THE EFFECT OF INTERCROPPING BEANS ON *ELDANA SACCHARINA* WALKER (LEPIDOPTERA: PYRALIDAE) ARTHROPOD PREDATOR POPULATIONS IN SUGARCANE

by

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PREFACE

This work was completed at the South African Sugar Association Experiment Station Entomology Department. The author was registered with the Zoology Department at the University of Durban-Westville from February 1996 –December 1998. Professor Carolyn Baker and Dr Desmond Conlong supervised this work.

DECLARATION

This thesis represents original work by the author and has not been submitted for degree purposes to any other University. Where use was made of work of others, it has been duly acknowledged in the text.

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ABSTRACT

Commercial sugarcane in South Africa is a monoculture, and therefore lacks vegetation diversity, which is instrumental in increasing associated faunal diversity. Diverse habitats tend to support more stable populations of herbivorous and predacious animals. It is hypothesised that lack of this diversity in sugarcane was partially responsible for the existence of *Eldana saccharina* infestation levels that are higher than is commercially acceptable.

Amongst the available *E. saccharina* control strategies, is habitat management. This has been developed with the view of increasing and enhancing predator foraging activity. Through increasing arthropod predator abundance and activity, it is believed that *E. saccharina* control may be enhanced. In this study, habitat diversity was increased through intercropping beans within sugarcane. Arthropod populations were monitored throughout the sugarcane-growing period, to determine what effect this intercropping had on known potential arthropod predator populations of *E. saccharina.*

The study site was divided into two plots: the intercrop (beans planted within sugarcane rows: sugarcane-bean intercrop) and sole sugarcane: control plot. At monthly intervals, epigeal arthropods were sampled with pitfall traps, while foliage associated arthropods were sampled with a suction trap. Predator activity at the base of the sugarcane stalk, where *E. saccharina* lays its eggs was monitored with sticky traps. Sampling took place in the sugarcane-bean intercrop and control plots as well as in the roadway bordering the study site. Epigeal predator habitat preference was assessed by randomly placing pitfall traps in the sugarcane rows, bean rows, interrows between sugarcane rows, interrows between sugarcane and bean rows and the roadway. Corresponding with monthly trapping, an *E. saccharina* infestation and damage survey was conducted. Environmental factors such as weather, light intensity, plant (beans and sugarcane) phenology and weed density were measured, and their effect on *E. saccharina* potential arthropod predators examined. At harvest, sugarcane stalks were sampled for sucrose yield analysis.

Potential *E. saccharina* predators that were captured included species of the orders and/or families Acarina, Blattidae, Formicidae (*Pheidole megacephala* and *Dorylus helvolus)* and Araneida (Lycosidae, Oxyopidae, Thomisidae and Salticidae). *P. megacephala* and species of Acarina were the only predators caught with all three trapping techniques, thus indicating that they occurred both on the ground and foliage. *D. helvolus* and Acarina were the only predators caught in significantly higher numbers in the intercrop, suggesting that increased habitat management had positively affected their population sizes. *D. helvolus* were captured both on the ground and length of sugarcane stalk, while species of Acarina were captured on the ground, foliage and at the base of sugarcane stalk, indicating that they forage at the base of the stalk, where *E. saccharina* activity is concentrated. Specific ground habitats preferred by *D. helvolus* included the sugarcane rows and bean rows, while Acarina preferred the interrows between sugarcane and bean rows.

Despite the generally low *E. saccharina* infestation levels during this study, significantly higher levels of infestation occurred in the intercrop when compared to sole sugarcane. As expected with high infestation, higher (although not statistically significant) damage occurred in the intercrop. Surprisingly, sucrose yield and sugarcane stalk mass were slightly higher in the intercrop.

The implications of the observations made during this study are discussed in the context *E. saccharina* management.

CHAPTER 1

A REVIEW OF *ELDANA SACCHARINA* AND HABITAT MANAGEMENT

1.1 Introduction

The development of special strains of plants and their introduction to different parts of the world has altered the balances in animal species that once existed (Smith and Hagen, 1959). Commercial sugarcane in South Africa is one of these plants. Similar monocultures of other crops have reduced arthropod species diversity and abundance (Laster, 1974). Consequently, pest population stability brought about by natural enemies is lost. This factor could have contributed to the high populations of African sugarcane stalkborer, *Eldana saccharina* Walker (Lepidoptera: Pyralidae) found in South African sugarcane. *E. saccharina* was first recorded as a pest in South African sugarcane in 1939 (Dick, 1945). Following this outbreak, however, populations remained very low for thirty years. In 1970 it resumed pest status (Carnegie, 1974). Carnegie (1979) estimated crop loss due to *E. saccharina* to be 0.1% less sucrose for every 1% stalks damaged. Current monetary loss due to this pest is estimated at 60 million Rand per year (Black *et al.,* 1995).

Several aspects of *E. saccharina* biology make it difficult to control.

- The eggs are well concealed by ovipositing females. They are laid under dead leaf sheaths and in the area between the stem and soil (Carnegie, 1974).

- The damaging stage of the life cycle, the larva, is cryptic due to its boring habit. After a two-week period of either feeding on cane leaves or scavenging on oddments of organic matter behind the leaf sheaths, larvae disperse in search of shelter and penetration sites on the sugarcane stalk. These include buds, root primordia and cracks (Carnegie, 1974).

- The species has evolved effective defenses (e.g. encapsulation) against natural enemies (Keeping, 1995).

- The mature larva spins a protective cocoon and pupates within it. This may be located either in the boring or attached to the outside of the stalk, usually beneath the leaf sheath (Carnegie, 1974).

- The species has many overlapping life stages, making it difficult to target a particular life stage for control over a discrete period of time (Keeping, 1995).

Since the re-appearance of the pest in the early 1970's many research papers on its biology (Dick, 1945; Girling, 1972; Waladde, 1983) and control (Carnegie, 1979; Carnegie, 1982; Leslie, 1982; Conlong and Hastings, 1984) have been published. Research aimed at control included crop management (pre-trashing, harvest management and nitrogen application), use of resistant varieties, chemical control and biological control (Carnegie, 1981). Conlong (1994 a) reviews the whole biological control programme, which includes search for exotic parasitoids from other parts of the world, and indigenous parasitoids in Africa (Carnegie, 1981). In addition, arthropod predators of *E. saccharina* were identified by Leslie and Boreham (1981) using serological methods. Except for work done by Conlong (1995), no other work has been done on within-crop habitat management to enhance arthropod predator populations.

Since 1993, the biological control programme expanded to include predator manipulation studies (Conlong pers. comm.). This was based on the fact that in other crops, numerous authors have conclusively shown that increased diversity in specific crops led to increased predator foraging activity, which reduced pest populations. For example, Laster (1974) intercropped grain sorghum with cotton and successfully controlled bollworm, *Heliothis zea* (Fabricius; Lepidoptera: Noctuidae) with ladybird beetles, *Rodolia cardinalis* Mulsant (Coleoptera: Coccinellidae). Fuller and Reagan (1988) showed that sweet sorghum intercropped with sugarcane reduced sugarcane stalk borer, *Diatraea saccharalis* (L.) (Lepidoptera: Pyralidae) populations, predominantly by red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae). Abate (1991) used weed management to reduce African bollworm, *Heliothis armigera* (Hübner) (Lepidoptera: Noctuidae) partly by a predatory wasp, *Tiphia* sp. (Hymenoptera: Tiphiidae). Capinera *et al.,* (1985), strip intercropped pinto beans with sweet corn, which reduced the Mexican bean beetle, *Epilachna varivestris* (L.) (Coleoptera: Coccindellidae) while increased predators such as green lacewings, *Chrysopa carnea* Stephens (Neuroptera: Chrysopidae) and lady beetles, *Hippodamia convergens* Guerin (Coleoptera: Coccinellidae).

Other benefits that may be derived from intercropping include:
An improvement in total farm economy. For example, sugarcane (an annual crop) may be intercropped with a fast growing cash crop (e.g. dry beans). In this way a farmer can subsist and derive a financial resource from the cash crop before the annual crop is harvested. This is particularly relevant to small developing growers.
Partial complementary use of resources by the two intercropped species could be an additional benefit of intercropping. Beans, for example, have the potential to fix atmospheric nitrogen (Pilbeam *et al.,* 1994) while sugarcane relies on previously fixed nitrogen in the soil.

It is therefore clear that intercropping can be used in habitat management with some success in pest control and without adversely affecting the primary crop. In South African sugarcane there has been minimal success achieved in *E. saccharina* control using present strategies. In the light of successes achieved in the control of other pests in other crops elsewhere using habitat management, assessment of the impact of crop diversity on *E. saccharina* arthropod predators is desirable.

1.2 History

Eldana saccharina was first described in 1865 in Sierra Leone, West Africa (Girling, 1972; Conlong, 1994 b). Dick (1945) reported that a specimen of the insect had been recorded in Beira, Mozambique in 1903. In 1939 specimens were collected in Kenya, East Africa (Girling, 1972). The insect is therefore, indigenous to Africa (Carnegie, 1974) and co-evolved with the native grasses and wetland sedges (Shanower, *et al.*, 1993). It occurs through West to East Africa, and down the coast to Kwazulu-Natal in South Africa, where a specimen was collected in the Nyalazi River in 1928 (Dick, 1945).

1.3 *Eldana saccharina* in South Africa

Figure 1 illustrates the spread of *E. saccharina* in Southern Africa. In 1939 a severe infestation of *E. saccharina* in sugarcane was found on the Umfolozi flats (Atkinson *et al.*, 1981) (Figure 1). That outbreak did not spread to other regions of the sugar belt, and the insect disappeared fourteen years later (Atkinson *et al.*, 1981). It reappeared at Hluhluwe in 1970 (Carnegie *et al.*, 1976). This outbreak rapidly spread north and southwards. Three years later recordings were made as far north as Eastern Transvaal (now called Mpumalanga). In 1975 it was recorded in Darnall, south of the Tugela River, which had been regarded as a barrier to the spread of *E. saccharina* prior to this time (Carnegie *et al.*, 1976). By 1980 the spread had reached as far south as Port Shepstone and by 1983 was recorded at New Hanover in the Kwazulu-Natal midlands.

Carnegie *et al.* (1976) suggest that passive transportation from one area to another of eggs, larvae and pupae on cut seed cane and millable cane could have been one of the reasons for the spread of *E. saccharina* in South Africa.

However, the evidence of infestations at sites as far apart as Hluhluwe in 1970 and Mhlume in 1972 (figure 1), suggests that there were sporadic incursions into sugarcane from indigenous hosts at several different points (Atkinson *et al.*, 1981). A combination probably of climatic, bionomic and/or genetic factors caused its numbers suddenly to increase to noticeable levels (Carnegie, 1974).

Way (1994) recently postulated that the spread of *E. saccharina* into cooler regions such as the Midlands of Kwazulu-Natal, could have been facilitated by increase in winter temperatures in those regions. Mean winter temperatures that were up to 106% of the long term mean (LTM) during the early part of this decade indicate this. Way (1994) alternatively suggests that the insect could have adapted to lower temperatures, thus enabling it to spread to regions that were previously considered too cold for its development. Further, it has also been suggested that the more agile adult stage, the moth, could have spread the species (Carnegie *et al.*, 1976).

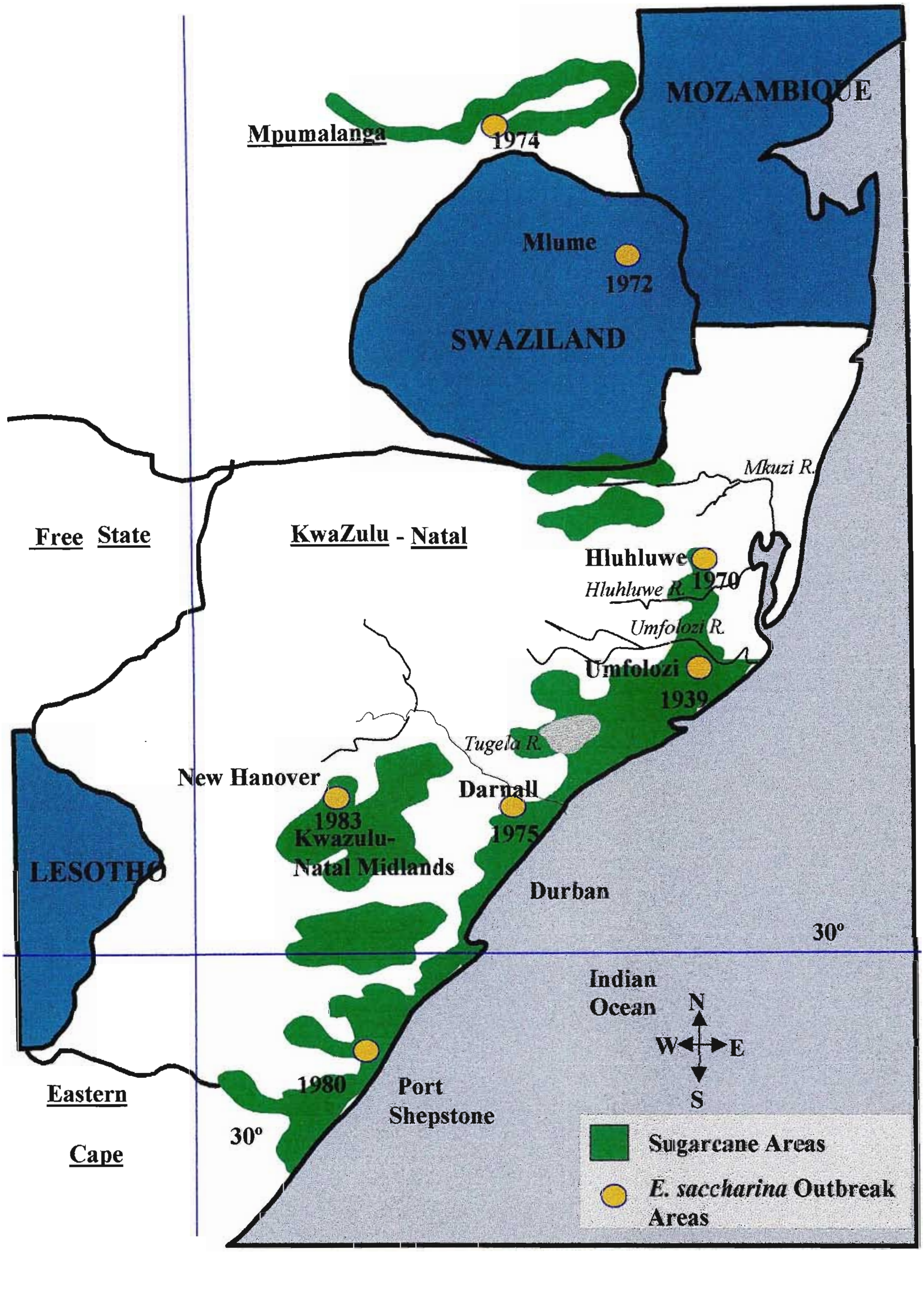

Figure 1. Chronological development of the *Eldana saccharina* epidemic in the South African sugar-belt. (Adapted from Carnegie, 1974).

However, studies on the life cycle of *E. saccharina* have revealed that mating generally takes place on the night of emergence (Dick, 1945) and that moths are not active fliers (Carnegie *et al.*, 1976).

1.4 Life cycle of *Eldana saccharina*

Figure 2 illustrates the general life cycle of *E. saccharina*. The length of the life cycle is variable, as duration of egg incubation and larval periods are determined by temperature (Dick, 1945; Girling, 1972; Carnegie, 1974). The life cycle is shorter in warm temperatures and longer in cold ones.

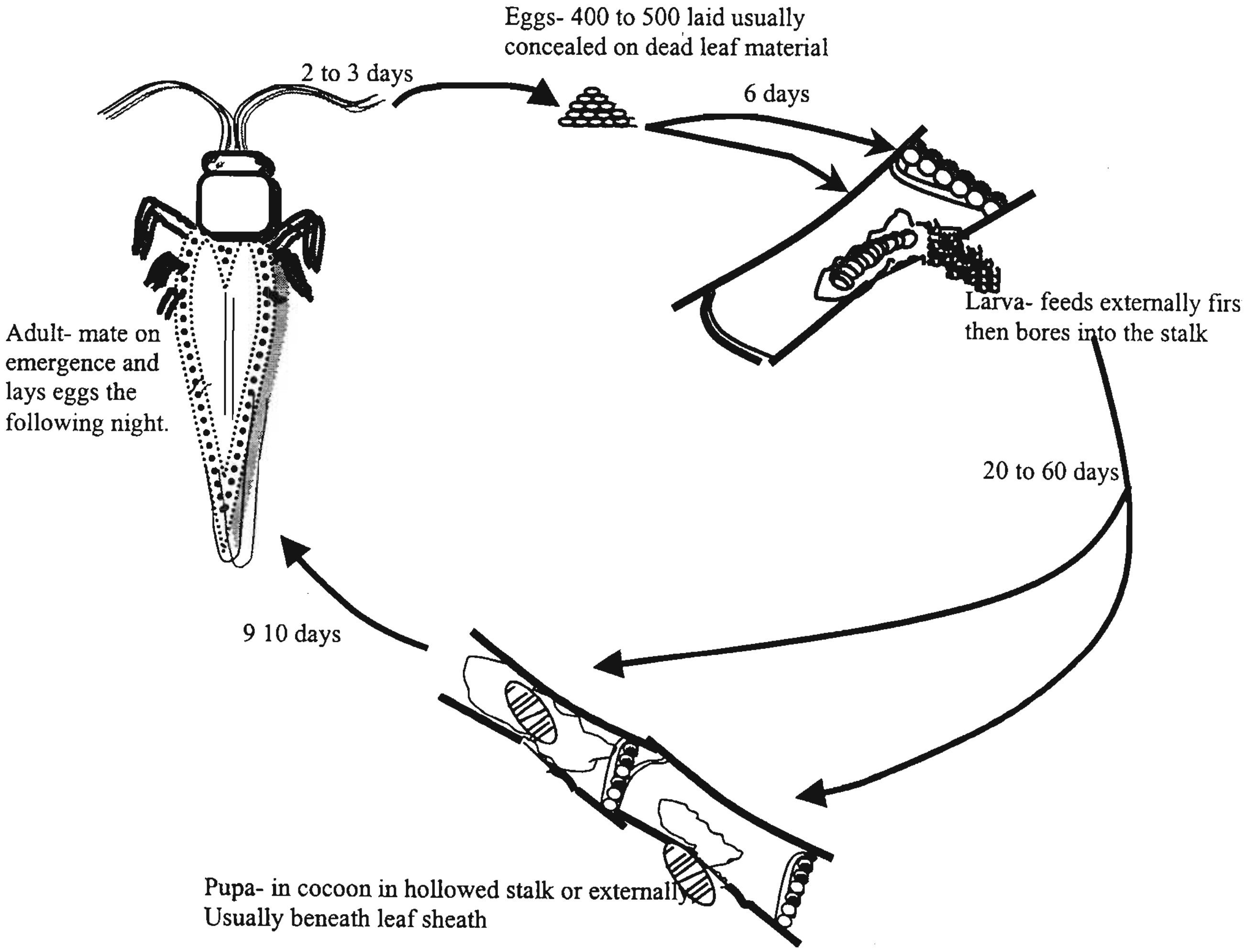

Figure 2. The life cycle of *E. saccharina*. Adapted from Rutherford (1993)

Mating takes place on the night of adults' emergence (Dick, 1945; Betbeder-Matibet, 1981). Eggs are laid closer to the emergence site on the second night after the adults' emergence (Dick, 1945; Betbeder-Matibet, 1981; Carnegie, 1974). A female moth lays a total of between 400 and 500 eggs (Betbeder-Matibet, 1981) in batches of between 20 (Carnegie, 1974) and 200 (Girling, 1972) eggs over 2 to 3 days. At a mean temperature of 25°C, the egg incubation period is about 6 days (Betbeder-Matibet, 1981). Oviposition sites include trash on the ground, under leaf sheaths and the area between stem and soil (Girling, 1972; Carnegie, 1974).

