Defoliation of sesbania by *M. ochroptera* has been reported to prevent seedling establishment and causes heavy loss of biomass in established plants (Pfeiffer, 1990; Wale *et al.*, 1996). At the moment, quantitative information is scanty on the effect of different densities of *M. ochroptera* on the performance of *S. sesban* and the losses due to different levels of defoliation.

All definitions of integrated pest management (IPM) include some reference to economic damage (Alfaro, 1991) and assessment of damage is a critical step in IPM. In any damage assessment procedure, a number of components are required in order to establish the intensity of insect attack and to evaluate the extent of loss incurred (Alfaro, 1991). The main purpose of yield damage assessment experiments is to determine the extent to which pest intensity influences plant yield. Pest intensity can be described as the product of the number of pests (density), their developmental stage and duration of attack. It is the combination of these factors that influence crop yield and studies based solely on the number of insects present are unlikely to describe the true situation (Dent, 1991).

The type of pest damage is also important as it influences both the probability and the extent of yield loss of the crop (Hill, 1983). Chewing insects such as *M. ochroptera* reduce the photosynthetic area available to the plant. However, plants can tolerate certain amounts of defoliation without any effect on yield and it has been shown in a number of cases that plants can compensate for damaged tissue by enhanced growth (Poston *et al.*, 1983; Trumble *et al.*, 1993). In forestry and agroforestry, the time between tree establishment and harvest is often many years. Therefore, what may seem to be a loss now may prove to be innocuous at harvest time (Wickman, 1980).

The potential damage of insects on plant yield can be measured through artificial removal of plant parts (Kulman, 1971; Simmons and Yeargan, 1990). Despite its known drawbacks, the use of artificial defoliation could readily advance studies of the influence of insect damage on plant yield, particularly when compensatory growth is suspected (Dent. 1991). Artificial defoliation is valuable because it permits randomisation and exact measurement of defoliation intensity (Kulman, 1971; Alfaro, 1991). A systematic study of the permutations of levels of defoliation with duration of defoliation and crop growth stage would also determine the conditions under which compensatory growth occurs and to what extent it influences yield (Waddill *et al.*, 1984).

The objectives of this study were (1) to estimate the degree of compensatory growth in sesbania after damage by *M. ochroptera*, and (2) to determine the time and degree of defoliation that leads to reduction in growth and biomass production by *S. sesban*.

6.2. MATERIALS AND METHODS

The study was conducted at Msekera Research Station in the Eastern Province of Zambia. The physical and chemical properties of the soils of the study site are given in Chapter 5 (Table 5.2).

6.2.1. Artificial infestation

The effect of artificial infestation was assessed using sesbania seedlings grown in pots. The popular sesbania provenance Kakamega (*S. sesban* var *nubica*, Batch No. 2987/001/89) was used. In March 1999, three months old potted seedlings were placed in muslin cages (30-cm breadth x 30-cm width x 50-cm height) and five densities of larvae and adults (0, 10, 20 and 30 and 40/plant) were arrived at by introducing the corresponding number of second instar larvae and adults separately. As each did not produce more than 25% defoliation, the number of larvae was increased to 60 (2 egg masses), 90 (3 egg masses), 120 (4 egg masses) and 150 (5 egg masses) per seedling in the second year (April-March 2000). The treatments were then arranged in completely randomised design with four replications. After one week of introduction, the degree of defoliation caused by the different densities was assessed based on a visual scale. The scale is a modified version of the one which was used in screening accessions (Chapter 5): 1 = little or no visible damage of leaflets; 2= up to 20% defoliation (consumption of leaflets); 3 = up to 30% defoliation; 4 = up to 40% defoliation; 5 = up to 50% defoliation; 6 = up to 60% defoliation; 7

= up to 70% defoliation; 8 = all lower leaves consumed or shed, some damage on the fully expanded terminal leaves; 9 = all lower leaves shed, most of the fully expanded terminal leaflets consumed; 10 = all leaflets consumed, terminal and lateral buds chewed, stem debarked. Assessment on more than three months old seedlings was not practical because of difficulty of keeping potted plants in cages. Instead, field assessments were made to relate percent damage to the number of larvae/plant in the field. One-month old seedlings were transplanted in field plots. Each plot consisted of 15 plants used as replicates. One of the five larval densities (30, 60, 90, 120 or 150 second instar larvae/plant) were used to infest each plot at two or three months after planting. The degree of defoliation was assessed as above.

6.2.2 Simulated damage

The *S. sesban* provenance Kakamega was used for the simulated damage assessment. This was planted in 5 m x 3m field plots with one meter between plants and between-rows. In the first year, one date of defoliation was used to simulate the amount of losses caused by *M. ochroptera*. Twelve weeks after transplanting (in mid-March), 0, 25, 50, 75 and 100% of the foliage was manually removed from the plant. To achieve the desired percentage defoliation, the leaflets of each leaf were clipped with a pair of scissors leaving the rachis. *S. sesban* leaves are composed of leaflets (folioles) arranged along the rachis in an opposite or sub-opposite fashion (paripinnately compound leaves). Thus, clipping half of the leaflets on one side of the rachis constituted 25% defoliation, clipping all the leaflets on one side of the rachis constituted 50%, and so on. The date of defoliation was adjusted to coincide with the peak population of *M. ochroptera*. The five defoliation rates were laid out in a randomised complete block design with three replicates. In the second year, the experiment consisted of a factorial combination of five defoliation rates (0, 25, 50, 75 and 100%) and three times of defoliation (four, eight and twelve weeks after transplanting). The treatments were laid out in randomised complete block design with three replicates. All plots were protected by a fortnightly application of Carbaryl (Sevin 85S) at 1.2kg/ha and Cypermethrin (Ripcord 5% EC) at 600 ml/ha.