The concealment of eggs suggests that egg predation and/or parasitism was a strong selection pressure in the evolution of the insect. *E. saccharina* has tactile sensilla on the tarsi and ovipositor (Wallade, 1983). The ovipositor sensilla, which are on the sharp, V-shaped tip of the prehensile ovipositor ensure concealment of eggs (Waladde, 1983). It has been shown that oviposition sites should stimulate all the ovipositor sensilla before oviposition can take place (Wallade, 1983). This attribute has some implications for the control of *E. saccharina*. Arthropod egg predators that are physically big in size will have difficulty accessing the concealed eggs.

Newly hatched larvae do not enter the sugarcane stalk immediately, but feed initially as scavengers on oddments of organic matter behind the leaf sheath (Carnegie, 1974). When the larva is sufficiently robust, about 10 days after hatching, it tries to penetrate into the interior of the stalk (Betbeder-Matibet, 1981).

Penetration sites include buds, root primordia and cracks (Carnegie, 1974). The larval period varies between individuals even when conditions such as climate and host plant are the same (Betbeder-Matibet, 1981). Some larvae, from the same batch of eggs, develop faster than others. The larval period also varies seasonally, from 20 days in summer to 60 days in winter (Carnegie, 1974). This variability has implications for the control of the pest. In particular, it means that overlapping life stages may exist at any one point in time, thus making it difficult to target a particular generation for control. The mature larva spins a protective cocoon and pupates within it (Carnegie, 1974). The pupa may be located either within the hollowed stalk or be attached to the outside of the stalk, usually beneath a leaf sheath (Carnegie, 1974).

The adult moth emerges about 9 - 10 days after pupation (Carnegie, 1974; Betbeder-Matibet, 1981) and mates on the night of emergence, although it may be delayed until the following night in cooler temperatures (Dick, 1945), thus initiating a new life cycle.

1.5 Nature of damage of *Eldana saccharina*

Sugarcane quality is adversely affected by *E. saccharina* infestations (Smaill and Carnegie, 1979). The borer destroys and consumes part of the contents of the internode. Its excretions together with material discarded without being eaten, which remain in the tunnel, reduce the sucrose content and purity of the juice extracted from the bored internodes (Betbeder – Matibet, 1981). Attack by the borer facilitates invasion of the internode by pathogenic agents, which may facilitate the inversion of sucrose into glucose (Betbeder – Matibet, 1981).

1.6 Control measures for *Eldana saccharina*

Research into controlling *E. saccharina* has been continuous since the early 1970's, after the pest's recrudescence in South Africa as indicated by published papers discussed in the introduction section of this chapter. Distribution and ecology, crop management, biology of *E. saccharina*, diet/host preferences, biological control, chemical control and sugarcane variety resistance have been the main areas of research.

Sugarcane accumulates large amounts of dead leaf material, known as trash, from 6 to 9 months of age onwards (Atkinson, 1980). Manual removal of trash is called pre-trashing (Carnegie, 1981). Pre-trashing as a crop management tool, has shown some positive results (Carnegie, 1981; Carnegie and Smaill, 1982).

Chemical control has not shown encouraging results (Carnegie, 1981; Atkinson and Carnegie, 1989). This is probably due to the cryptic nature of *E. saccharina* since a combination of pre-trashing and chemical control application has shown some positive results (Heathcote, 1984).

While commonly grown sugarcane varieties in South Africa are subject to *E. saccharina* attack and economic loss, there are varietal differences in susceptibility (Carnegie, 1981). Research on biological control has included the use of endemic and exotic parasitoids (Carnegie and Leslie, 1979; Carnegie, 1982; Conlong and Hastings, 1984), predators (Leslie, 1981; Leslie and Boreham, 1981; Leslie, 1982, Conlong, 1995) and pathogens (Herrera and Thompson, 1989; Spaull, 1990).

Serological tests on a number of potential predators have shown positive results. These include species in the arthropod orders Formicidae, Araneida, Blattaria, Heteroptera, and Coleoptera (Leslie and Boreham, 1981). However, the most frequently encountered ant genera (*Paratrechina* and *Pheidole*) are not the most frequent feeders on *E. saccharina* (Leslie and Boreham, 1981).

1.6.1 **Habitat Management**

Monocultures discriminate against natural enemies in favour of development of exploding pest populations (Hagen and Hale, 1974). This is because insect parasites and predators usually have more complex food requirements than most phytophagous insects. Natural ecosystems are characterised by a greater diversity of animal and plant species (van Emden and Dabrowski, 1994). It is in these natural habitats that greater stability in arthropod species populations is to be expected when compared with monocultures. However, agriculture necessitates modifications of the natural habitat to accommodate the needs of the crop to be produced. Despite this, some form of habitat management can achieve a balance between habitat diversity in the agroecosystems on the one hand, and optimal crop production on the other (van Emden and Dabrowski, 1994).

Habitat management in agroecosystems can take three forms:

1. Simultaneous growth of two or more crops in the same field (within-crop habitat management);
2. Selected weed control; and
3. Intentional creation of floral diversity on land outside the crop (without-crop diversity) (van Emden, 1990).

In the South African sugarcane context, Atkinson (1978) suggested preservation of riverine woodland and plantation of fast growing trees on the riverbanks south of the Tugela River, in order to achieve some form of habitat management with the view of reducing *E. saccharina* populations. This was intended to exclude *Cyperus immensus* C. B. Cl., a sedge that is a favoured host of *E. saccharina*, which could act as a reservoir for the insect. Exclusion of the sedge in this area, Atkinson (1978) postulated, would thus reduce the potential of the insect infestation of sugarcane.

Intercropping

Intercropping, the simultaneous culture of two or more crops in the same field is an age-old practice that has long been used by subsistence farmers in Africa (Abate, 1991; Skovgård and Päts, 1996). Most of the food consumed in Africa, tropical Asia and Latin America is produced through intercropping (van Emden and Dabrowski, 1994). Primary objectives of this practice are twofold: to increase total land productivity and serve as insurance against the failure or unstable market of a single crop.

Intercropping can take various forms (Capinera *et al.*, 1985):

- Culture of two or more crops without distinct row arrangement (mixed intercropping);
- Alternate multiple-row patterns of crops (strip intercropping); and
- Alternate single-row patterns of crops (row intercropping).

The use of intercropping as a cultural method of pest control is based on the principle of minimising insect pest populations by increasing the diversity of an agroecosystem. Nevertheless, in spite of the evidence that crop diversity can have pest management potential, the choice of partners and timing of intercropping remains important. Van Emden and Dabrowski (1994) report that cotton and maize grown together have been found to promote *Helicoverpa* (Lepidoptera: Noctuidae) damage in cotton when planted simultaneously. However, by timing the emergence of maize tassels to coincide with bud formation on cotton, produces the opposite effect. Bean intercrops, in many instances, have been shown to have positive results on pest management (van Emden and Dabrowski, 1994). Table 1 shows the cases where the intercrop of beans and another crop has reduced pest populations.

Table 1. Cases where the intercrop of beans and another crop has lead to reduction in pest populations

Crop	**Insect Pest/s**	**Author**
Sweet corn ('Jubilee')	European corn borer, *Ostrinia nubilalis* (Hbn.; Lepidoptera: Pyralidae) Corn earworms, *Heliothis zea* (Fabricius; Lepidoptera: Noctuidae)	Capinera *et al.* (1985)
Maize (*Zea Mays;* L.)	African bollworm, *Heliothis armigera* HÜbner; Lepidoptera: Noctuidae)	Abate (1991)
	Leafhoppers, *Empoasca kraemeri* (Lib.; Homoptera: Cicadellidae) Leaf beetles, *Diabrotica balteata* (Say; Coleoptera: Chrysomelidae)	van Emden and Dabrowski (1994)

In terms of crop production, a quick maturing food crop such as beans is a suitable intercrop in sugarcane because of the relatively slow sugarcane growth rate during the first two to three months after establishment (Anonymous 1984). Competition for light is reduced during period (Anonymous, 1984). However, there is evidence that there is a strong competition between sugarcane and beans for water and nutrients ((Leclezio, *et al.*, 1984). Because of the well-established ratoon sugarcane root system, competition for water and nutrients does not adversely affect ratoon sugarcane as does with plant sugarcane (Anonymous, 1984).

At maturity, yields of both the sugarcane and beans are unaffected by intercropping, particularly in row intercropping (Anonymous, 1984). This is true for plant sugarcane as well, despite competition that is evident during the first three months (Leclezio). Further, competition for water and nutrients can be remedied by irrigation and fertilization (Anonymous, 1984).

Intercropping in sugarcane

Pike (1992) attributes poor performance of many agricultural and rural development projects in sub-Saharan Africa to two factors. Firstly, human attempts to effect crop production and support for agricultural institutions were ignored in the drive to increase foreign aid flows to African agriculture. Secondly, there has been a lack of analytical research on institutionalised development of subsistence farmers. Zimbabwe however, emphasised the importance of subsistence farmers after its independence. These lessons prompted a realisation for a need for more research into the development of small-scale cane growers in South Africa. Consequently the South African Sugar Industry Agronomists' Association (SASIAA) declared the year 1992 "the year of small cane growers". Subsequently, Greenfield (1994) suggested intercropping as an alternative strategy for cane growers. Early in 1995 the Agronomy Departments of the South African Sugar Association Experiment Station (SASEX) and the Department of Agriculture agreed to work on joint intercropping trials. Demonstration trials were established in Makhathini Experiment Station and Amatikhulu farm (both on the north coast of KwaZulu-Natal). Results of the demonstration trials will not be presented in this thesis, however.

It was anticipated that yield related results would emerge from the demonstration trial projects. In addition, farmers' fears that introduction and expansion of sugarcane would adversely affect farmer's food security, would be allayed. However, with the economic importance of *E. saccharina* in the sugar industry the impact of intercropping on its populations could not be ignored. Consequently arthropod populations were monitored in Makhathini Flats and Amatikhulu. This was intended to determine whether or not intercropping would influence the abundance of *E. saccharina* potential predators. Further, monitoring of arthropods in the intercrop situations would provide a better understanding of the full complement of arthropod groups that become available in sugarcane, as a result of specific crops used for intercropping. Consequently, decisions about the merits of intercropping would be based upon the agronomic and economic viability of the crops involved as well as the potential advantages and disadvantages of the arthropod groups that become available in sugarcane through intercropping.

The present study is an extension of the preliminary pitfall trapping trials in sugarcane/maize and sugarcane/sorghum intercrops at La Mercy by Conlong (1995). To date, the demonstration trials and Conlong's (1995) work are the only recorded intercropping experiments in sugarcane where arthropod populations have been monitored.

Intercropping and predators

Vegetation diversification through polycultures and selective weed control has resulted in lower pest infestations in many experiments (Root, 1973; Showler *et al.,* 1990; van Emden, 1990; Skovgård and Päts, 1996). One of the theories that attempts to explain this observation is that the natural enemy populations are enhanced in vegetatively diversified crops (Showler *et al.,* 1990). According to van Emden (1990) a low crop, such as grain legumes, between maize changes the crop background both visually and olfactorily to arriving insects. The intercrop may also provide shelter and higher humidity conditions near the ground for epigeal predators. Thus relatively more stable predator populations persist in the intercrop situations because of the presence of food (pollen and nectar), refugia and suitable microhabitats. Conlong (1995), who found higher arthropod populations (that contained potential *E. saccharina* predators) in sugarcane/sorghum and maize intercrops when compared to pure sugarcane plots, supported this. Thus the potential usefulness of intercropping as a pest management strategy provided the basis for the present study.

CHAPTER 2

MATERIALS AND METHODS

2.1 Study site

Sampling took place on the SASEX Field Station at La Mercy, Kwazulu-Natal (29^0 36'S; $31^0$05'E). The study site is located about 4 km inland from the Indian Ocean and 27 km north of Durban. Elevation above sea level is 90 m. Treatment and control plots (Plate 1) were chosen in such a way that differences in slope, altitude and aspect between them were minimal. Soil type was Westleigh derived from middle ecca sediment.

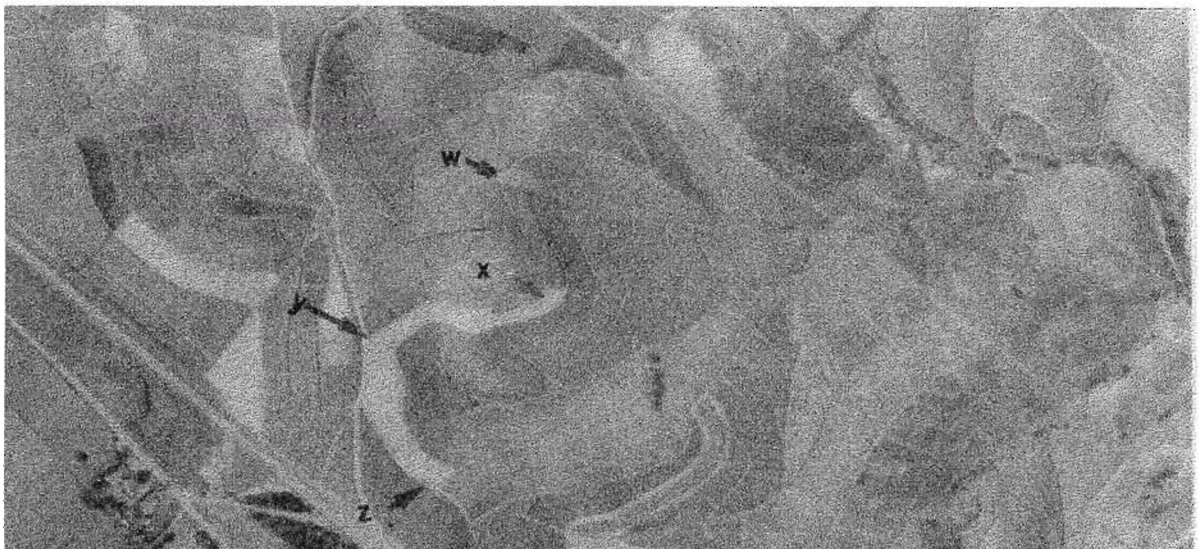

Plate 1. Aerial map (strip no. 60, photo no. 12125 and photo date = 17/06/83) of the study site (z to w) showing sugarcane-bean intercrop (w – x) and control (y – z) plots.

The study area was divided into sugarcane-bean intercrop (beans intercropped within sugarcane rows) and control (sole sugarcane) plots. The sugarcane-bean intercrop was 300m long and 30 rows wide. The control plot was 275m long and 28 rows wide. Sugarcane row spacing was 1.5m. A 100m long guard area was left between the two sites. Bordering the study area was a five metre wide roadway. Within the sugarcane-bean intercrop and control plots the habitats for pitfall trapping were defined as sugarcane rows, bean rows and interrows between sugarcane and bean rows.

2.2 Weather

La Mercy farm has no weather station except for a rainfall recording site. Temperature data were thus obtained from the nearby Tongaat weather station (29^0 34'S; 31^0 08'E). Elevation above sea level of the weather station is 72m. Long term mean (LTM) records of the mean monthly maximum and minimum temperatures were examined. These records represent the means of the past thirty years (1965-95 inclusive). Monthly fluctuations in temperature during the study period, which was 14 months long, were contrasted against LTM records.

Monthly rainfall data, during the study period, were collected from La Mercy. As with temperature, LTM rainfall records were examined, which represented the records of mean monthly rainfall for the past 22 years (1973-95 inclusive).

Using a lux meter (Plate 2), light intensity was measured during each month of sampling. Light intensity measurements took place in sugarcane and bean rows as well as interrows between sugarcane rows in the control plot, and between sugarcane and bean rows in the sugarcane-bean intercrop. All light intensity measurement were taken at ground level.

2.3 Soil nutrients

In January 1996, the two handled Mount Edgecombe soil sampler was used as described by Beater (1959) to sample soil for nutrient analysis, from both the sugarcane-bean intercrop and control plots. Five samples, randomly selected, were taken from each plot. Nitrogen

(N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Aluminum (Al) and water alkalinity and/or acidity.

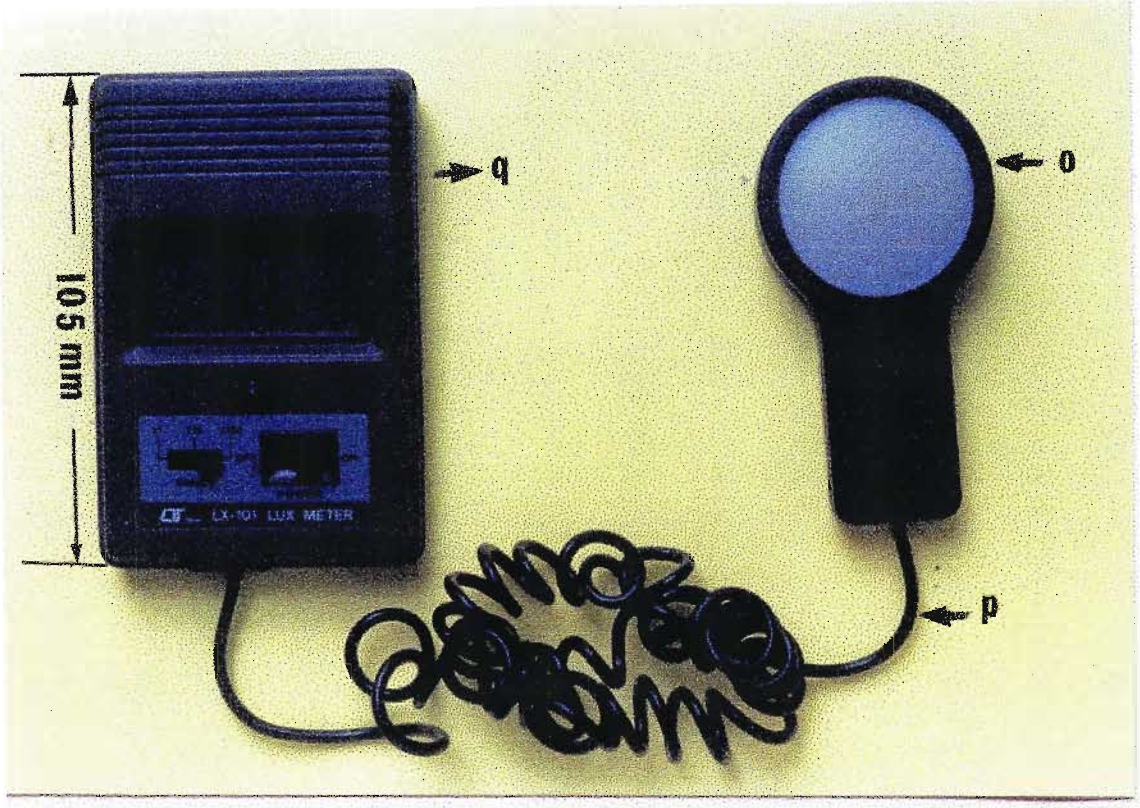

Plate 2. Lux meter for measuring light intensity. (O = sensor, p = cable, q = recorder).

2.4 Plant phenology

Sugarcane (variety NCo376), was intercropped (Plate 3) with dry beans (*Phaseolus vulgaris*). Sugarcane was in the eighth ratoon and the previous harvest was January 1996. Planting of beans took place early in April 1996.

Using a meter stick, sugarcane and bean heights were measured during each month of sampling. Sugarcane was measured from ground level to the last visible node at the apex.

Bean height was measured at the same time as sugarcane. Beans were also measured fro0m ground level to the first leaf at the apex.

Weed density at the pitfall trap sampling units, was visually estimated on a scale of 0% to 100%. Zero percent indicated no ground cover and, 100% complete ground cover. As with sugarcane and bean heights, weed density was estimated during each month of sampling.

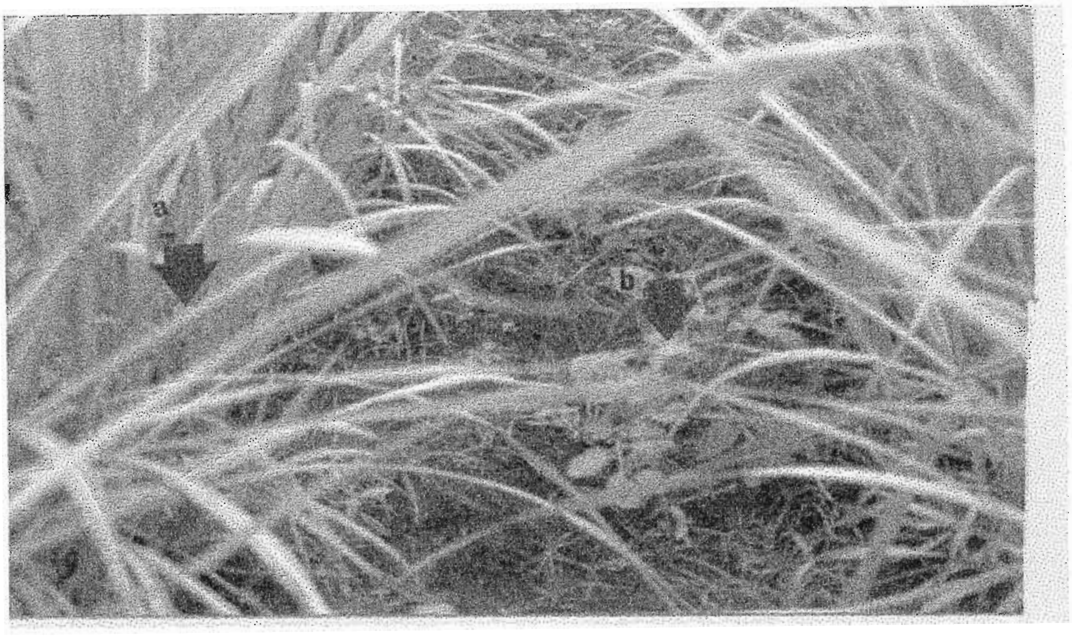

Plate 3. Beans planted within sugarcane rows in the sugarcane-bean intercrop at La Mercy, (a = sugarcane and b = beans.)

2.5 Arthropods

Every month from April 1996 to May 1997 pitfall, suction and sticky traps were used to monitor arthropods in the sugarcane-bean intercrop and control plots as well as the roadway bordering the experimental site.

Pitfall traps were made up of 18mm x 150mm glass test tubes containing two to three ml of a mixture of 70ml denol and 30ml glycerol (7:3). Each trap was placed in 20mm x 200mm of black irrigation piping, which was permanently sunk into the ground, and corked when

not in use. This system limited habitat disturbance to the time when the pitfall trap case was placed in position (Samways, 1983). When in operation, a test tube was dropped into the uncorked pipe, with the lip of the test tube flush with the soil surface.
Sampling with the pitfall traps, was continuous over a period of 96 hours, which is sufficient for maximum capture (Samways, 1983). A period of 30 days lapsed between sampling, which allowed a rest period when no epigeic arthropods were removed from the habitat (Conlong, 1995). A series of three pitfall traps, one meter apart constituted a sampling unit. A total of fifteen sampling units, randomly chosen, were placed in the sugarcane-bean intercrop (sugarcane/bean intercrop). A group of five of these sampling units was placed in the sugarcane rows, while each of the remaining two groups of five were placed in bean rows and interrows between sugarcane and bean rows. In the control plot only ten randomly chosen sampling units were used. Five in the sugarcane rows and five in the interrows.

Sticky traps were made up of 47mm x 130mm double-sided pieces of sticky tape. These were wound around sugarcane stalks 20 cm above the ground (Plate 4). There were five sampling units in each plot, randomly selected. A sampling unit was made up of a series of three traps one-meter apart. As with the pitfall traps, sampling with the sticky traps was over a 96-hour period and took place during the same time as pitfall traps.

A motorised suction sampler (Plate 5) such as that described by Dietrick (1961), was used to sample foliage-associated arthropods. This backpack portable motor fan unit is made up of two components: First, the single-cylinder, air-cooled, two-cycle petrol engine of the type used on lawn mowers. This engine is used to turn the lightweight fan that draws air; secondly, a flexible air duct connects the various collecting attachments to the fan intake. A wire framework holds the duct open. A perforated cotton bag sieves the insects as near to the collecting head as possible.

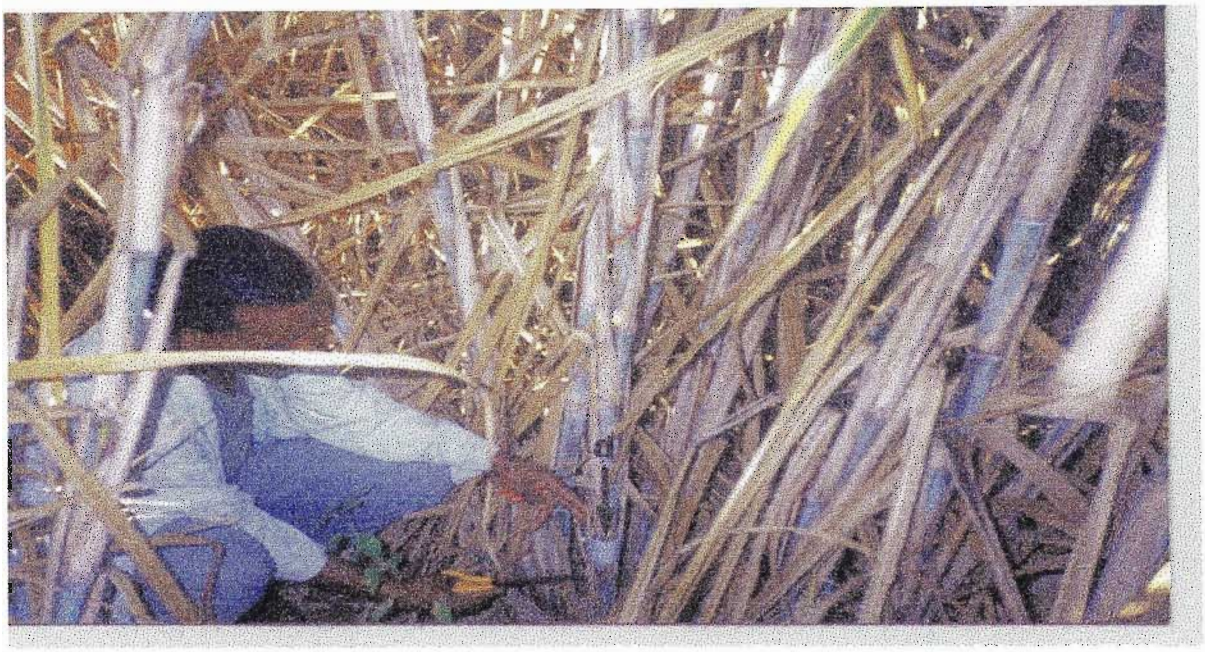

Plate 4. Double-sided sticky tape (d) used as a sticky trap.

Plate 5. Motorised suction sampler used for suction trapping. (A = engine, B = air duct and C = collecting attachments.)

Suction trap sampling took place one day after pitfall and sticky traps had been removed. This was done to minimise habitat interference while pitfall and sticky traps were in place. Five sampling units, randomly selected, were sampled monthly from April 1996 to May 1997. A distance of three meters constituted a sampling unit. As dew, sun and wind were liable to change as the day progressed, their effect was minimised by consistently, sampling between 10H00 and 11H00 throughout the sampling period. Sugarcane stalks were suctioned from about 30 centimeters above the ground to the last visible node on top.

Arthropod samples, from all three trapping techniques, were taken to the laboratory for sorting, identification and enumeration.

2.6 *Eldana saccharina* infestation and damage

At the end of each arthropod sampling period, 200 sugarcane stalks, selected at random, were sampled from each plot. Timing of sampling of these stalks was intended to reduce human interference during the arthropod census. Stalks were dissected and examined for *E. saccharina* infestation and damage (Plate 6). The number of nodes of each stalk were counted and recorded. The number of *E. saccharina* entrance holes into the sugarcane stalk, the number of larvae, larval stages of development and pupae found were recorded. Larval developmental stage was visually estimated. Each stalk was roughly divided, along its length, into three segments: bottom third, middle third and top third. The segment of the stalk, where larvae and pupae were found, was also recorded. *E. saccharina* larvae and pupae found during the survey were taken to the laboratory to be screened for parasitoids.

2.7 Sucrose yield

Twelve stalks were sampled from the sugarcane-bean intercrop and control plots for sucrose yield assessment at the SASEX mill room. Selection of the stalks was random, but so distributed as to represent the entire plot. Sampling of these stalks took place at harvest (May 1997).

The following, as defined by Anonymous (1985) were measured during sucrose yield analysis: DM % Cane (percentage of dry mass of sugarcane), where Cane is a common name for sugarcane, a botanically tall grass of the genus *Saccharum*; Brix %Cane (solids concentration of a sucrose containing solution); Brix %DM (percentage dry mass of brix); Fibre %Cane (the water insoluble matter of sugarcane and bagasse from which the brix-free water has been removed); Pol %Cane (the apparent sucrose content of any substance expressed as a percentage by mass and determined by the single or direct polarisation method); Purity (the percentage ratio of sucrose (or pol) to the total soluble solids (or brix) in a sugar product); Cane G/stalk (the average mass of a sugarcane stalk) and Sucrose G/stalk, (mass of pure disaccharide α-D-glucopyranosyl-β-D-fructofuranoside in a sugarcane stalk).

Plate 6. Sugarcane stalk dissected during *E. saccharina* infestation and damage survey. (s = dissected sugarcane stalk and t = *E. saccharina* damage).

2.8 Data analysis

Data were analysed using STATGRAPHICS Plus version 7. The effect of sugarcane-bean intercrop (bean intercrop and sole sugarcane) and factors such as: temperature, rainfall, light intensity, weed density, sugarcane height and bean height were tested using Multifactor Analysis of Variance (mutifactor ANOVA). Rainfall, temperature, light intensity, sugarcane height, bean height and weed density were treated as covariates. Month, plot and habitat were treated as the main independent factors. Similarly, multifactor ANOVA was used to test the effect of time and sugarcane-bean intercrop on *E. saccharina* infestation and damage. Further standard error bars (Std error bars) from Microsoft Excel were inserted in all charts. This was done to facilitate analysis and help in visual appraisal of the results. However, Microsoft excel does not allow selected insertion of Std error bars in a data series, hence these have been included even in zero recordings.

Unlike pitfall trapping, which had an extra five sampling units in the sugarcane-bean intercrop when compared to the control plot, sticky and suction traps had equal number of traps in both plots. Hence, Student t-Test: Paired for Two Sample Means was used to separate the means of total number of individuals of all groups and samples. To be able to separate the means of pitfall trap captures using Student t-Test: Paired for Two Sample Means, some modifications on those data were made. The number of traps used in a plot was divided by the total number of individuals of each group from all samples of each plot, so that there were a number of individuals of a particular group per trap. The Student t-Test was also used to separate the means of LTM temperature and rainfall and temperature and rainfall recorded during this study. Soil analysis and sucrose yield results were treated with the Student t-Test.

CHAPTER 3
ENVIRONMENTAL INFLUENCES

3.1 Introduction

Weather affects animal life functions such as growth, maturation, movement, dispersal, feeding, mating and egg laying (Johnson, 1969). Temperature, rainfall and light intensity were, therefore, measured in this study. In addition, soil nutrients such as nitrogen affect crop growth (Pilbeam, *et al.*, 1994). Biotic factors, such as plant phenology were also measured, as they are known to affect the occurrence of pests (Flynn and Reagan, 1984). Similarly, sucrose yield analysis was conducted since *E. saccharina* infestation reduces sucrose yield, while increasing fibre content of sugarcane (Smaill and Carnegie, 1979; Betbeder-Matibet, 1981). Consequently this chapter concerns itself with the influences of abiotic factors, such as climate and soil nutrients prevailing during the present study, as well as biotic factors such as vegetational composition, sucrose yield phenology on arthropod predator species assemblages and abundance. In addition, the extent and effects of *E. saccharina* infestation are examined.

3.2 Abiotic factors

3.2.1 Temperature

Long term mean (LTM) monthly maximum and minimum temperatures from Tongaat weather station are shown in Figure 3. From these data, it is shown that the highest temperature (28^0C) occurred during the summer months of December to March. June and July were the coolest months, with the mean minimum monthly temperature of 8^0C.

Figure 3 also shows the maximum and minimum temperature recorded for each month during the sampling period. The highest temperature (28.5°C) was recorded during the month of December. While the lowest (13°C) was recorded during the month of July. The LTM minimum temperatures were significantly ($0.05 > P > 0.01$) lower than minimum temperature recorded during this study, while the there were no significant differences in maximum temperatures.

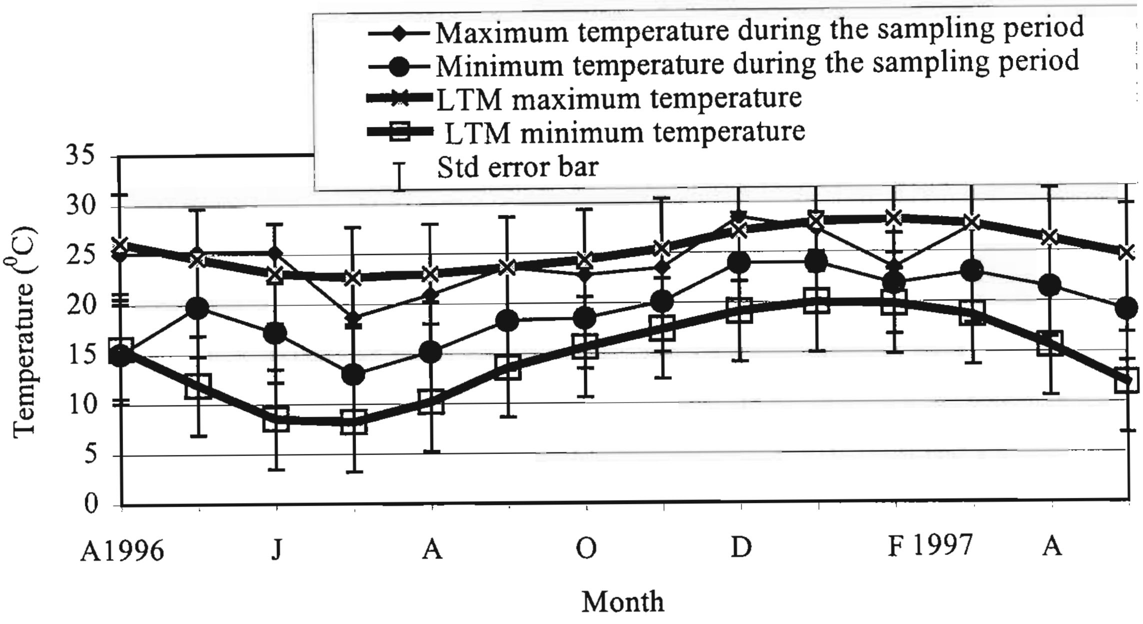

Figure 3. Long term temperature fluctuations (1965 - 1995) and temperature recorded at Tongaat weather station during the study period.

3.2.2 Rainfall

Figure 4 shows the LTM and monthly rainfall records during the sampling period. The heaviest LTM rainfall occurred during the summer months of October to March. A steady decline from March (125mm) onwards occurred, so that the lowest (27.9mm) rainfall was recorded in July.

Mean monthly rainfall during the sampling period is also shown in Figure 4. Rainfall recorded during the months of July, January, February and April was her than the LTM rainfall records. However, the differences between the LTM and mean of the monthly records during the sampling period were not significant. Highest rainfall (205mm) was recorded during the month of January 1997.

Light intensity

Great fluctuations in light intensity occurred during the course of this study as a result of cloud cover and cloud movement, thus making graphical representation of the results of light intensity difficult. However, the effect of light intensity on selected predators was examined as explained in data analysis in Chapter 2.

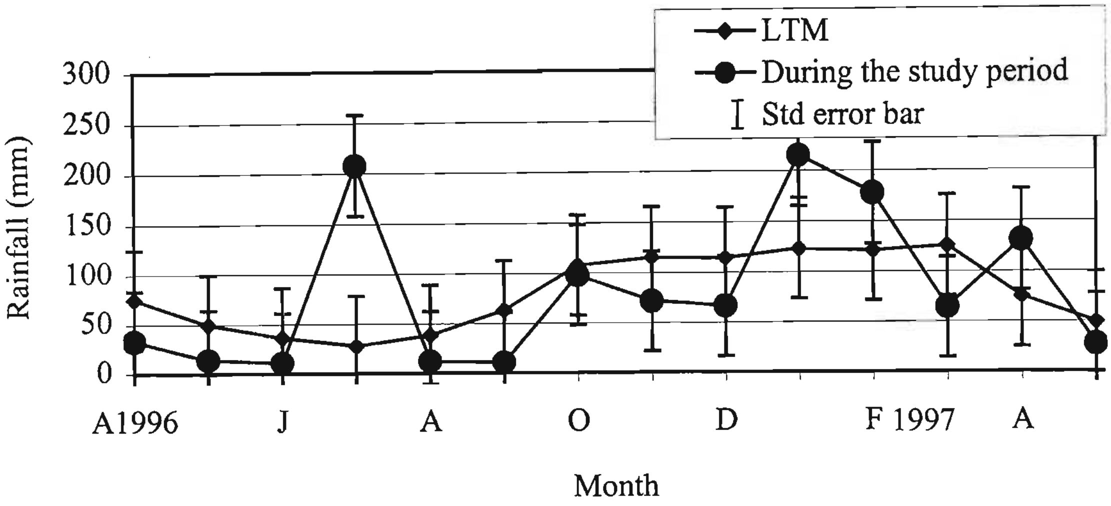

Figure 4. Long term mean monthly rainfall (1973 - 1995) and monthly rainfall recorded at La Mercy Field Station during the study period.

3.2.4 Soil nutrients

Table 2 shows the results of soil analysis. Phosphorus and potassium were markedly higher in the sugarcane-bean intercrop when compared to the control plot, while calcium,

Table 2. Results of soil nutrient analysis taken during the month of January (1997) from the sugarcane-bean intercrop and control plots.