At 11 months after planting (MAP), data were collected on height, branch number, basal (collar) diameter, and fresh leaf and stem weight. Data on plant mortality was not collected because a complex of secondary agents and pre- and post-defoliation weather conditions are known to complicate direct cause-effect relationships between defoliation and mortality (Kulman, 1971). Height was measured from the ground to the highest growing point of the tallest stem. Basal diameter was measured at a point 10 cm above the ground. To determine above ground biomass, the plants were cut down and separated into leaf and stem portions and fresh weights taken. Oven dry weight was not used due to limitations in facilities (oven and personnel). The data were then subjected to analysis of variance.

6.3 RESULTS

6.3.1 Artificial infestation

In the first year, artificial infestation of three month old seedlings with 5 to 30 larvae produced less than 20% defoliation (score 1-2). Infestation with up to 30 adults similarly produced less than 20% defoliation (Fig. 6.1), but the differences between the defoliation caused by the different densities were significant (Table 6.1). In the second year, significant differences ($P<0.05$) were recorded only between 30, 60 and 90-150 larvae per seedling (Table 6.1). Artificial infestation of two months old seedlings with 90-150 larvae (>3 masses of eggs) led to 80-100% defoliation. On the other hand, the same density of larvae only caused 50-80% defoliation in three months old seedlings. The defoliation did not significantly differ between 90, 120 and 150 larvae per plant (Table 6.1). Infesting seedlings with 40 or more adults was found to be irrelevant because this rarely happens in nature in *S. sesban* seedlings though common on annual species.

6.3.2 Simulated damage

In the first year trial, manual defoliation three months after transplanting did not significantly ($P>0.05$) influence branch number, basal diameter and stem fresh weight. Only height growth, leaf fresh-weight and total fresh weight showed differences ($P<0.05$) between the treatments. The plants were significantly taller in the 25% than in 50-100% defoliation and the control. The tallest (3.6 m) and shortest (2.7 m) plants were found in the 25% and 100% defoliation rates, respectively. Similarly leaf weight and total above ground fresh weight were significantly higher in the 25% than in 100% defoliation, but there was no difference between the control and 50-100% defoliation rates (Table 6.2). In the second year trial, significant differences ($P<0.05$) were observed between treatments in the number of primary branches, basal diameter, stem weight and total above-ground fresh weight. Treatments did not significantly differ in height at both 5 and 11 MAP. There were significantly more number of primary branches per plant in 25% than in 100% defoliation. However, the difference between the control and 100% was not significant. Similarly basal diameter measurements, stem weight and total weight were significantly higher in 25% than 100% defoliation. Except in basal diameter and stem weight, there was no difference between the control and 100% defoliation (Table 6.3).

The effect of time of defoliation on growth, branching and above ground biomass is presented in figures 6.2, 6.3 and 6.4, respectively. Manual removal of more than 25% of the foliage within one month after transplanting showed a reduction in most of the variables measured compared to those done two and three months after transplanting.

6.4 DISCUSSION

The interpretation of the relationship between insect density and defoliation is not always straightforward (Dent, 1991). Larval densities above 90/plant (or the equivalent of three egg masses) led to 80% defoliation in two and three month old *S. sesban* seedlings. Although the differences in defoliation due to different densities of larvae are obvious, the loss of photosynthetic leaf area may not necessarily result in a concomitant loss in plant yield or reduction in growth (Waddill *et al*., 1984). Therefore, these observations must be interpreted in the light of the results obtained from the experiment on manual defoliation.

The manual defoliation was assumed to produce essentially the same plant response as damage caused by the normal pest complex of *S. sesban*. This assumption was based on studies reported on other plants (Brook *et al*., 1992a, b). In my study, manually removal of up to 100% of the foliage during the rainy season did not significantly reduce growth and aboveground biomass. This is probably because *S. sesban* is tolerant to defoliation (also see Chapter 5).

Manual removal of 25-50% of the foliage appeared to stimulate production of more side branches and leaves compared to the undefoliated check. At this level of defoliation *S. sesban* probably overcompensates for defoliation. Though there was an increase in the amount of leaf biomass due to defoliation, the quality of biomass produced after defoliation may probably be different. *S. sesban* litter (leaves, branches and roots) decomposes in the soil and releases nutrients that can be used by other plants growing in the enriched soil (Kwesiga and Coe, 1994). Therefore, the effect of defoliation on the quality of biomass and yield of the subsequent maize crop needs to be further investigated. Early defoliation of seedlings may also adversely affect root development and nodulation. As stem height, basal diameter and weight did not differ between the 100% and undefoliated plants, the quality of products such as fuelwood, poles and stakes from *S. sesban* fallows may not be significantly affected by defoliation. In fact there was an improvement in these variables with 25-50% defoliation.