Element	**Units**	**Treatment**	**Control**
N	CAT	2	2
Ph	WATER	5.15	4.88
P	PPM	5	2
K	PPM	149	100
Ca	PPM	382	547
Mg	PPM	168	220
Al	PPM	20	28
CLAY	%	19	27

aluminum and % clay were higher in the control plot. However, the difference between the means of all nutrients in the sugarcane-bean intercrop and control plots was not significant. Concentrations of these nutrients indirectly affect *E. saccharina* infestation by affecting the sugarcane health (Anonymous, 1986). *E. saccharina* infestation tends to be high in stressed sugarcane (Anonymous, 1986).

3.3 Biotic factors

3.3.1 Vegetation

For the duration of the study period no significant difference in sugarcane height (0.5m-2m) between the sugarcane-bean intercrop and control plots (Figure 5) was recorded.

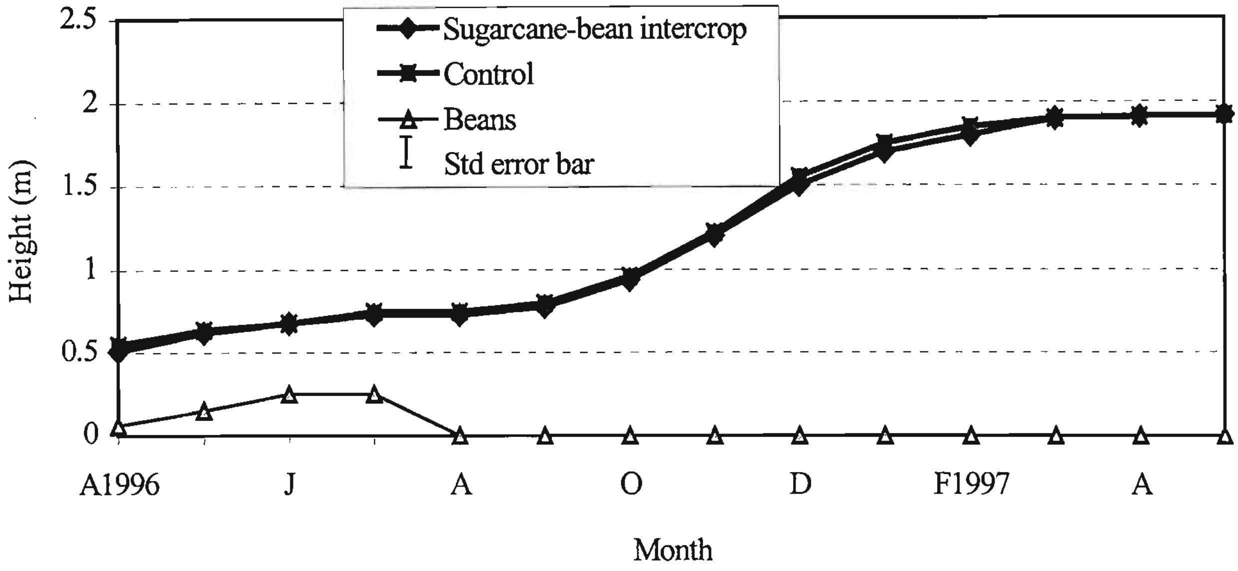

Figure 5. Sugarcane and bean height in the sugarcane-bean intercrop and control plotsduring the sampling period.

Following the drying out of pods in July 1996 the leaves and stems of the bean crop dried out too. Bean crop height is also given in Figure 5. Because it was a short-term crop (three months), and no trace of them remained after August, bean height data was not recorded from August onwards. Beans had flowered when the second arthropod sample (May, 1996) was taken and pods had formed when the third sample was taken (June, 1996). At the time of drying out the bean crop had attained a maximum higher of 27cm.

The vegetation in the roadway comprised a mixed grass sward, which was regularly mowed. The grass species, in the order of percent density, were made up of *Cynodon dactylon* (L.) Pers, *Sporobolus africanus* (Poir.) and *Eleusine indica* (L.) Gaertn. While weed density was consistently higher in the sugarcane-bean intercrop, there was no difference in weed density between the two plots (Figure 6). Significantly ($0.05 > P > 0.01$) higher ground cover occurred on the roadway. The dominant weed and grass species within crop in both plots were *Conyza floribunda* L. and *Digitaria sanguinalis* Stent respectively.

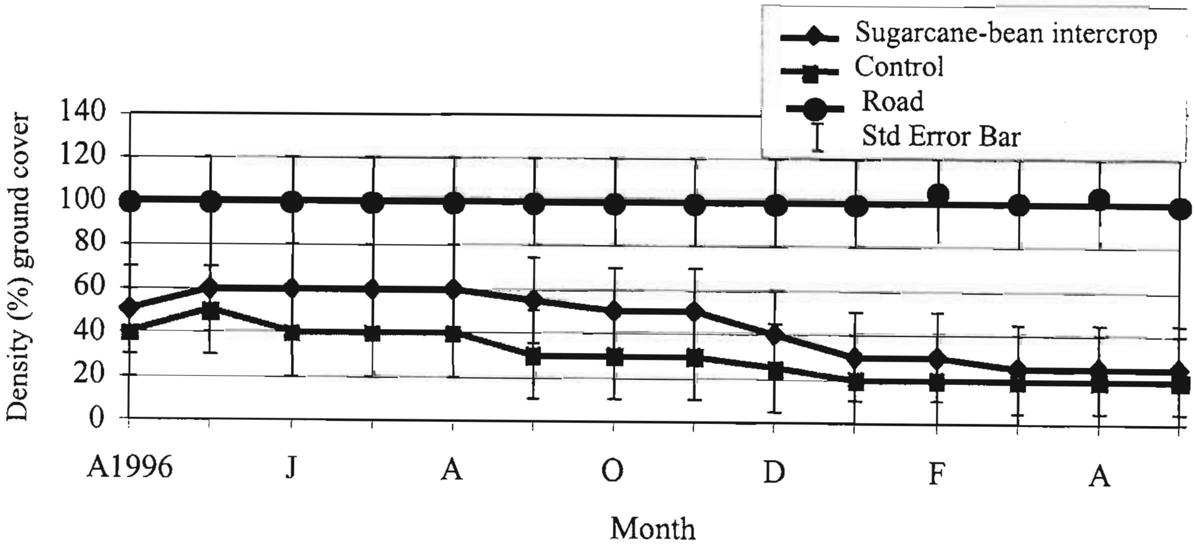

Figure 6. Weed density in the roadway, sugarcane-bean intercrop and control plots during the study period

3.3.2 *Eldana saccharina*

Figure 7 shows the infestation *E. saccharina* per 100 stalks (E/100 stalks), which represent *E. saccharina* larval infestation in the sugarcane-bean intercrop and control plots, during the period May 1996 to May 1997. Infestation was significantly ($0.05 > P > 0.01$) higher in the sugarcane-bean intercrop during the first two months (May and June)) and the last month of sampling. During the first two months infestations were 7 and 8 E/100 stalks in the sugarcane-bean intercrop and 4.5 and 2 E/100 stalks in the control plot, while there were 5 and 0,5 E/100 stalks infestation in sugarcane-bean intercrop and control plots respectively, during the last month of sampling. Infestation significantly ($P < 0.01$) decreased from June to October in both the sugarcane-bean intercrop and control plots. Sugarcane was 4 months old (0.5m high) when sampling commenced, while it was 16 months old (2m high) when the last sample was taken and sugarcane harvested.

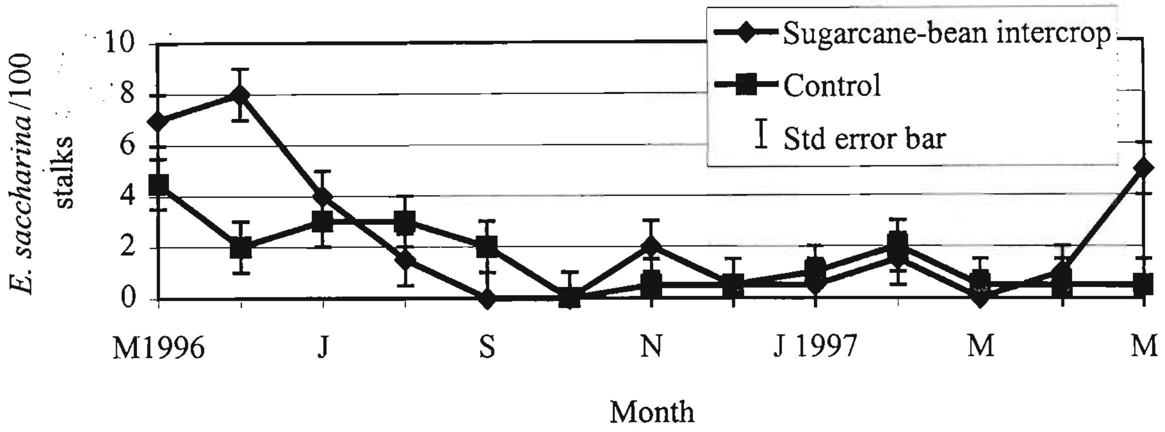

Figure 7. *Eldana saccharina* infestation in the sugarcane-bean intercrop and control plots during the study period.

Percent bored internodes, which represent damaged sugarcane stalks in the sugarcane-bean intercrop and control plots are shown in Figure 8. While percent bored internodes fluctuated

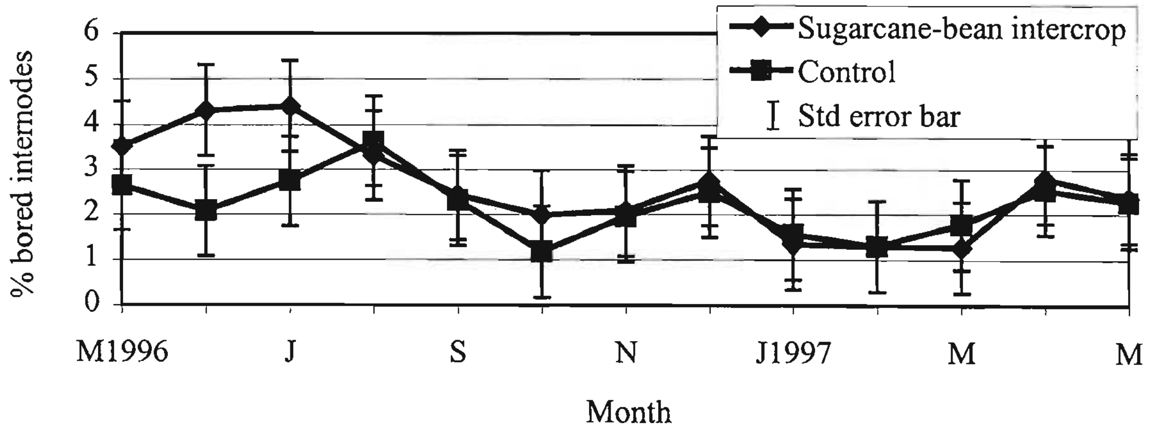

Figure 8. Percent bored internodes in the sugarcane-bean intercrop and control plots during the study period.

during the study period , differences between months were not significant. The damage fluctuation trends were similar to those of infestation. While markedly higher damage occurred in the sugarcane-bean intercrop when compared to the control plot during the first three months of sampling, damage decreased markedly from July to October, in both plots.

3.3.3 Sucrose yield

Table 3 shows sucrose yield analysis results of sugarcane stalks from the sugarcane-bean intercrop and control plots. Sugarcane stalk mass in the sugarcane-bean intercrop was 775 CANE G/stalk (56.4% higher) while in the control plot it was 600 CANE G/stalk. Sucrose mass in the sugarcane-bean intercrop was 93 SUCROSE G/stalk (53.3% higher), while in the control plot it was 81.5 SUCROSE G/stalk. Purity, on the other hand, was 91.4% in the control plot (51.2% higher) while it was 87.2% in the sugarcane-bean intercrop. However, no significant difference in the total measurements in the sugarcane-bean intercrop and control plots was observed.

Table 3. Sucrose yield assessments from the sugarcane-bean intercrop and control plots.

Measurement	**Treatment**	**Control**
DM %Cane	27.3	28.8
FIBRE %Cane	13.6	13.9
BRIX %Cane	13.8	14.9
BRIX %DM	50.5	51.8
PURITY	87.2	91.4
POL %Cane	12.0	13.6
CANE G/stalk	775	600
SUCROSE G/stalk	93.0	81.5

3.4 Discussion

3.4.1 Abiotic factors

La Mercy lies within the Coastal region of KwaZulu-Natal, which extends from Umbogintwini (29^0 58'S; 30^0 56'E) in the south to Empangeni (28^0 46'S; 31^0 55'E) in the north (Beater, 1945) and is characterised by relatively high temperatures, second to Inland valleys. There was no significant difference between LTM maximum temperature records and maximum temperature records collected during the course of this study suggesting that maximum temperatures during this time were neither abnormally high nor low. However, significant ($0.05 > P > 0.01$) difference was observed between the LTM minimum temperature and minimum temperature records of this study, which suggests that winter temperatures during the present study were warmer when compared to the LTM winter records. Way (1994) found similar results in the Kwazulu-Natal Midlands, which he hypothesised as having accelerated *E. saccharina* spread into regions that were previously considered too cold for it to develop. Thus, the minimum temperature records during the present study that were higher than LTM minimum temperatures suggest that temperature conditions likely to have been suitable for *E. saccharina* development.

The sugar belt extends along the KwaZulu-Natal coast from 30^o 45' S at Umzimkhulu to approximately 28^o15' S latitude at Hluhluwe. Beater (1945) divided this region into seven rainfall zones, which run almost parallel to the sea and to one another. La Mercy lies in the second zone from the sea, and is characterised by relatively low annual rainfall of between 892.5 to 1123.6 mm. Despite the markedly higher rainfall recorded during the months of July, January, February and March, the mean total monthly rainfall (81.6) recorded during the study was markedly lower than the LTM monthly rainfall (96.6 mm) over the same months. However, this difference was not significant, suggesting that sugarcane was not water stressed. Water stressed sugarcane is known to be susceptible to *E. saccharina* infestation (Anonymous, 1986). An annual rainfall of 700 mm and less is considered to be low enough to cause stress to sugarcane (Anonymous, 1986). However, a total of 1142.6 mm of rainfall were recorded over the 14 months period in the present study (Anonymous, 1986). Therefore, even though temperature conditions were conducive to *E. saccharina* development, the healthy state of the sugarcane brought about by the good rainfall was not conducive to *E. saccharina* infestation.

Thus, hypothetically the collective temperature and rainfall results should have led to decreasing *E. saccharina* infestation levels during the study period.

Differences in soil nutrients between the intercrop and sole sugarcane plots were not significant, which may have contributed to the fact that there was no difference in sugarcane growth rate between the plots. Thus, any differences in arthropod abundance detected between the plots were not attributable to sugarcane health brought about by differences in soil nutrients.

3.4.2 Biotic factors

Leslie and Boreham (1981) considered 1 to 10 *E. saccharina* larvae per 100 stalks as low levels of infestation, and 50 to 100 larvae per 100 stalks as a severe infestation. Based on this criterion, there were generally low levels of *E. saccharina* infestation during the current study. *E. saccharina* levels never exceeded 10 larvae per 100 stalk. One possible explanation for low infestation levels, is the fact that sugarcane was not water stressed as result of relatively good rains which fell during the course of this study (see Figure 4).

A second point arising from the *E. saccharina* infestation and damage survey is the fact that the difference in percent bored internodes, between the intercrop and sole sugarcane was not significant, despite the fact that significantly more immature *E. saccharina* stages were found in the sugarcane-bean intercrop. However, as expected with the higher infestation in the sugarcane-bean intercrop, markedly higher damage occurred there. Paradoxically, sucrose yield and sugarcane stalk mass were slightly higher in the intercrop when compared to the control plot. In general these measurements are usually adversely affected in damaged sugarcane (Smaill and Carnegie, 1979). Beans could have improved the general sugarcane quality in the intercrop because they are known to have a potential to fix atmospheric nitrogen (Pilbeam *et al.*, 1994) while sugarcane relies on previously fixed nitrogen in the soil. Furthermore, fibre content, which increases in damaged sugarcane (Smaill and Carnegie, 1979), was slightly lower in the intercrop. Collectively, these results suggest that damage levels were generally too low to have an effect on sugarcane quality.

Despite the generally low infestation levels, significantly higher *E. saccharina* levels were found in the intercrop when compared to sole sugarcane. This does not necessarily suggest predator inefficacy, in the intercrop. Instead, the generally low larval infestation could imply that *E. saccharina* population fluctuations were independent of generalist predators. Rather these generalist predators could have fed on more numerous prey, as it is known that the predator/prey encounter rate during foraging influences the choice of prey (Stephens and Krebs, 1986). Leslie (1982), also found that predation on *E. saccharina* eggs was greatest where infestation levels were high, thus supporting the predator/prey encounter rate notion.

CHAPTER 4

EPIGEAL AND FOLIAGE ASSOCIATED ARTHROPODS

4.1 Introduction

The impact of *E. saccharina* on sugarcane planted with bean intercrop and sole sugarcane is discussed in Chapter 4. In the initial stages of the project, significant differences in *E. saccharina* populations between the two sugarcane situations were shown. The causes of these can be many. However, as the literature survey given in Chapter 2 shows, predators can have marked impacts on pest populations, especially in intercrop situations. As a result, the populations of arthropods found in the two sugarcane situations were sampled for the period the sugarcane was standing. Those arthropods caught were identified and predatory ones separated from the rest.

In the South African sugarcane context, Conlong (1995) showed how epigeal predator numbers were increased in a sugarcane/sorghum and maize intercrop situation. He however, did not determine if these predators moved up the sugarcane stalks, nor if they foraged in the areas where *E. saccharina* usually oviposited. In addition, there was no sampling of the canopy and stalks of the sugarcane to determine if flying predators were searching these areas.

In this study the whole sugarcane stalk was sampled, and this chapter focuses on the whole environment available for predation, i.e. in addition to ground, sugarcane stalk and foliage are also examined. It also determines whether or not predator populations have an effect on the *E. saccharina* population differences reported in Chapter 3.

4.2 Epigeal arthropods (pitfall traps)

Shown in Table 4 are arthropod groups caught in pitfall, sticky and suction traps from the roadway, sugarcane-bean intercrop and control plots during the study period.The differences among the

Table 4. The total arthropod groups caught in pitfall, sticky and suction traps in the roadway, treatment and control plots and their relative abundance throughout the study period (NC = Not caught with the trap).

Group			Pitfall						Sticky				Suction			
			Roadway		Treatment		Control		Treatment		Control		Treatment		Control	
Order	Family/Subfamily	Species	No.	% in relation to the total in this plot	No.	% in relation to the total in this plot	No.	% in relation to the total in this plot	No.	% in relation to the total in this plot	No.	% in relation to the total in this plot	No.	% in relation to the total in this plot	No.	% in relation to the total in this plot
Orthoptera	Gryllidae		707	3.8	2145	13.5	1336	22.6	10	1.7	11	1.3	1	0.2	2	0.4
Orthoptera	Acrididae		2	0.0	4	0.0	3	0.1	NC	_	NC	_	NC	_	NC	_
Coleoptera	Carabidae		367	2.0	513	3.2	311	5.3	NC	_	NC	_	NC	_	NC	_
Coleoptera	Staphylinidae		92	0.5	120	0.8	158	2.7	NC	_	NC	_	NC	_	NC	_
Coleoptera	Cucujidae		2622	13.9	1796	11.3	786	13.3	NC	_	NC	_	NC	_	NC	_
Coleoptera	Scarabidae		1	0.0	3	0.0	2	0.0	NC	_	NC	_	NC	_	NC	_
Coleoptera	Anthicidae		17	0.1	31	0.2	16	0.3	7	1.2	2	0.2	2	0.3	1	0.2
Coleoptera	Coccinellidae		14	0.1	1	0.0	7	0.1	0	0.0	3	0.4	NC	_	NC	_
Araneida	Lycosidae 1		139	0.7	153	1.0	46	0.8	NC	_	NC	_	NC	_	NC	_
Araneida	Lycosidae 2		43	0.2	47	0.3	23	0.4	NC	_	NC	_	NC	_	NC	_
Araneida	Lycosidae 3		27	0.1	17	0.1	17	0.3	NC	_	NC	_	NC	_	NC	_
Araneida	Comidae		21	0.1	20	0.1	12	0.2	NC	_	NC	_	NC	_	NC	_
Araneida	Oxyopidae		18	0.1	13	0.1	8	0.1	NC	_	NC	_	NC	_	NC	_
Araneida	Salticidae 1		8	0.0	9	0.1	3	0.1	NC	_	NC	_	45	7.2	9	1.6
Araneida	Salticidae 2		NC	_	NC	_	NC	_	NC	_	NC	_	2	0.3	7	1.3
Araneida	Salticidae 3		NC	_	NC	_	NC	_	NC	_	NC	_	2	0.3	2	0.4
Araneida	Thomisidae		NC	_	NC	_	NC	_	28	4.7	27	3.3	89	14.3	87	15.6
Araneida	Nesticidae		NC	_	NC	_	NC	_	3	0.5	1	0.1	213	34.1	218	39.2
Araneida	Philodromidae		NC	_	NC	_	NC	_	NC	_	NC	_	16	2.6	8	1.4
Araneida	Cyantholipidae		NC	_	NC	_	NC	_	NC	_	NC	_	11	1.8	10	1.8
Hymenoptera	Formicidae	*Pheidole megacephala* Fabr.	3398	18.1	1236	7.8	463	7.8	298	50.1	613	74.4	1	0.2	9	1.6
Hymenoptera	Formicidae	*Dorylus helvolus* L.	8051	42.8	6172	38.8	1381	23.4	24	4.0	0	0.0	NC	_	NC	_
Hymenoptera	Formicidae	*Tetramorium laevithorax*	51	0.3	96	0.6	0	0.0	NC	_	NC	_	NC	_	NC	_
Hymenoptera	Apocrita		7	0.0	13	0.1	0	0.0	NC	_	NC	_	NC	_	NC	_
Dermaptera			21	0.1	16	0.1	5	0.1	21	3.5	17	2.1	NC	_	NC	_
Blattoidae			238	1.3	83	0.5	103	1.7	NC	_	NC	_	NC	_	NC	_
Acarina			30	0.2	35	0.2	16	0.3	170	28.6	127	15.4	94	15.1	100	18.0
Collembola			1523	8.1	1590	10.0	628	10.6	NC	_	NC	_	NC	_	NC	_
Diptera			1395	7.4	1775	11.2	579	9.8	NC	_	NC	_	NC	_	NC	_
Hemiptera			0	0.0	2	0.0	0	0.0	NC	_	NC	_	NC	_	NC	_
Hemiptera	Cicadidae		NC	NC	NC	NC	NC	NC	34	5.7	23	2.8	112	17.9	86	15.5
Aphidoidea	Aphididae		10	0.1	0	0.0	3	0.1	NC	_	NC	_	25	4.0	3	0.5
Heteroptera	Anthocoridae		NC	NC	NC	NC	NC	NC	NC	_	NC	_	1	0.2	2	0.4
Total			18802	100.0	15890	100.0	5906	100.0	595	100.0	824	100.0	624	100.0	556	100.0
Mean			752.08		635.6		236.24		54.1		74.9		39		34.75	
Std Error			351.4		268.8		81.6		28.4		54.9		14.9		14.9	
Total groups caught						**25**				**10**				**16**		

plots, in mean number of individuals caught per pitfall trap were significant (0.05 > P > 0.01), with the highest number of individuals being caught in the roadway (18802) followed by the sugarcane-bean intercrop (15890) and control plots (5906) (Table 4). *Dorylus helvolus* L. (Hymenoptera: Formicidae) was the most common capture in pitfall traps. In the roadway it constituted 42.8% of all arthropods, while in the sugarcane-bean intercrop it made up 38.8% of the capture and in the control 23.4% of all arthropods caught (Table 4). *Pheidole megacephala* Fabr. (Hymenoptera: Formicidae) was the second most common capture (18.1%) in the roadway while gryllids (Orthoptera) were the second most common capture in the sugarcane-bean intercrop (13.5%) and control plots (22.6 %).

Epigeal Cucujidae (Coleoptera) were also caught in relatively higher numbers when compared to the majority of other groups. It constituted 13.9%, 11.3% and 13.3% of arthropods caught in the roadway, sugarcane-bean intercrop and control plots respectively. Most other groups contributed below 5% (Table 4).

Amongst epigeal Araneida, the Lycosidae, Cornidae, Oxyopidae and species 1 of Salticidae were caught in relatively low numbers, each contributing less than 1% to the total. The other araneids: Salticidae species 2 and 3, Thomisidae, Nesticidae, Philodromidae and Cyantholipidae were not caught on the ground (with pitfall traps). The same was true for Cicadidae (Hemiptera) and Anthocoridae (Heteroptera).

4.3 Arthropods at the base of sugarcane stalk (sticky traps)

Relatively fewer (10) arthropod groups were caught at the base of the sugarcane stalk (based on sticky trap counts) when compared to epigeal arthropods (25) (Table 4).The means of the total number of arthropod individuals caught in the sugarcane-bean intercrop and control plots were 54.1 and 74.9 respectively. However, there was no significant difference between the two.

Of all the arthropod groups caught at the base of the sugarcane stalk, Gryllidae, Anthicidae (Coleoptera), Coccinellidae (Coleoptera), *P. megacephala*, *D. helvolus*, Dermaptera and mites (Acarina) were also caught on the ground, while Philodromidae (Araneida), Cyantholipidae (Araneida) and Cicadidae in contrast, were caught on foliage using a suction trap.

P. megacephala was the most common capture in sticky traps, constituting 50.1% of the arthropods caught in the sugarcane-bean intercrop and 74.4% of arthropods in the control plot. Mites (Acarina) were the next most common group in both plots. They contributed 28.6% to the total number of arthropods caught in the sugarcane-bean intercrop and 15.4% in the control plot. Most other arthropod groups contributed less than 5% to the total in each plot.

4.4 Foliage-associated arthropods (suction trapping)

No significant difference was found in abundance of foliage-associated arthropods (based on suction trap counts) between the sugarcane-bean intercrop and control plots (Table 4). The most dominant arthropod group caught in suction traps were araneids, specifically of the family Nesticidae. They contributed 34.1% to the total in the sugarcane-bean intercrop and 39.2% in the control plot. The cicadid bugs were the second most dominant group in the sugarcane-bean intercrop (17.9%), while mites (Acarina; 18%) were the second most dominant group in the control plot. The majority of other groups contributed less than 2%.

4.5 Arthropods common to the three trapping sites

Gryllids, anthicids (Coleoptera), *P. megacephala* and Acarina were the arthropod groups caught in all trapping sites (Table 4). Most gryllids were caught in pitfall traps, and contributed 3.8%, 13.5% and 22.6% to the total number of arthropods caught in the roadway, sugarcane-bean intercrop and control plots respectively, while they contributed less than 2% in the sticky and suction traps (Table 4). At the base of the sugarcane stalk in the sugarcane-bean intercrop, anthicids contributed 1.2% while they contributed less than 1% in all other sites and plots (Table 4). *P. megacephala* was the most dominant group at the base of the sugarcane stalk, contributing 50.1% and 74.4% in the sugarcane-bean intercrop and control plots respectively. In pitfall traps it contributed equally (7.8%) in the sugarcane-bean intercrop and control plots, while it contributed 18.1% in the roadway. *P.*

megacephala contributed 0.2% and 1.6% of the total number of arthropods caught on foliage in the sugarcane-bean intercrop and control plots respectively. Most mites (Acarina) were captured at the base of the sugarcane stalk, contributing 28.6% and 15.4% to the total in the sugarcane-bean intercrop and control plots respectively. Foliage was the next site where most Acarina occurred, contributing 15.1% and 18% to the total in the sugarcane-bean intercrop and control plots respectively.

Coccinellids (Coleoptera), *D. helvolus* and Dermaptera are arthropod groups that were common to the ground and the base of the sugarcane stalk only, while cicadids were common to foliage and the base of the sugarcane stalk (Table 4). In both sites coccinellids contributed less than 1% while epigeal *D. helvolus* contributed 42.8%, 38.8% and 23.4% in the roadway, sugarcane-bean intercrop and control plots respectively. At the base of the sugarcane stalk *D. helvolus* was caught in the sugarcane-bean intercrop only, contributing 4% to the total. Most cicadids were caught on foliage, contributed 17.9% and 15.5% in the sugarcane-bean intercrop and control plots respectively, while they contributed 5.7% and 2.8% in the sugarcane-bean intercrop and control plots respectively at the base of the sugarcane stalk.

4.6 Discussion

4.6.1 Pitfall traps

Significantly ($0.05 > P > 0.01$) higher numbers of epigeal arthropods were caught in the roadway bordering the sugarcane plots, when compared to the intercrop and sole sugarcane. Better ground cover on the roadway (Chapter 4) and greater species diversity (as the roadway was a mixed sward of grasses and herbs) may have accounted for higher arthropod numbers there. Ground cover provides shelter and higher humidity conditions near the ground, which support greater abundance and diversity of arthropods (van Emden, 1990). Conlong (1995) found similar results with pitfall traps in sorghum/ sugarcane and maize/sugarcane intercrops.

Epigeal arthropod numbers were significantly ($0.05 > P > 0.01$) higher in the sugarcane/bean intercrop (sugarcane-bean intercrop) when compared to sole sugarcane (control). This suggests that floral diversity provided by intercropping lead to increased arthropod abundance in the intercrop. Work carried out by van Emden (1990) supports the view that more stable arthropod populations are sustained in complex vegetation, which is provided by intercropping. This is due to continuity of food such as pollen and nectar as well as the presence of refugia in complex habitats. Similar results have been reported to have had pest control management value (Root, 1973; Laster, 1974; Altieri, 1993). In these studies predator populations have also been enhanced, thus leading to reduction in pest populations.

Epigeal predators caught in the present study include carabids (Coleoptera), staphylinids (Coleoptera), coccinellids (Coleoptera), lycosid species 1, 2 and 3 (Araneida) (Leslie and Boreham, 1981), cornids (Araneida), oxyopids (Araneida), (Whitcomb, 1974,) *P. megacephala D. helvolus*, dermapterans, blattids and mites (Acarina) ((Whitcomb, 1974,) (Leslie and Boreham, 1981; Leslie, 1982; Scholtz and Holm, 1985; Ali and Reagan, 1985) Table 4). Amongst these, predator species from the families; Formicidae, Araneida, Blattidae and mites (Acarina) were reported to be the most frequent egg and larval predators of *E. saccharina* (Leslie and Boreham, 1981; Leslie, 1982). Thus, there was a diversity of predators that were caught during the course of this study. The efficacy of these predators in controlling *E. saccharina* is clarified in Chapter 6, where predator population fluctuations are contrasted against *E. saccharina* population fluctuations.

Amongst the Formicidae, *P. megacephala* and *D. helvolus* were notable, while the lycosids amongst araneids, were the most likely larval predators in Leslie and Boreham's (1981) and Leslie's (1982) studies. However, in addition to lycosids, araneid species belonging to the Oxyopidae were also caught in the present study. These belonged to the genus *Oxyopes,* which are known to either ambush or search for lepidopterous adult moths or larvae and other prey (Whitcomb, 1974). This behaviour justifies a detailed examination of *Oxyopes* populations in the present study, despite the fact that Leslie and Boreham (1981) and Leslie (1982) did not list them.

4.6.2. Sticky traps

Sticky trap results show that the total number of arthropods was lower, though not significantly so, in the sugarcane-bean intercrop when compared to control plot. Further, there were fewer arthropod species caught in sticky traps when compared to the pitfall trap captures. In particular, sticky traps were designed to monitor the activity of epigeal arthropods and foliage-associated arthropods at the base of the sugarcane stalk where *E. saccharina* oviposits. The lower sticky trap captures in the sugarcane-bean intercrop suggests that bean intercropping did not increase arthropod activity at the base of the stalk, despite the significantly higher epigeal arthropod abundance in the sugarcane-bean intercrop. Predators that were captured at the base of the sugarcane stalk included *P. megacephala*, *D. helvolus*, dermapterans, coccinellids and mites (Table 4). All these were also captured on the ground, with *P. megacephala* and mites also being captured on foliage. Literature reports on the influence of floral diversity on the activity of arthropods including predators, at the base of foliage, are scarce. However, these are all important predators of *E. saccharina* (Leslie and Boreham, 1981; Leslie, 1982). which are likely to influence the pest populations.

4.6.3 Suction trapping

As with the sticky traps, there was no significant difference in the total number of arthropods caught in suction traps in the sugarcane-bean intercrop and control plots, suggesting that bean intercropping did not influence the occurrence of foliage-associated arthropods. Lack of increased foliage-associated arthropod abundance in the intercrop in the present study, contradicts Ali and Reagan's (1985) findings, that floral diversification in sugarcane increases the abundance of both the epigeal (based on pitfall trap counts) and foliage-associated (based on suction and sweep net counts) arthropods. The possible reasons why beans failed to increase foliage-associated arthropods in the present study are discussed in the next chapter.

4.6.4 Important predatory arthropods

Of the arthropods that were caught on foliage with the suction trap, araneid species belonging to Salticidae, Philodromidae and Cyantholipidae; *P. megacephala*; mites; and Anthocorids (Heteroptera) were identified as predators (Whitcomb, 1974; Scholtz and Holm, 1985). Of these however, only *P. megacephala* and mites were also caught at the base of the sugarcane stalk where *E. saccharina* oviposits and eggs hatch, hence the populations of *P. megacephala*, *D. helvolus* and mites only will be examined.

In conclusion, it was established in this chapter that mites, *P. megacephala* and *D. helvolus* at the base of the sugarcane stalk, where *E. saccharina* oviposits and eggs hatch. Further, these groups are also reported in other studies (Leslie and Boreham, 1981; Leslie, 1982) to be frequent *E. saccharina* egg and larval predators.

It would be interesting to see how populations of *P. megacephala*, *D. helvolus* and mites.

- Fluctuated over the study period?;
- Which factors and how did they influence the predator populations?; and
- Where did these predators foraged, in terms of the sugarcane rows, bean rows and interrows between sugarcane and bean rows?

Chapter 5 attempts to answer these questions and the, relevance of mites, *P. megacephala* and *D. helvolus* in habitat management. Further, justification for detailed study of these predators is given.

CHAPTER 5

SEASONAL ABUNDANCE AND DISTRIBUTION OF ARTHROPOD PREDATORS

5.1 Introduction

Temperature was excluded as a possible reason for the decline in infestation levels during the first stages of the project (Chapter 4) because minimum temperatures were significantly warmer during the course of the study when compared to the LTM minimum temperatures. Warmer winter temperatures are known to accelerate *E. saccharina* development (Way, 1994). Similarly, the low rainfall that occurred during the months of August and September should have resulted in water stressed sugarcane, which is usually characterised by higher *E. saccharina* infestation (Anonymous, 1986). In contrast, infestation levels declined during this period and no *E. saccharina* larvae were recorded in the sugarcane-bean intercrop during September. These data suggest that other factors could be responsible for the decline *E. saccharina* infestation levels.

The seasonal abundance and distribution of selected predators are examined in this chapter, with the view of establishing if any one or the combination of two or more predators could have been responsible for the decline in *E. saccharina* populations.

5.2 Acarina

5.2.1 Seasonal abundance and distribution among plots

Pitfall traps

Epigeal Acarina were caught in markedly higher numbers in the roadway (14) in August and sugarcane-bean intercrop (15) in October (Figure 9). No Acarina were recorded during April of 1996 and 1997. Consistently lower numbers were recorded from the control plot when compared to either the roadway or sugarcane-bean intercrops.

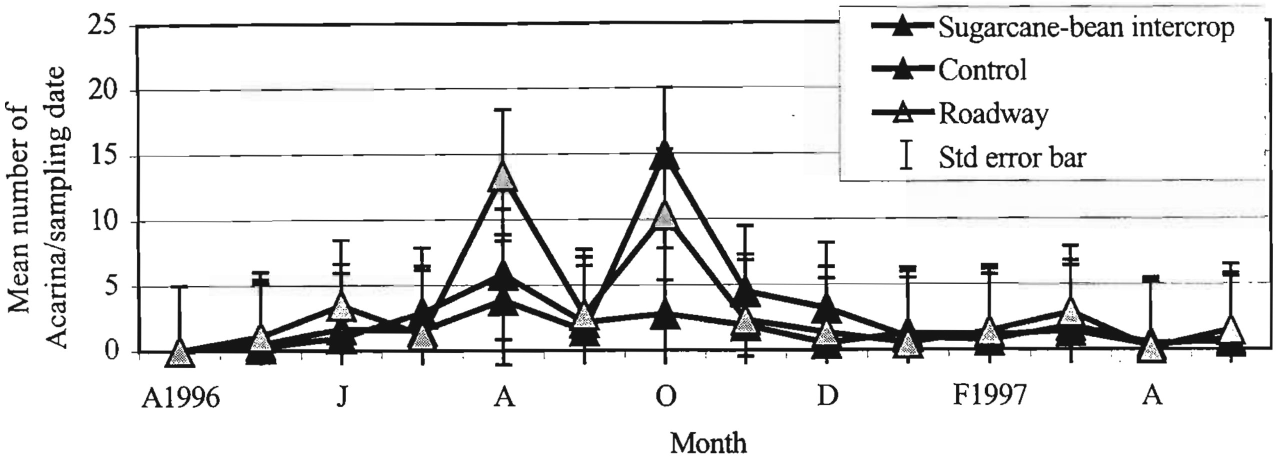

Figure 9. Mean number of Acarina caught in pitfall traps in the roadway, sugarcane-bean intercrop and control plots during the study perriod.

Sticky traps

Sticky trap captures of Acarina were higher in the sugarcane-bean intercrop during the months of June (6.2), February1997 (6.8) and May 1997 (8.2), while there were none recorded during the months of August September and October (Figure 10). Captures were higher in the control plot during the month of November 1996.