Plants respond to herbivory through a wide range of defence mechanisms and also exhibit a variable capacity of compensatory growth (Trumble *et al.*, 1993). Apparently 25-50 % defoliation leads to increase in growth and aboveground biomass production probably showing overcompensation in *S. sesban*. Overcompensation is defined as plant growth or yield becoming greater than the undamaged controls (Hjältén *et al.*, 1993). In other words, growth or reproduction of the plant is actually higher in the presence of herbivores than in their absence. Increases in plant fitness following defoliation has been experimentally demonstrated in several plant-herbivore systems (Paige and Whitham, 1987; Paige, 1992; Dyer *et al.*, 1993). This has led some workers to speculate that some levels of herbivory may be beneficial to plants, and may lead to increase in their fitness (Dyer and

Bokhari, 1976; Owen and Weigert, 1976; Paige and Whitham, 1987). Many factors, including plant species (Escarre *et al.*, 1996), resource availability (Alward and Joern, 1993), the type of defoliation (Hjältén *et al.*, 1993) and defoliation history (Turner *et al.*, 1993) all influence the degree of compensation. In this study, the effect of time and degree of defoliation on aboveground growth and development were examined. Therefore, the results should be interpreted in the light of these factors. The effect of defoliation on belowground development of *S. sesban* needs to be further investigated. In conclusions, despite these limitations, the study has shown that *S. sesban* can tolerate severe defoliation and produce substantial amount of biomass even after 100% of the foliage has been removed.

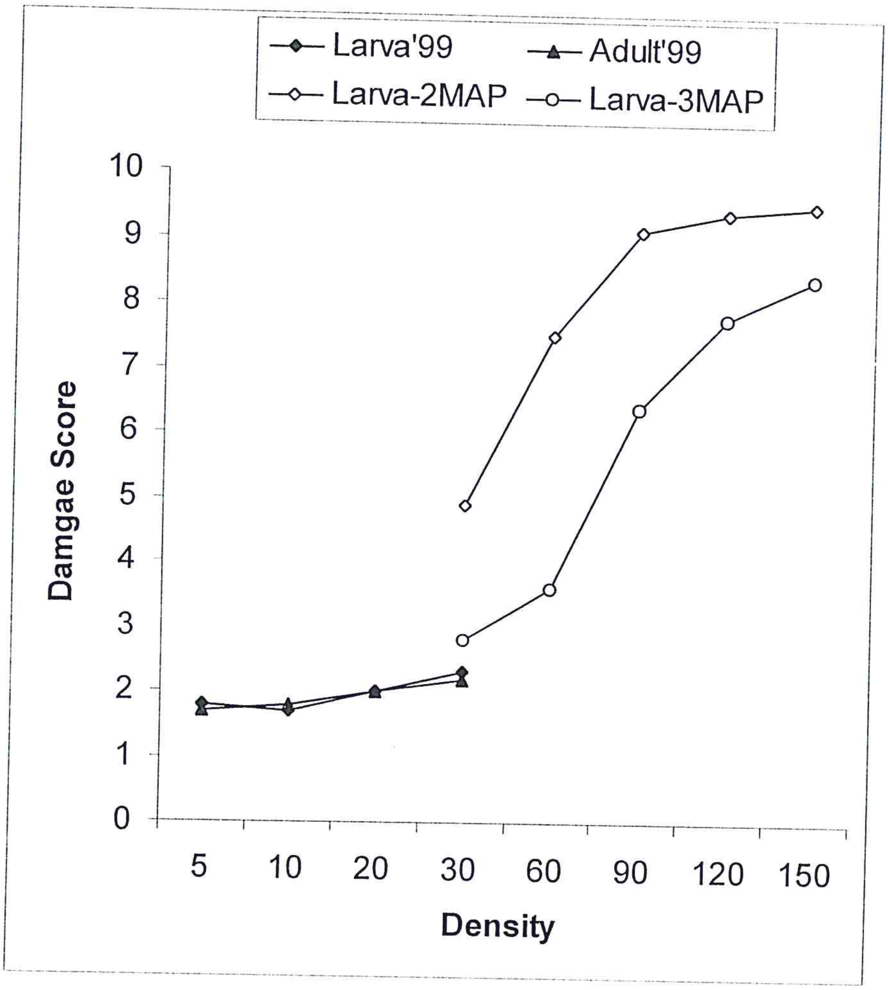
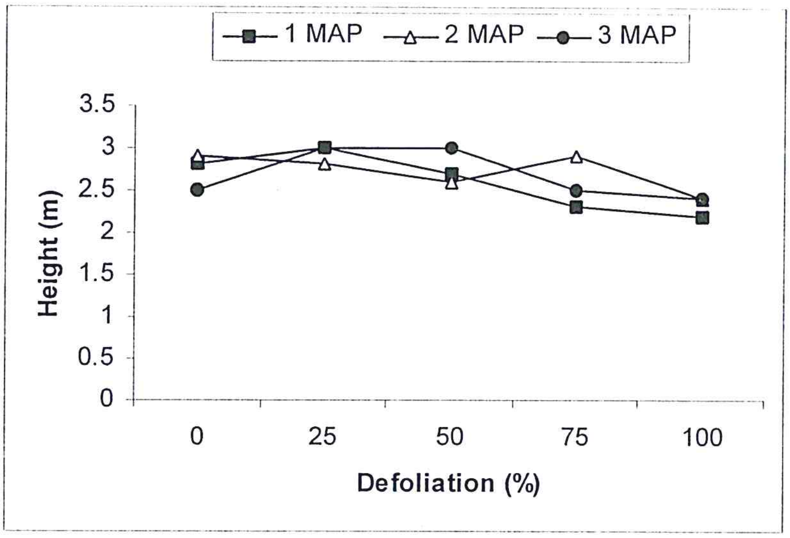


Fig. 6.1. Defoliation caused by different densities of *M. ochroptera* larvae and adults on two and three months (2 MAP, 3 MAP) old *S. sesban* (accession Kakamega) seedlings. Larval (larva'99) and adult (adult'99) densities were 5 to 30 per plant in 1999.



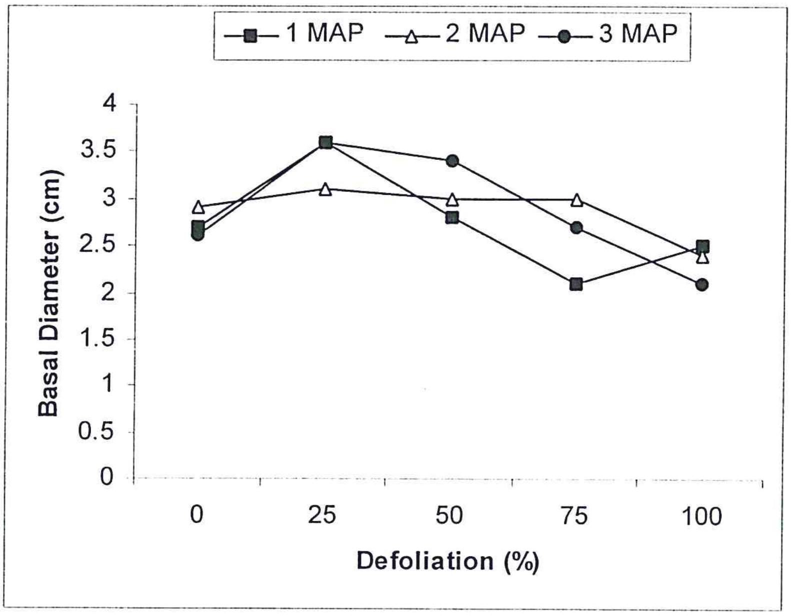


Fig. 6.2. The effect of time of manual defoliation on the growth in height and diameter (basal diameter) of *S. sesban* (accession Kakamega) at Msekera, eastern Zambia. Time of defoliation: one, two and three months after transplanting (1 MAP, 2 MAP and 3 MAP).

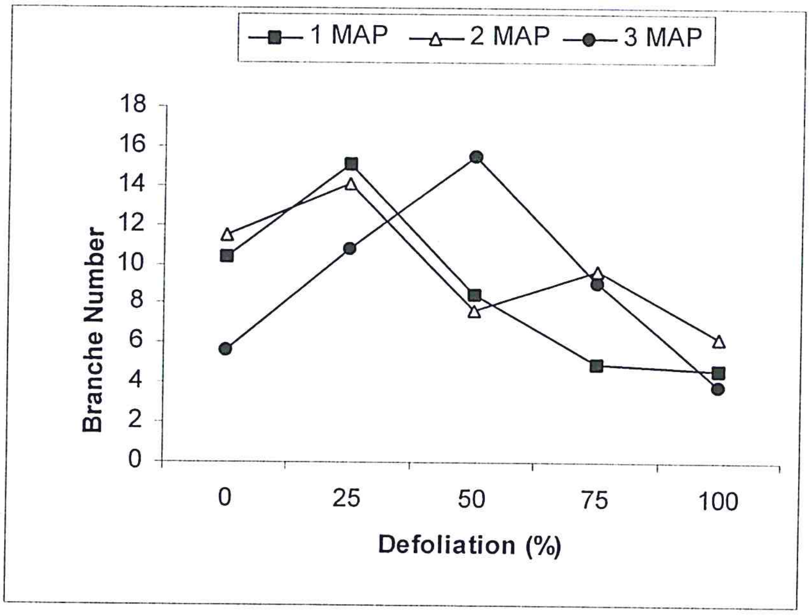


Fig. 6.3. The effect of time of manual defoliation on the production of primary branches by *S. sesban* (accession Kakamega) at Msekera, eastern Zambia. Time of defoliation: one, two and three months after transplanting (1 MAP, 2 MAP and 3 MAP).