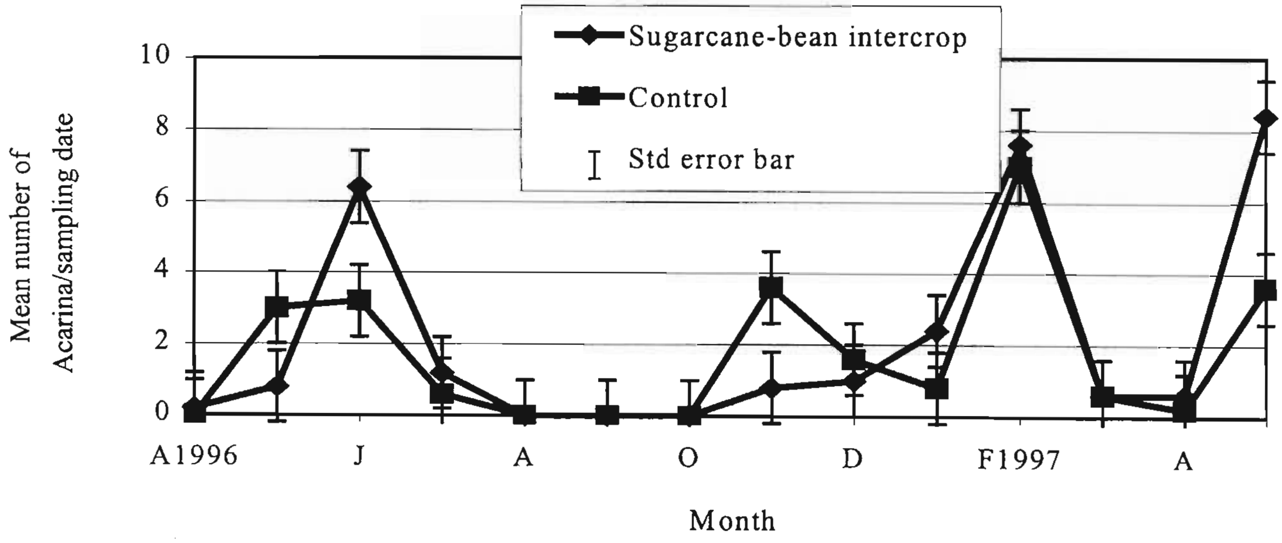

Figure 10. Mean number of Acarina caught in sticky traps in the sugarcan-bean intercrop and control plots during the study period.

Suction traps

On foliage, higher numbers were captured during the month of November (10.5) from the control plot (Figure 11). In addition, higher numbers of Acarina were caught in the control plot during the months of July (2.6) and August (2.5), while higher numbers were caught in the sugarcane-bean intercrop during the months of April of 1996 (1), June (2), and March (2.2).

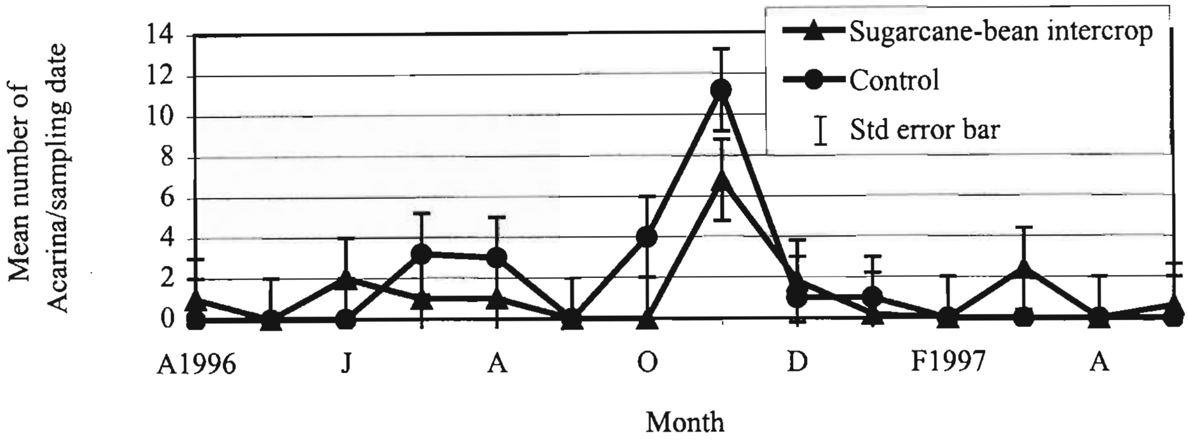

Figure 11. Mean number of Acarina caught in suction traps in the sugarcane-bean intercrop and control plots during the study period

However, with the exception of the month of November, the differences in Acarina numbers between the plots were not significant. No Acarina were caught on foliage during the months of May 1996, September, February and April 1997.

5.2.2 Distribution in the rows and interrows

During the month of October most epigeal Acarina in the sugarcane-bean intercrop were caught in the interrows (22) between sugarcane and bean rows followed by bean rows (17) and sugarcane rows (7.5) in that order (Figure 12). There were no marked differences in number of Acarina caught in sugarcane rows, bean rows and interrows during the other months. Low numbers of Acarina were caught in the sugarcane rows (6) and interrows (5.2)

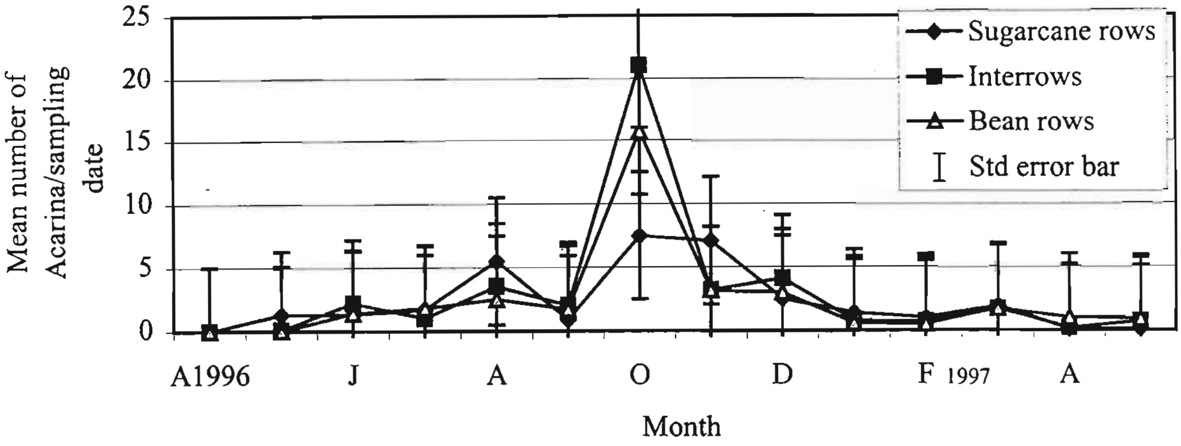

Figure 12. Mean number of Acarina caught in different habitats provided by the sugarcane-bean intercrop during the study period.

in the control plot when compared to those in the sugarcane-bean intercrop (Figure 13). There were no marked differences between the sugarcane rows and interrows.

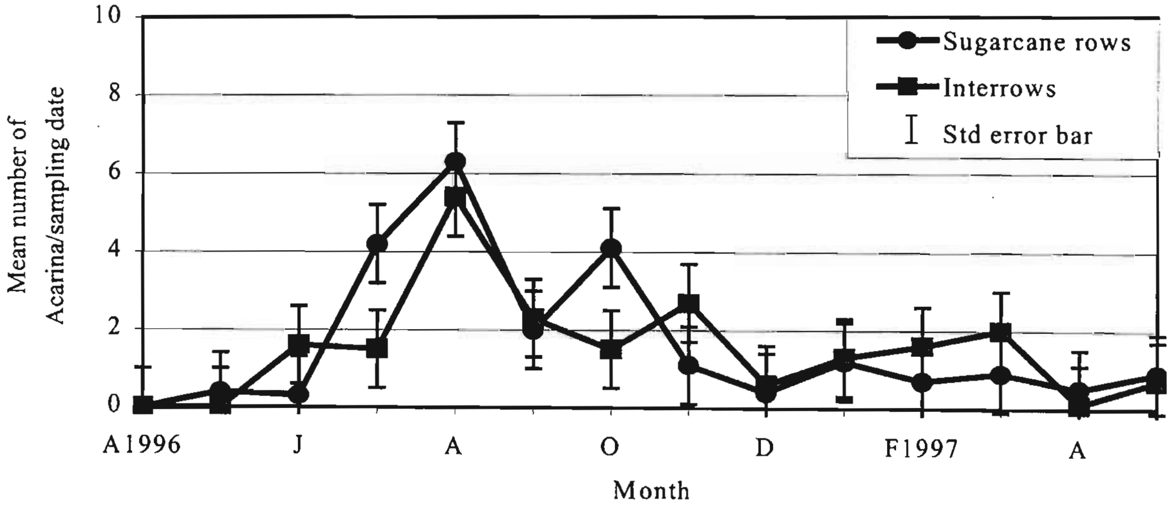

Figure 13. Mean number of Acarina caught in different habitats provided by sole sugarcane in the control plot during the study period.

5.2.3 Influence of environmental factors

Abiotic factors

Epigeal Acarina capture rate the ground was significantly affected by light intensity only, while rainfall significantly affected occurrence on foliage (Table 5). Higher numbers were caught at 205mm of rainfall, which fell during the month of July 1996 (Figure 4 in Chapter 4).

Table 5. Acarina caught in pitfall, sticky and suction traps from all sampling units, and the environmental factors influencing its capture rate. Asterisks indicate significance level of the influence. (** = 0.01 < P < 0.05 and *** = P < 0.01.)

	Factor	**Trap**	**Significance level**
Biotic factors	Weed density	Pitfall	**
		Sticky	
		Suction	
	Bean height	Pitfall	
		Sticky	
		Suction	
	Cane height	Pitfall	
		Sticky	
		Suction	
Abiotic factors	Light intensity	Pitfall	**
		Sticky	
		Suction	
	Rainfall	Pitfall	
		Sticky	
		Suction	***
	Temperature	Pitfall	
		Sticky	
		Suction	

The nature of variation did not allow determination of the effect of light intensity, except to indicate that its effect was significant.

Biotic factors

Of the biotic factors, only weed density significantly affected the capture rate of Acarina (Table 5). Most individuals were caught at 50% ground cover.

5.3 *Pheidole megacephala*

5.3.1 Seasonal abundance and distribution among plots

Pitfall traps

With the exception of December and February, consistently higher numbers (18) of epigeal *P. megacephala* were caught in the roadway (Figure 14). Relatively higher numbers were caught during the months of June in the roadway (17) and sugarcane-bean intercrop (7) and September in the roadway (12.5) Differences between the sugarcane-bean intercrop and control plots were not significant. Of all plots, roadway was the most preferred.

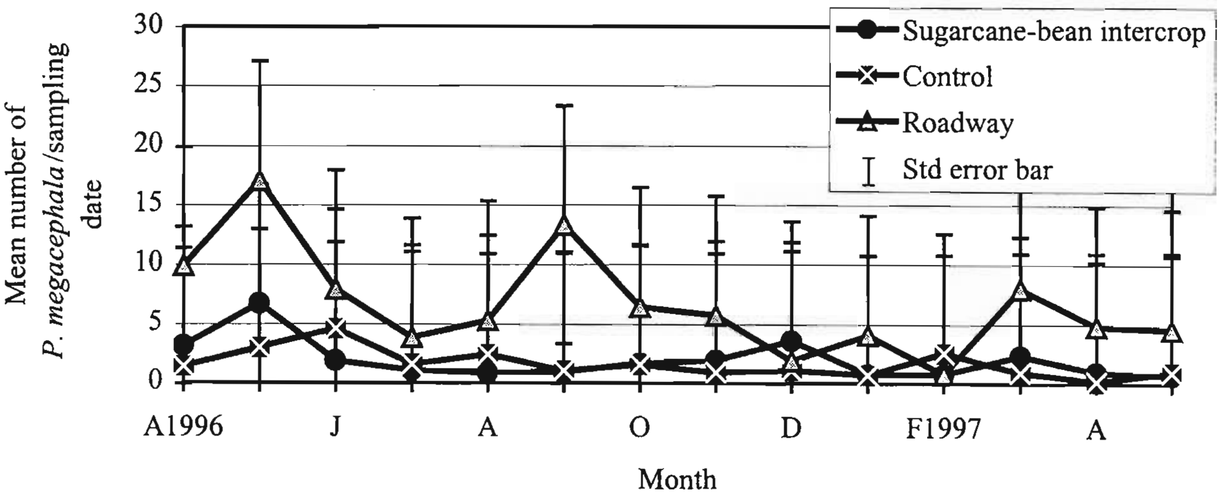

Figure 14. Mean number of *Pheidole megacephala* caught in pitfall traps from the sugarcane-bean, control and roadway plots during the study period.

Sticky traps

As on the ground, *P. megacephala* were significantly ($0.05 > P > 0.01$) most active at the base of the sugarcane stalk, during June and August in the control plot and March in the sugarcane-bean intercrop (Figure 15).

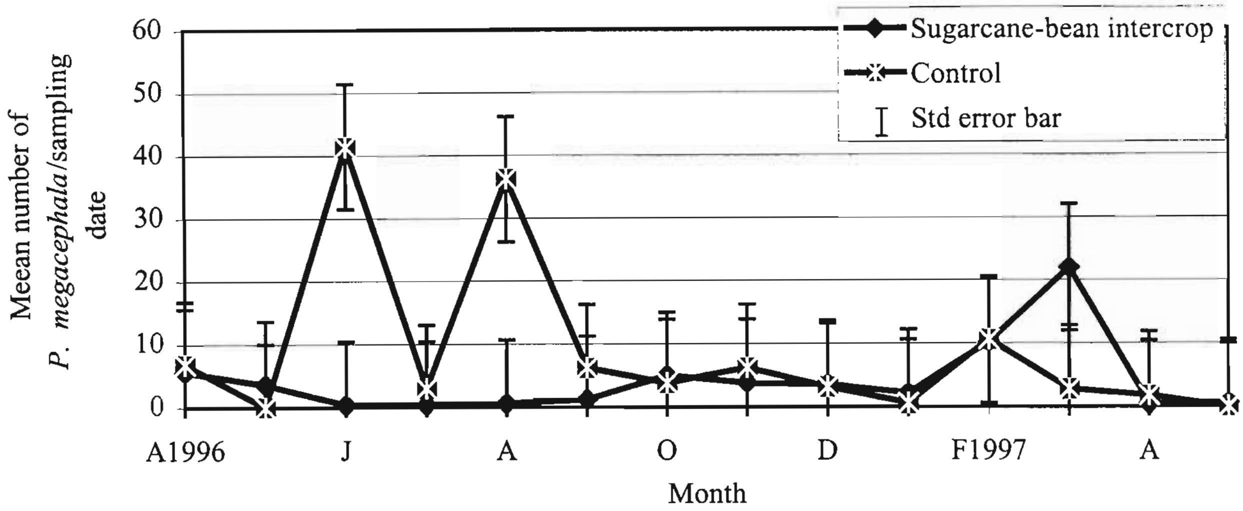

Figure 15. Mean number of *Pheidole megacephala* caught in sticky traps in the sugarcane-bean intercrop and control plots during the study period.

Suction traps

Few *P. megacephala* (2) were caught on foliage in both plots (Figure 16). In the control plot *P. megacephala* occurred in three samples (September 1996, October 1996 and May of 1997) only during the entire sampling period. Significantly higher numbers were caught in the sugarcane-bean intercrop during the month of May 1996, while higher numbers occurred in the control plot during the months of September and May of 1997 (Figure 16).

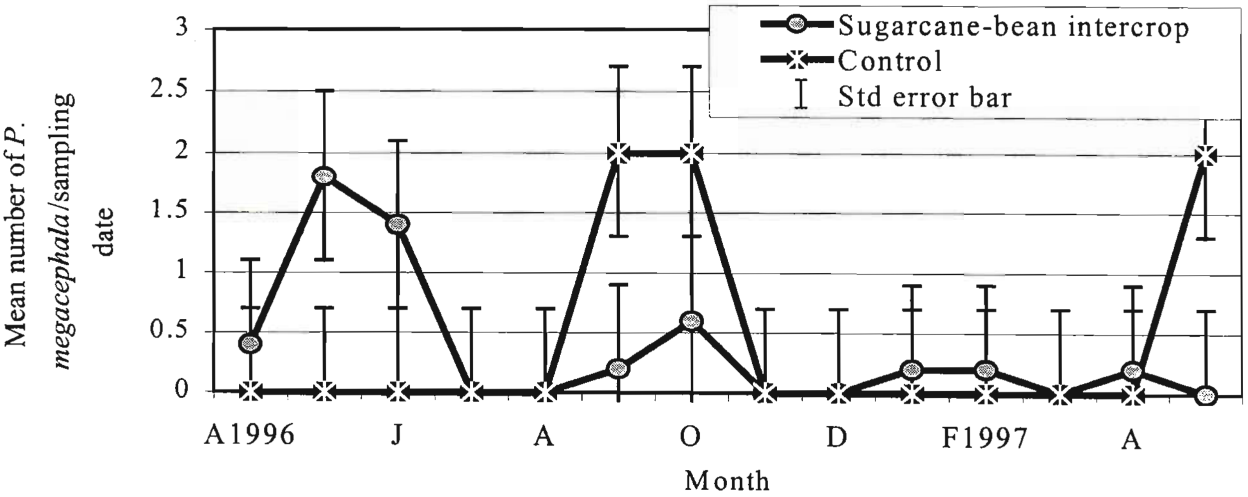

Figure 16. Mean number of *Pheidole megacephala* caught in suction traps in the sugarcane-bean intercrop and control plots during the study period.

5.3.2 Distribution in the rows and interrows

In the sugarcane-bean intercrop, high numbers of *P. megacephala* were caught in sugarcane rows and interrows during the month of May 1996 and in bean rows during the month of December 1996 (Figure 17).

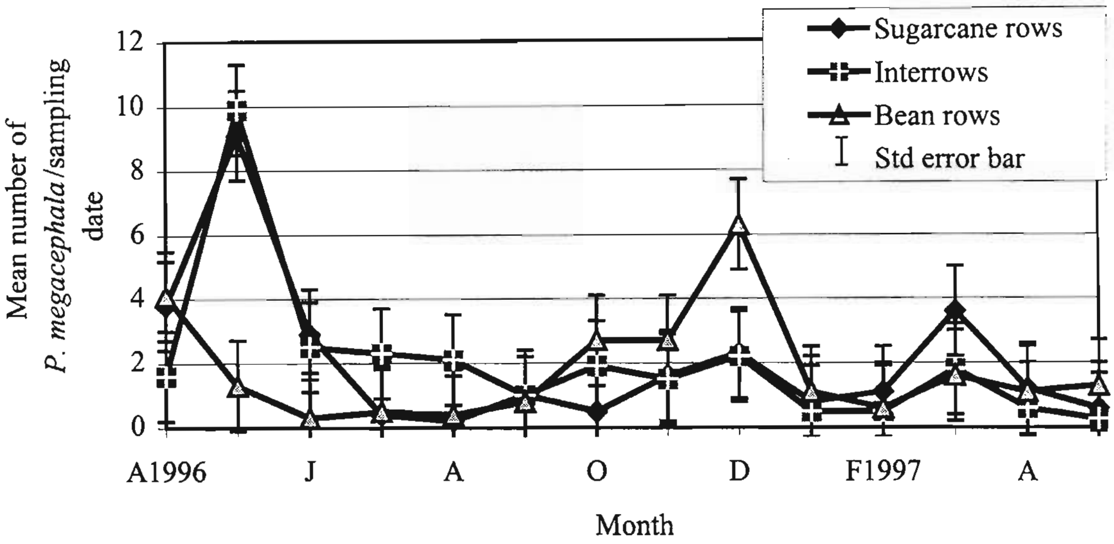

Figure 17. Mean number of *Pheidole megacephala* caught in different habitats provided by the sugarcane-bean intercrop during the study period.