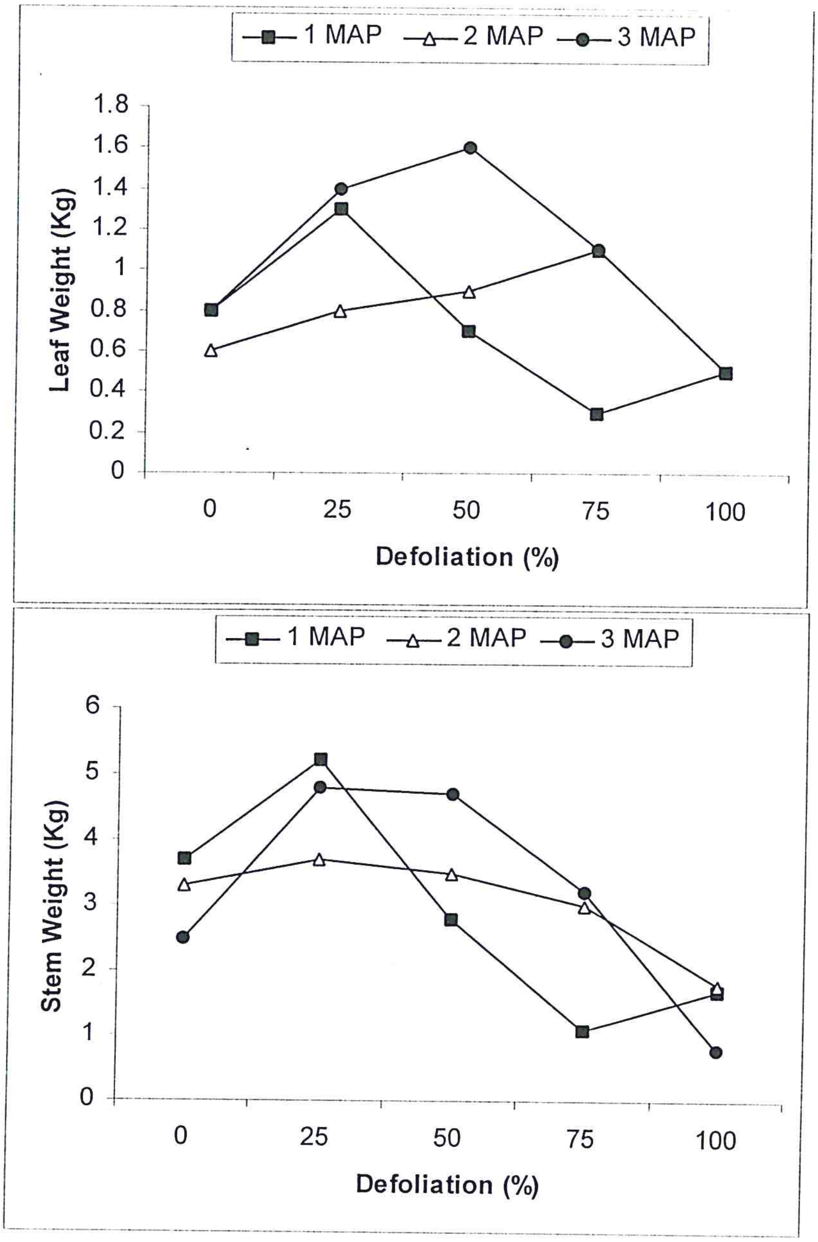


Fig. 6.4. The effect of time of manual defoliation on fresh leaf and stem weight of *S. sesban* (accession Kakamega) at Msekera, eastern Zambia. Time of defoliation: one, two and three months after transplanting (1 MAP, 2 MAP and 3 MAP).

Table 6.1. The effect of artificial infestation with different densities of larvae and adults on defoliation of *S. sesban* plants during 1999 and 2000

Larval and adult damage score during 1999			Larval damage score during 2000		
Larval or adult density	Larval damage	Adult damage	Larval density	Age of plant	
				2 months	3 months
5	1.8 a	1.7 b	30	4.9 c	2.8 c
10	1.7 a	1.8 a	60	7.5 b	3.6 c
20	2.0 a	2.0 ab	90	9.1 a	6.4 b
30	2.3 a	2.2 a	120	9.4 a	7.8 a
--	--	--	150	9.5 a	8.4 a

Means followed by the same letters within a column are not significantly different according to the Student-Newman-Keul's test.

Table 6.2. The effect of different levels of defoliation three months after transplanting on growth and biomass production by *S. sesban*- 1998/1999

Defoliation (%)	Height (m)	Primary branch no.	Basal diameter (cm)	Fresh weight/3 plants (kg)		
				Leaf	Stem	Total
0	3.1ab	22.2a	3.0a	0.4b	3.2a	3.5ab
25	3.6a	25.6a	3.3a	0.9a	4.4a	5.3a
50	2.9b	22.0a	3.1a	0.5ab	2.7a	3.3ab
75	3.0b	19.1a	3.0a	0.5ab	3.4a	4.0ab
100	2.7b	20.3a	2.9a	0.4b	2.6a	3.0b

Means followed by the same letters within a column are not significantly different according to the Student-Newman-Keul's test.

Table 6.3. The effect of different levels of manual defoliation one, two and three months after transplanting on growth and biomass production by *S. sesban*-1999/2000

Defoliation (%)	Height (m)		Primary branch no. 11 MAP	Basal diameter (cm)		Fresh weight/3 plants (kg)		
	5 MAP	11 MAP		5 MAP	11 MAP	Leaf	Stem	Total
0	2.7a	2.7a	9.2ab	2.4ab	2.7bc	0.7a	3.2a	3.9ab
25	2.7a	3.0a	13.4a	2.8a	3.4a	1.2a	4.5a	5.8a
50	2.8a	2.8a	10.5ab	2.6ab	3.1ab	1.0a	3.7a	4.7a
75	2.5a	2.6a	7.9ab	2.1bc	2.6bc	0.8a	2.6ab	3.4ab
100	2.2a	2.3a	4.9b	2.0c	2.3c	0.5a	1.4b	2.0b

Means followed by the same letters within a column are not significantly different according to the Student-Newman-Keul's test.

CHAPTER 7

7.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.2. GENERAL DISCUSSION AND CONCLUSIONS

The survey in farmers' fields and natural stands attempted to identify various arthropods associated with *S. sesban* and also elucidated their role. A broad overview of the common pests and some of their natural enemies is presented in Chapter 2. Over 55 species of herbivore insects including some major pests of legume crops were found to feed on *S. sesban*. The study has indicated the potential for a number of insects to assume pest status on *S. sesban* if the use of this species intensifies in agroforestry systems. The study has also established that *S. sesban* is an alternative host of important insect pests of legumes such as *A. fabae*, *A. curvipes*, *H. armigera*, *N. viridula*, *Ootheca* spp., *M. dicincta* and *M. sjostedti*. These species are widely distributed in southern Africa (Lee, 1971; Bohlen, 1973; Hill, 1983) where sesbania is being eagerly adopted in agroforestry land use systems. However, this should not be taken as a warning of possible disaster for the use of sesbania in agroforestry systems. The results suggest the strong need for caution over the consequences of growing taxonomically related species in terms of pest build up in agroforestry practices such as the sesbania-pigeon pea-maize relay intercropping system in Malawi.

The study has also conclusively shown that most of the seedling damage attributed to *M. ochroptera* is caused by at least three species of beetles—*M. ochroptera*, *Exosoma* sp. and *Ootheca* spp. The most critical time in establishing *S. sesban* fallows is probably the seedling stage, and seedlings may be completely lost in the nursery or immediately after transplanting in the field due to the combined effect of defoliation by beetles and grasshoppers.

Among the beetles, *M. ochroptera* clearly stood out as the most serious pest both in terms of frequency of occurrence, abundance and the damage caused to the foliage. *M. ochroptera* has been recorded from time to time in eastern and southern Africa (Hargreaves, 1924; Smee, 1935; Harris, 1937; Hill, 1966; Kwesiga, 1990; Onim *et al.*, 1990; Pfeiffer, 1990; Mchowa and Ngugi, 1994; Steinmüller, 1995; Wale *et al.*, 1996; Critchley *et al.*, 1999; Kwesiga *et al.*, 1999). It is certainly an endemic pest of *S. sesban*. The defoliation caused by *M. ochroptera* has been reported to reduce the economic value of sesbania foliage (Steinmüller, 1995; Wale *et al.*, 1996). Therefore, *M. ochroptera* was confirmed as a "major seedling pest" of *S. sesban* and its biology was studied (Chapter 3) in order to develop management practices appropriate for smallholder farmers.

An overview of the natural enemies of *M. ochroptera* is presented in Chapter 4. Several generalist predators attacked the beetle and most of them have potential in exerting some degree of control on other pests of sesbania and crop plants. Unfortunately, the beetle has only a few parasites and its populations suffered from very low parasitism, which is probably one of the contributing factors to the development of outbreaks in the fallows. In the present situation, it is practical but probably not economically feasible to mass-produce and release natural enemies in sesbania fallows. However, there are opportunities for manipulating the predator activity and augmenting the natural enemy populations.

M. ochroptera fed on many species of *Sesbania* in the study area and this has been reported elsewhere in Africa (Onim *et al*., 1990; Singh Rathore, 1995; Steinmüller, 1995). In Chapter 5, results of screening of 31 *Sesbania* accessions collected from eastern and southern Africa for resistance against *M. ochroptera* are presented. Three mechanisms of resistance—antixenosis, antibiosis and tolerance—were found in *Sesbania* accessions. The survival, growth and yields of most *S. sesban* accessions were not significantly influenced by defoliation, while annual species such as *S. bispinosa* died after the beetle damage. It is concluded that *S. sesban* accessions were more tolerant to damage compared to the other *Sesbania* species.