In the control, *P. megacephala* was caught in higher numbers in the sugarcane rows during the months of June and August. No significant difference was observed between the sugarcane rows and interrows (Figure 18).

5.3.3 Influence of environmental factors

Abiotic factors

Light intensity, rainfall and temperature significantly affected the capture rate of epigeal *P. megacephala*, while light intensity and temperature only affected its capture rate on foliage (Table 6).

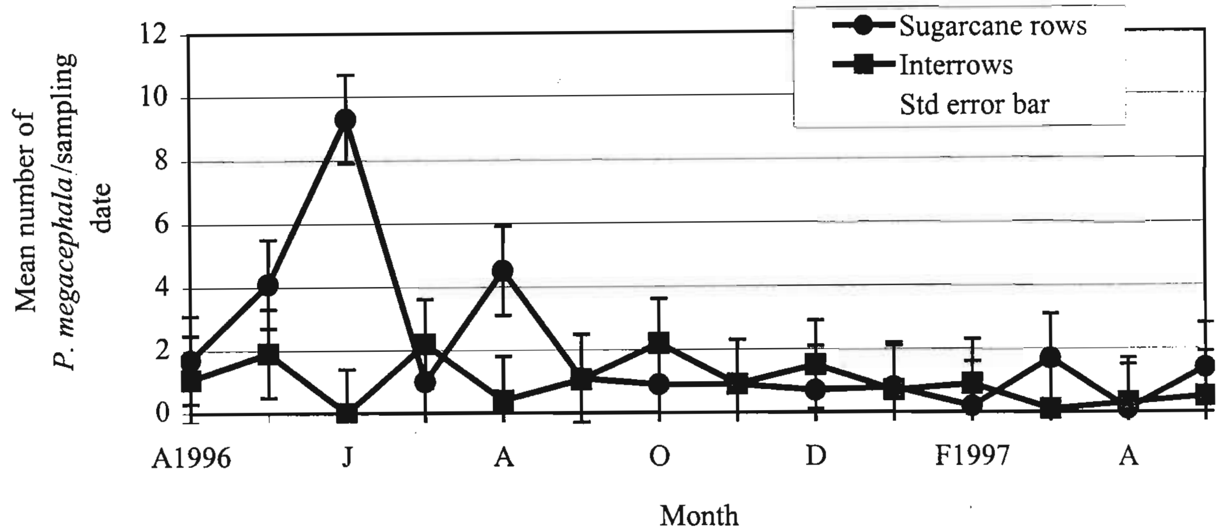

Figure 18. Mean number of *Pheidole megacephala* caught in different habitats provided by sole sugarcane in the control plot during the study period.

Higher numbers of *P. megacephala* were caught when no rainfall was recorded and in the 18^0 C to 20^0 C temperature range.

Biotic factors

The capture rate of *P. megacephala* was significantly affected by weed density only. Most individuals were caught at 100% ground cover (Table 6).

5.4 *Dorylus helvolus*

5.4.1 Seasonal abundance and distribution among plots

Pitfall traps

Figure 19 shows the mean number of *D. helvolus* caught in pitfall traps during the sampl;ing period. Epigeal *D. helvolus* were caught in significantly (P < 0.01) higher numbers in the roadway (25, 20 and 52) during the first three months, November 1996 (32), January 1997 (20), April (25) and May 1996 (35) and in the sugarcane-bean intercrop in April 1996 (24) and April 1997 (12).

Table 6. *Pheidole megacephala* caught in pitfall, sticky and suction traps from all sampling units and the environmental factors influencing its capture rate. Asterisks indicate significance level of the influence. (** = 0.01 < P < 0.05 and *** = P < 0.01.)

	Factor	**Trap**	**Significance Level**
Biotic factors	Weed density	Pitfall	***
		Sticky	***
		Suction	
	Bean height	Pitfall	
		Sticky	
		Suction	
	Cane height	Pitfall	
		Sticky	
		Suction	
Abiotic factors	Light intensity	Pitfall	***
		Sticky	
		Suction	***
	Rainfall	Pitfall	***
		Sticky	
		Suction	
	Temperature	Pitfall	***
		Sticky	
		Suction	**

D. helvolus were more common in the roadway from April until June (50) (Figure 19), and

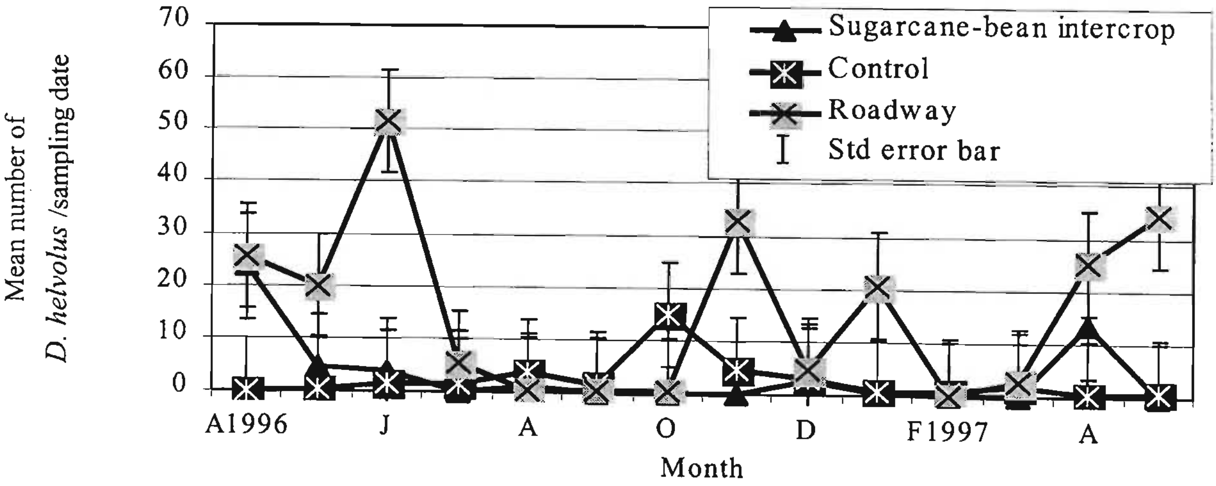

Figure 19. Mean number of *Dorylus helvolus* caught in pitfall traps from the sugarcane-bean intercrop, control and roadway plots during the study period.

again in November (31) and January 1997 (20). In April and May 1997 they were most common again, as was recorded during the same months in 1996 (Figure 19). They were also common foragers in the sugarcane-bean intercrop in April 1996 (24) but population dropped to below 5 for the rest of the sampling period until the following April (12).

It would seem that the control plot was least preferred by *D. helvolus*, least individuals being caught there, except in October 1996 (13) (Figure 19).

Abundance records show that there is a definite seasonality in *D. helvolus* foraging activity, with peaks being recorded in the autumn months (April to June and in spring October, November; Figure 19).

Sticky traps

While there were no *D. helvolus* individuals caught on foliage, there were few (4.6) that were caught at the base of the sugarcane stalk in the sugarcane-bean intercrop. As was recorded on the ground *D. helvolus* was most active in the sugarcane-bean intercrop, at the base of the sugarcane stalk, during the autumn month of April 1997 (Figure 20).

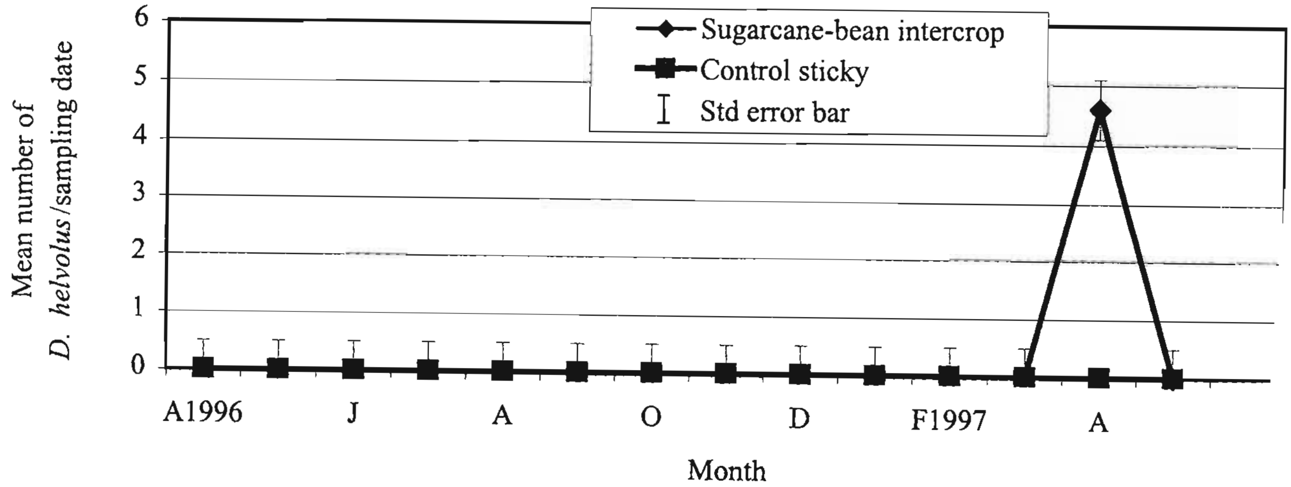

Figure 20. Mean number of *Dorylus helvolus* caught in sticky traps in the sugarcane-bean inetrcrop and control plots during the study period.

5.4.2 Distribution in the rows and interrows

As the sugarcane-bean intercrop had high populations of *D. helvolus* (Figure 19) it was important to see where they were actually foraging. Higher numbers of *D. helvolus* were caught in the bean rows during the months of April (28), May (70) and November 1996 (100); Figure 21). The high autumn (April to June 1996) captures in bean rows coincided with the presence of the growing bean crop in the sugarcane-bean intercrop during the same period (Figure 5). Again higher numbers were caught in the sugarcane rows of the sugarcane-bean intercrop during the months of November 1996 (70) and April 1997 (60). There were fewer (7) *D. helvolus* caught in the interrows of the sugarcane-bean intercrop, when compared to sugarcane and bean rows, throughout the sampling period (Figure 21).

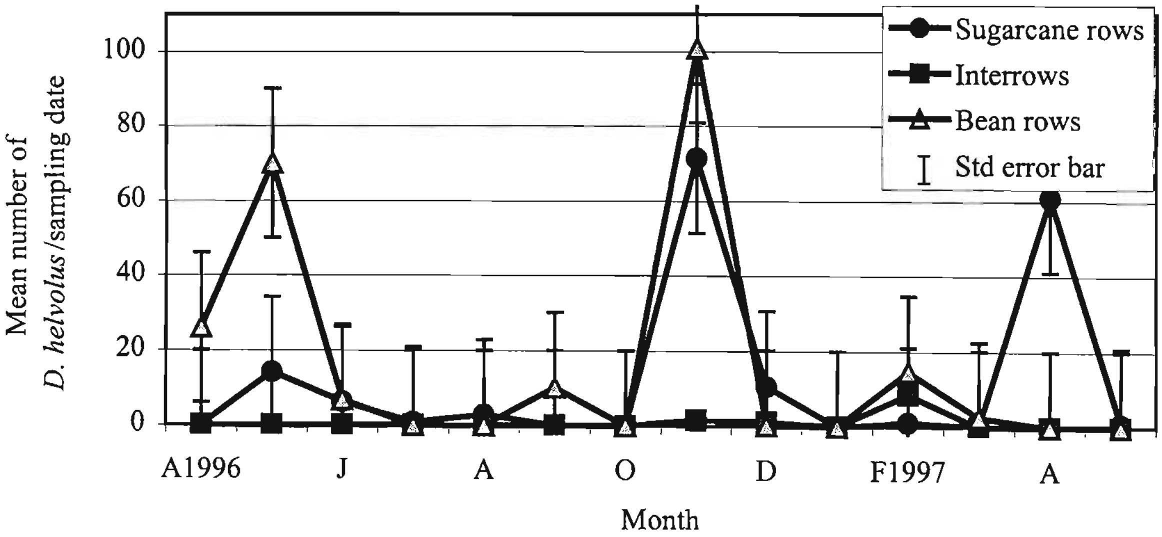

Figure 21. Mean number *Dorylus helvolus* caught in different habitats provided by the sugarcane-bean intercrop during the study period.

Low numbers of *D. helvolus* were caught in the sugarcane rows (mean ≤ 28) and interrows (mean ≤ 35) of the control plot when compared to the sugarcane and bean rows of the sugarcane-bean intercrop (Figure 22). Slightly higher numbers were caught in the interrows of the control plot during the month of April of the first season and in sugarcane rows during April of the second season.

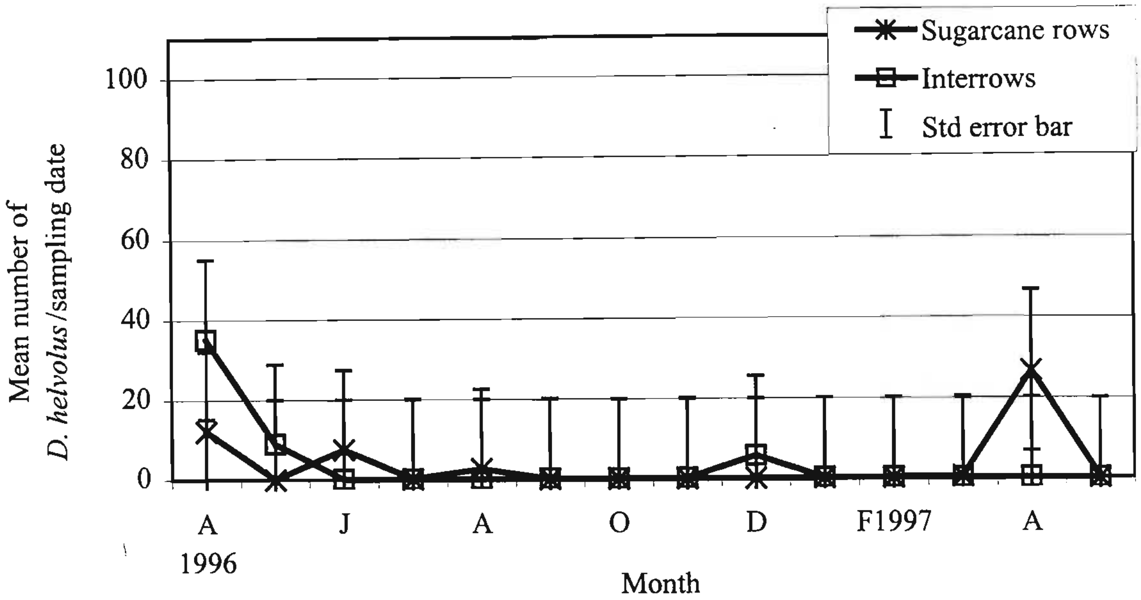

Figure 22. Mean number of *Dorylus helvolu*s caught in different habitats provided by sole sugarcane in the control plot.

5.4.3 Influence of environmental factors

Abiotic factors

As with *P. megacephala*, light intensity, rainfall and temperature significantly affected the capture rate, on the ground, of *D. helvolus*. Highest numbers were caught when 205mm rainfall were recorded and at temperatures ranging between 19.75^0C to 20.86^0C. However, neither of these factors affected occurrence at the base of the sugarcane stalk (Table 7).

Biotic factors

Weed density only significantly affected the capture rate of *D. helvolus* with most individuals being caught in 50% ground cover.

Table 7. *Dorylus helvolus* caught in pitfall, sticky and suction traps from all sampling units and the environmental factors influencing its capture rate. Asterisks indicate significance level of the influence. (** = $0.01 < P < 0.05$ and *** = $P < 0.01$. NC = not caught with the trap.)

	Factor	**Trap**	**Significance Level**
Biotic factors	Weed density	Pitfall	***
		Sticky	
		Suction	NC
	Bean height	Pitfall	
		Sticky	
		Suction	NC
	Cane height	Pitfall	
		Sticky	
		Suction	NC
Abiotic factors	Light intensity	Pitfall	**
		Sticky	
		Suction	NC
	Rainfall	Pitfall	***
		Sticky	
		Suction	NC
	Temperature	Pitfall	**
		Sticky	
		Suction	NC

5.5 Discussion

5.5.1 Acarina

Seasonal abundance and distribution among plots

Epigeal Acarina were most active during the autumn months of August and October 1996. Literature on the biology of Acarina deals with specific families, genera and species, while Acarina caught in the present study were not identified further than the order level. It was thus difficult to ascertain whether Acarina seasonal abundance observed in this study result from intercropping or the natural life cycles of the species involved. Whitcomb (1974) makes the point that lumping families, genera and species of related animals and treating them as a single entity may be misleading, since each species has its own niche. Acarina is no exception to this.

Leslie (1982) identified three species of Acarina (as type 1 to 3) as some of the most frequent *E. saccharina* egg predators. It is not clear from Leslie's (1982) study what sampling technique was used to collect these predators, however. Acarina caught from the roadway during the month of August and in the sugarcane-bean intercrop during the month of October, with the pitfall traps, made up most of the Acarina caught in the present study. In addition, significantly ($P < 0.01$) higher numbers were caught with pitfall traps in the sugarcane-bean intercrop when compared to the control plot during the month of October, suggesting a positive response to habitat diversity there.

Further, sticky trap captures in the sugarcane-bean intercrop were higher during the months of June, November and February. This suggests that increased habitat diversity through bean intercropping may have influenced population activity at the base of the sugarcane stalk during these periods. This has important implications for *E. saccharina* control only if the assumption that the Acarina predators identified by Leslie (1982) were amongst the Acarina that were active at the base of the sugarcane stalk, as this is where *E. saccharina* oviposits and where eggs hatch.

Distribution in the rows and interrows

There were no marked differences in Acarina numbers caught in sugarcane and in the bean rows, and interrows between them. It would seem therefore that Acarina did not preferentially forage in any of these habitats, thus contradicting the observations made at the base of the sugarcane stalk, where markedly higher foraged were found in the intercrop. Lack of preferential foraging among habitats suggests that bean intercropping did not enhance Acarina foraging activity along sugarcane rows where *E. saccharina* activity is concentrated. However, it is probable that appropriate identification of Acarina to at least the generic level and an examination of the predacious ones, could yield different results. In other words, predacious Acarina amongst those that were caught in the present study, could have foraged in the sugarcane rows, but grouping different species together and treating them as a single entity may have obscured preferential foraging by predacious Acarina.

Influence of environmental factors

Abiotic factors

Of the abiotic factors only light intensity significantly affected the capture rate of Acarina caught in pitfall traps, while there was no significant effect on Acarina caught in sticky and suction traps. However, it was not possible to establish the nature of the effect of light intensity because light intensity records varied greatly with cloud movement on windy days. Shading, which is related to light intensity, is likely to have influenced the activity of some Acarina. Rainfall significantly affected the capture of Acarina in suction traps. Most individuals of Acarina were caught in suction traps at high rainfall during the month of June, suggesting a positive response to rainfall (Johnson, 1969).

Biotic factors

Weed density was the only biotic factor that significantly affected the capture rate of Acarina in pitfall traps. Most individuals were caught at 50% ground cover, suggesting that Acarina positively respond to moderate ground cover.