Some accessions of *S. sesban* and *S. rostrata* possessed high levels of antibiosis against *M. ochroptera*. Since plants with high levels of antibiosis tend to be unproductive and even could adversely affect activity of natural enemies (van Emden, 1991), very high levels of resistance should not be considered as the solution to the beetle problem. Instead, plant resistance should be viewed as an adjunct to other techniques such as use of cultural practices or natural enemies and all available techniques should be used in as compatible a manner as possible. In addition to variations in resistance to *M. ochroptera*, *S. sesban* accessions also showed variability in agronomic variables. Therefore, there is a need for further screening of *S. sesban* genotypes from a wider geographic range and selecting those that perform better.

The loss assessment study (Chapter 6) showed that *S. sesban* plants fully recovered to produce sufficient biomass even after 100% defoliation. However, even if the plants fully recovered, there may be a loss of biomass at a time when it is needed most (Wale *et al.*, 1996) and this may retard overall growth or alter the quality of biomass. Defoliation may also weaken the plants and increase the risk of termite attack during the drier years. These aspects need further investigation.

7.2 RECOMMENDATIONS

1. Since *S. sesban* is attacked by a wide range of insect, accurate identification of the target pest becomes a critical issue in IPM. Confusion over the identity of the beetles has already arisen in many places. As a result, damage to *S. sesban* by any beetle has been ascribed to *M. ochroptera*. Therefore, it is recommended that the identity of the pests be

clearly established before any control action is considered. To facilitate this, production of a simple field identification manual should be treated as a priority.

2. *Exosoma* sp. is one of the serious pests of *S. sesban* seedlings. Its biology and ecology are not known and these must be studied and management techniques developed urgently.
3. Continuous monitoring and assessment of the species of insects associated with *S. sesban* are fundamental if the benefits from agroforestry systems are to be fully realised. Proper emphasis should be placed on monitoring the following group of insects:

- Monitoring of the weevil *Diaecoderus* sp. should be taken up as a matter of extreme urgency. Its larva commonly called "Fat John" is also known to damage maize roots. The activity of the "Fat John" in the subsequent maize crop must also be monitored regularly.
- The build up of pests shared between *S. sesban* and associated crops such as bean, pigeon pea and cowpea should be monitored regularly.

4. Since *M. ochroptera* was considered to be one of the major problems affecting *S. sesban*, recommendations on control practices are urgently need for the success of agroforestry technologies in southern Africa. Based on the different studies on the biology and ecology of *M. ochroptera,* cultural practices that are likely to reduce the adverse effects of *M. ochroptera* in sesbania planted fallows are recommended:

- Phenological asynchrony between the beetle and the critical stage of seedling growth may be created by early sowing of sesbania in the nursery and transplanting seedlings as soon as the rains start. Wherever applicable, sowing in the nursery should start in October and 8-10 week old seedlings should be transplanted at the beginning of the rainy season.
- Prompt weeding to reduce both weed competition and the build-up of *M. ochroptera*. Other *Sesbania* species on which the beetle may breed in the absence should also be weeded out.
- As *M. ochroptera* pupates in the soil, cultivation has a potential in reducing the population of the beetles. Adult Coleoptera (e.g. *Ootheca* spp., *Diaecoderus* sp.) feed on aerial parts where as their larvae feed on the root system. Populations of these and many other soil-inhabiting insects would be depleted in numbers by normal cultivation methods.
- Clearing the surrounding vegetation 2 to 3 m away within one to three months after transplanting seedlings may potentially reduce survival of the larvae. This may also serve as a firebreak and reduce the chances of fire damage to the fallows during the dry season.
- Though *M. ochroptera* is essentially a seedling pest, the beetles emerging from winter habitats are able to breed successfully on older sesbania trees including fallows ready for clearing. Sesbania fallows are cleared after 2 to 3 years for subsequent cropping. Clear felling the fallow normally takes place

in November In order to avoid spread of beetles from such fallows into newly planted sesbania, the fallows may be cleared before the onset of the rains and emergence of over-wintered beetles.

- Since the beetles over-wintered in older sesbania fallows spread to newly planted seedlings, farmers should avoid establishing sesbania fallows every year in the same field.
- As bush fires are a recurrent threat to sesbania fallows, keeping a strip of land 5-10 m wide around fallow free of vegetation is mandatory. Controlled burning may be more advantageous as it can destroy the over-wintering beetles.
- Before they produced substantial numbers of the second generation, beetles may be collected and destroyed at the beginning of the rainy season. In particular, seedlings transplanted from nurseries to the field should be inspected and adults, egg masses and larvae destroyed.
- Planting resistant/tolerant accessions of *S. sesban* may also be considered wherever the beetle is a serious problem.
- Maintaining agro-diversity is important not only to reduce *M. ochroptera* problems but also other pest organisms. This may be achieved through mixed planting of different fallow species or mixtures of different accessions of the same species (Sanchez, 1999). The potential of mixed planting needs to be further explored.

- Use of natural control agents is an area that needs to be seriously considered. Three priority areas are recognised for this purpose: (A) manipulation of predator activity and augmentation of their populations, (B) inoculation of *Hexamermis* sp. and *P. larvicida* in farmers fields where they are not yet found and (C) exploration and introduction of parasitoids that can effectively fill the empty parasitoid niches such as the egg and pupa stages of *M ochroptera*. Efforts should be made to encourage the build up of natural enemies such as predators. For this purpose, further studies are needed to determine the seasonal and cultural practices that favour the increase of natural enemies.

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9. APPENDIX

Appendix.1. List of Acronyms and Abbreviations

1. AFRENA =Agroforestry Research Network for Africa
2. ANOVA = Analysis of variance
3. BD = Basal diameter
4. CABI = International Center for Agriculture and Biosciences (UK)
5. CIDA = Canadian International Development Agency
6. cm = centimeter
7. DAAD = Deutscher Akademischer Austauschdienst (German Academic Exchange Program)
8. FAO = Food and Agricultural Organization of the United Nations
9. FRIM = Forestry Research Institute of Malawi (Malawi)
10. GRZ = Government of Zambia
11. h = hour
12. ha = hectare
13. ICIPE = International Center of Insect Physiology and Ecology (Kenya)
14. ICRAF = International Center for Research in Agroforestry (Kenya)
15. ILCA = International Livestock Center for Africa (Addis Ababa, Ethiopia)
16. ILRI = International Livestock Research Institute (Nairobi, Kenya)
17. KU = Kenyatta University

18. LSD = Least significant difference
19. m = meter
20. m. a. s. l. = meters above seas level
21. mg = milligram
22. mm = millimeter
23. MAFF = Ministry of Agriculture, Food and Fisheries, Zambia
24. MAP = Months after planting
25. MMCRS = Mount Makulu Central Research Station (Lusaka, Zambia)
26. MPT = multi-purpose tree
27. NHBGM = National Herbarium and Botanical Garden of Malawi
28. NANOVA = Non-parametric analysis of variance
29. NDSU = North Dakota State University
30. NMH = National History Museum (London, UK)
31. NNM = Nationaal Natuurhistorisch Museum (Leiden, The Netherlands)
32. PPRI = The Plant Protection Research Institute, Republic of South Africa (RSA)
33. RSA = Republic of South Africa
34. SADC = Southern Africa Development Community
35. TM = Transvaal Museum, RSA
36. WVI = World Vision International

Appendix 2: Questionnaires for survey of farmers' perception of pests of *S. sesban*

District ________________, Village ___________, Farm ○________

Name of farmer ______________ Head of household: male ☐, female ☐

1. Do you practice sesbania improved fallowing? yes ☐, no ☐

2. If not why? ______________________________________

3. When did you adopt the sesbania improved fallow technology?

____

4. How did you learn about the sesbania improved fallow technology?

____

5. Would you continue to practice fallowing? yes ☐, no ☐

6. What other trees do you include in your fallow? _________________

7. Which tree species is the best for improved fallow? ______________

8. Why? ____

9. What crops do you grow on the rest of your field? _______________

10. What crops do you grow at the end of the fallow period? _________

11. Why do you plant the sesbania fallow? What are the benefits?

a) Erosion control ☐ b. insect control ☐

c. Improved soil fertility ☐ d. disease control ☐

e. Source of fuel ☐ f. source of fodder ☐

g. Weed control ☐ h. others, specify ________________

12. What are the constraints to grow sesbania in improved fallows?

a) Lack of seedlings ☐ b. shortage of moisture ☐

c. Insect damage ☐ d. disease problem ☐

e. Weed problem ☐ f. Others, specify ______________

13. Which insects damage your fallow tree? How worst are they?

Pest species	Rank according to importance			
	First	Second	Third	Fourth
1				
2				
3				
4				
5				
6				
7				
8				

14. When did beetles start to become a problem? ______________________

15. Which year did beetles become more serious? __________________

16. How often do they appear in your fallow? ____________________

18. What time of the year does damage commence? ______________

peak ______________, end ________________________________

19. What factors do you think contributes to critical infestations?

a. heavy rains ☐

b. dry spell followed by heavy rains ☐

c. dry spell ☐

d. heavy rain followed by dry spells ☐

e. light shower ☐

f. dry spell followed by light shower ☐

g. others, specify _________________________________

20. Where do you think does the insect go at the end of the outbreak period?

____

21. How do you recognise the beetle? ___________________________

22. How many beetles or what proportion of infestation do you think is critical? ________________________________

23. What age of the fallow is most vulnerable to damage?

1 year old ☐, 2 ☐, 3 ☐

24. What stage of the tree suffers the greatest damage?

seedling ☐, 1 year old ☐, 2 ☐, 3 ☐

25. What other plant(s) is the beetle associated with? _____________

25. Do other animals prey upon the beetle? ____________________

26. Do you use control practices? yes ☐, no ☐

27. If yes which one? a. Chemicals _____________________

b. Cultural practices ______________________________

c. Others specify? ______________________________

28. Is the control agent avail______________________

29. What is the expected cost of control? ____________

30. Can you afford the cost of the control agent? __________

31. Is labour available? _________________

32. If you don't control the insect will there be a disaster? ___________

33. How much loss do you expect? _______________________________

34. Did you ever receive any advice/training on control of the pest? _______

35. If yes, what is the source of your advice?

a. Other farmers ☐ b. extension agents ☐

c. Private companies ☐ d. mass media ☐

e. Others, specify _______________________________________