5.5.2 *Pheidole megacephala*

Seasonal abundance and distribution among plots

With the exception of the month of December and February, epigeal *P. megacephala* were caught in consistently higher numbers in the roadway. However there were no significant differences among the plots. Better ground cover on the natural vegetation by the roadway provided higher humidity conditions near the ground as well as other microhabitats that offered refugia (van Emden, 1990) to *P. megacephala*, thus contributing to the consistently higher numbers there.

P. megacephala was most active at the base of the sugarcane stalk during the months of June, August 1996 and 1997. The opportunistic (Broekhuysen, 1941) and polyphagous (Showler *et al.* 1990) nature of *P. megacephala* made its capture rate in sticky traps erratic. Capture of other animals on those traps greatly influenced the presence *P. megacephala,* since on several occasions *P. megacephala* was observed feeding on gryllids and lizards caught on sticky traps. This factor made it difficult to make any inferences about the effect of bean intercropping on *P. megacephala* population activity at the base of the sugarcane stalk.

No significant difference in epigeal *P. megacephala* numbers between the sugarcane-bean intercrop and control plots was observed. The same was also true for those caught on foliage and at the base of the sugarcane stalk, thus suggesting that bean intercropping did not affect the population size. Instead, diversity that is greater than two intercropped crops such as sugarcane and beans in the present study could have been required to positively affect the *P. megacephala* populations. Or, greater groundcover in addition to diversity, as was observed on the roadway (Figure 6, Chapter 4) could be another factor that is required to improve the activity of *P. megacephala* in sugarcane. Conlong (1995) and van Emden (1990) have demonstrate that greater groundcover and floral diversity increase the activity of predatory arthropods

Distribution in the rows and interrows

P. megacephala numbers were markedly higher in the sugarcane rows and interrows in the sugarcane-bean intercrop during the month of May 1996. The occurrence of *P. megacephala* in those habitats coincided with the presence of the growing bean crop and high *E. saccharina* numbers (Chapter 4) in the sugarcane-bean intercrop, which declined thereafter. It is suggested that the presence of *E. saccharina* attracted *P. megacephala* during this period, thus confirming Leslie and Boreham's (1981) observation that *P. megacephala* is an important *E. saccharina* larval predator. In addition, the bean crop that was present during this time provided the necessary ground cover and vegetation diversity that is important for increasing predator activity (van Emden, 1990; Whitcomb, 1974). Similarly a peak in *P. megacephala* numbers during March 1997, followed an *E. saccharina* peak during February, thus suggesting a predator/prey relationship (Stephens and Krebs, 1986)

Influence of environmental factors

Abiotic factors

Light intensity, rainfall and temperature significantly affected the capture rate of *P. megacephala* in pitfall traps, suggesting that abiotic in addition to biotic factors (such as floral diversification) are important in determining the distribution of *P. megacephala* in sugarcane. Similarly, light intensity and temperature significantly affected *P. megacephala* capture rate in suction traps. Most individuals were caught at lowest rainfall, which fell during the month of September. This seems to indicate that rainfall influenced *P. megacephala* movement. Broekhuysen (1941) notes that *P. megacephala* invade houses when there are frequent rainfalls.

On the other hand, most individuals were caught at temperatures ranging from 18^0C to 21^0C during the months of May 1996, September and March. This, suggests that climate influenced *P. megacephala* seasonal abundance.

Biotic factors

Of the biotic factors weed density was the only one that affected the capture rate of *P. megacephala* in pitfall and sticky traps. Most individuals were caught at 100% ground cover, which occurred, on the roadway. Further, the vegetation on the roadway was comprised of a mixed grass sward. The influence of weed density on the capture rate of *P. megacephala* confirmed the notion that the availability of microhabitats and higher humidity conditions in dense vegetation result in greater predator stability as outlined by van Emden (1990).

5.5.3 *Dorylus helvolus*

Seasonal abundance and distribution among plots

As with *P. megacephala* on the roadway, epigeal *D. helvolus* was caught in consistently higher numbers in all the months, except August and February. This suggests that the same factors, such as ground cover, vegetation diversity, light intensity, rainfall and temperature are operational in influencing the populations of both formicids there. Populations increase with increasing ground cover and diversity and with decreasing rainfall. Further, numbers of *D. helvolus* caught in the sugarcane-bean intercrop with pitfall traps were significantly higher when compared to the control plot. *D. helvolus* is known to have a migrant habit, which makes its capture erratic (Samways, 1983). In the present study, often none would be present and then in one trap up to 400 individuals of *D. helvolus* were caught, thus confirming the notion of the erratic nature of its appearance. Despite *D. helvolus'* migrant habit, which made it erratic in its appearance in traps, its populations appear to be influenced by differences in habitats, as indicated by consistently higher numbers in the roadway and significantly higher numbers in the sugarcane-bean intercrop compared with the control plot. Bean intercropping may, therefore have attracted *D. helvolus* into the sugarcane-bean intercrop, as indicated by its higher numbers in the sugarcane rows of the sugarcane-bean intercrop during the first three months of sampling (which coincide with the presence of beans there). The April 1997 peaks in the pitfall and sticky trap captures, however, are unlikely to be directly related to bean intercropping, as they occurred nine months after the disappearance of bean crop. Other abiotic and biotic factors, which are dealt with below, may have influenced *D. helvolus* populations during these times.

The higher *D. helvolus* numbers in the sugarcane-bean intercrop during the first three months of sampling also coincide with higher numbers of *E. saccharina* in the bean-intercrop (Chapter 4). Although *E. saccharina* numbers were low (less than ten per 100 stalks) for appreciable larval predation (Leslie and Boreham, 1981), it is probable that *D. helvolus* was responsible for the decline of the pest after that period.

Distribution in the rows and interrows

Bean rows were the most preferred habitat during the months of April, May, September and November 1996, suggesting a positive response to presence of the bean crop. Sugarcane rows of the sugarcane-bean intercrop were the next most preferred habitat, while there were no marked differences between sugarcane rows and interrows in the control plot. Thus, it would seem that *D. helvolus* was attracted by the bean crop to the sugarcane field also foraged in the sugarcane rows. As with *P. megacephala, D. helvolus* peaks closely coincided with *E. saccharina* peaks, suggesting a similar functional response to increasing *E. saccharina* numbers. However, *D. helvolus* is recognised widely as a larval predator of *E. saccharina*, while *P. megacephala* is recognised as an egg predator (Leslie, 1982; Leslie and Boreham, 1981). Leslie and Boreham (1981) emphasise the importance of epigeal predators, such as lycosids in preying upon dispersing *E. saccharina* larvae. Thus, paucity of *D. helvolus* at the base of the sugarcane stalk, while it was abundant on the ground does not necessarily reduce its importance in *E. saccharina* control. Experiments on the dispersal behaviour of *E. saccharina* larvae have revealed that larvae disperse to distances of up 1.6m over a four day period after eclosion (Anonymous, 1991). They therefore become vulnerable to predators during this period, which is when epigeal *D. helvolus* could be important in *E. saccharina* control.

Influence of environmental factors

Abiotic factors

As with *P. megacephala* light intensity, rainfall and temperature significantly affected the capture rate of *D. helvolus* in pitfall traps. However, most *D. helvolus* individuals were caught at the second highest rainfall, which fell during the month of June, while *P. megacephala* was caught at lowest rainfall. This suggests that while the two formicids respond similarly to similar changes in their environment, their response to rainfall differs with *D. helvolus* responding a positively to rainfall. This varied formicid response to rainfall is important because *E. saccharina* populations also vary with rainfall. For instance, the pest is known to thrive in water stressed (during drought) sugarcane (Anonymous, 1986). On the other hand, most individuals of *D. helvolus* were caught at temperatures ranging from 18^0C to 21^0C. This suggests that seasonal abundance of *D. helvolus* was influenced by climatic conditions.

Biotic factors

Of the biotic factors weed density was the only one that affected the capture rate of *D. helvolus* in pitfall traps. Most individuals were caught at 50% ground cover, thus confirming the hypothesis that the availability of microhabitats and higher humidity conditions in dense vegetation (van Emden, 1990), lead to increased arthropod populations.

5.5.4 Predators that are likely to feed on *E. saccharina*

In Chapter 5 predators that foraged at the base of the sugarcane stalk, where *E. saccharina* oviposits and eggs hatch, were selected for further examination of their populations. These predators were Acarina, *P. megacephala* and *D. helvolus*. Following examination of these predator populations it may be useful to evaluate the likelihood of any of the three being a suitable *E. saccharina* predator. Based on a literature survey and within the context of the present study, an examination of the likelihood of any of these selected predators being suitable *E. saccharina* predator is presented.

Ehler (1990) citing many other authors, states that general predators identified as major biological control agents, particularly in short-term or disturbed environments, tend to display the following attributes:

- Colonising ability, which allows the natural enemy to keep pace with the spatial and temporal disruptions of the habitat;

- Temporal persistence, such that the predator (following colonisation) maintains its population, even in the absence of target pest species; and
- Opportunistic feeding habits, which permit the predator to rapidly exploit a food resource, such as a pest population.

A predator that meets the last two attributes is often polyphagous (Ehler, 1990). Formicids are usually such predators (Ali and Reagan, 1985). Prins *et al.*, (1990) report that while *P. megacephala* and *D. helvolus* are predatory they also feed on vegetation. *P. megacephala* for example, apparently attracted by the high sugar content, causes damage to chicory plants, while *D. helvolus* causes damage to potato and dahlia tubers (Prins *et al.*, 1990). The known biological control attributes of *P. megacephala* are that it preys on the diapausing larvae of the sorghum stemborer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) and pupae of the red bollworm *Diparopsis castanea* (Hmpsn.) (Lepidoptera: Noctuidae) (Prins *et al.*, 1990). Further, *P. megacephala* destroys the eggs of *E. saccharina* (Leslie, 1982). *Dorylus* sp. raiding workers, on the other hand, are known to forage in subterranean tunnels and cavities, beneath rocks and organic debris, and in the surrounding vegetation to heights of several meters (Gotwald, 1974). In addition, they prey on a wide range of animals, which include insects, chilopods and arachnids (Gotwald, 1974). Insects, and lepidopterans in particular, are the most preferred prey animals (Gotwald, 1974).

Thus, these two formicid species caught at the base of the sugarcane stalk in the present study, meet the last two attributes of a useful predator outlined by Ehler (1990). Further, they are able to build up their populations following habitat disturbance, such as burning of sugarcane before harvest, which took place in the study field. This is indicated by the fact that they were caught in relatively higher numbers in all sampling plots, with *D. helvolus* being the most dominant epigeal arthropod in many plots and *P. megacephala* the next most dominant. This further suggests that they also meet the first attribute of a useful predator.

Many species of predatory mites are specialist, rather than generalist predators (Whitcomb, 1974), This precludes them as good predators according to Ehler (1990). In the present study mites, dermapterans and coccinellids were not identified beyond the order level while literature deals with specific predacious families, genera and species. Consequently, an objective determination as to whether or not those caught in this study are good predators was not possible. The same was also true for dermapterans. However, on the strength of Leslie's (1982) results, which indicated *E. saccharina* egg predation by mites and not dermapterans and coccinellids, the populations of mites only was examined.

A further point arising out of seasonal occurrence of all three selected predators were peaks in their populations that coincided with *E. saccharina* peaks. There were two peaks, the first occurred during the first four months of sampling and the second during the last four months. These peaks in predator and prey populations suggest that there was a predator positive response to prey population build up. Thus, although the two formicid predators are generalists predators (Prins *et al.*, 1990; Gotwald, 1974) it is probable that they kept *E. saccharina* numbers under control. The next chapter examines the impact of the combination of predators on *E. saccharina* populations.

CHAPTER 6

SUMMARY AND RECOMMENDATIONS

6.1 Introduction

The seasonal variations in *E. saccharina* and selected predator populations over the study period have been shown in the preceding chapters. The effects of the environmental factors influencing the variations in these populations were also shown. Some individual predator populations have also been shown to peak when *E. saccharina* populations peaked, suggesting a predator/prey relationship. In order to establish whether or not the combination of all selected predators had an impact on *E. saccharina* seasonal variations, seasonal variations in the complex of selected predators is contrasted with variations in *E. saccharina* populations in this chapter.

Lack of increased general arthropod populations on foliage was shown in Chapter 5. This was despite the significantly higher numbers of epigeal arthropods in the sugarcane-bean intercrop. There was also a lack of flying predators that foraged at the base of the sugarcane stalk. These observations indicate that the bean crop did not have an effect on foliage associated arthropods. Possible reasons for the failure of the bean crop to attract arthropods on foliage are discussed below.

6.2 *Eldana saccharina* infestation and seasonal occurrence of selected predators.

Shown in Figure 23 are seasonal fluctuations in the sum of selected predators (Acarina, *P. megacephala* and *D. helvolus*) and *E. saccharina* in the sugarcane-bean intercrop. There was a concurrent decline in predator and *E. saccharina* populations from the beginning of the project to the month of September. However, there was an increase in predator population in October, which decreased again until January. The last peak in predator populations occurred during the month of March, whereafter populations decreased until the end of the project. *E. saccharina* populations peaked, after the initial decline, during the months of October, February and May 1997. The concomitant predator and *E. saccharina* population decline at the beginning of the project suggest a predator-prey relationship in the sugarcane-bean intercrop, so that predators were most likely responsible for *E. saccharina* decline during this period.

However, the functional response, that is the relationship between prey density and number of prey attacked, is not always linear (O'Neil, 1989). O'Neil (1989) argues that the most common functional response of an arthropod predator is nonlinear and reaches a plateau where the number of attacks remained essentially constant. The time needed to capture, quell, consume and digest prey (collectively known as the handling time) limits the number of prey a predator can attack, thus resulting in a nonlinear response. This means that the predator-prey relationship is not a stable one under a nonlinear functional response.

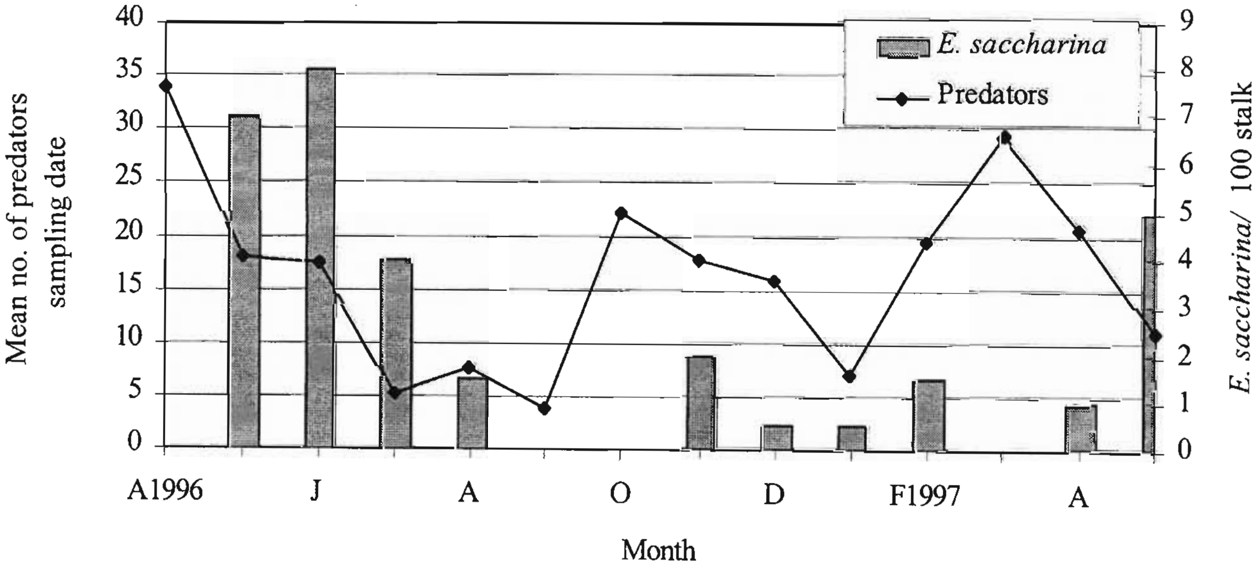

Figure 23. Mean monthly number of all selected predators, superimposed over monthly *E. saccharina* populations in the sugarcane-bean intrecrop during the study period.

Therefore, the observed disparities in seasonal fluctuations of combined predator and *E. saccharina* populations in the sugarcane-bean intercrop from September 1996 onwards is still a characteristic of a predator-prey relationship.

In agricultural systems, according to O'Neil (1989), a predator's functional response is commonly the reason for that predator's failure to contain pest density below economic thresholds. Therefore, thorough knowledge of the predator's functional response is required in order to predict the its efficiency. Also, the time-lag in the production of offspring by both the predator and prey needs to be taken into account as impacts on the predator-prey relationship (O'Neil, 1989).

Figure 24 shows seasonal fluctuations in the sum in selected predators (Acarina, *P. megacephala* and *D. helvolus*) and *E. saccharina* in the control plot.

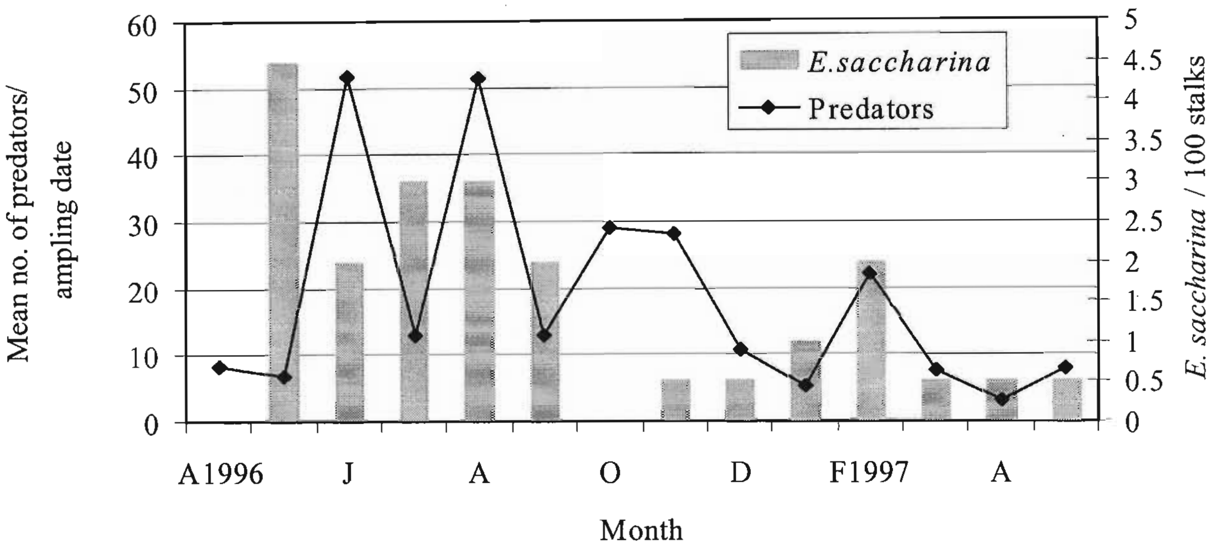

Figure 24. Mean monthly number of all selected predators, superimpopsed over monthly *E. saccharina* populations in the control plot during the study period.

Predator populations fluctuated greatly in the control plot during the initial decline in *E. saccharina* populations, resulting in two peaks, one in June and the other in August. There were increases in predator populations in the control plot during the months of October, November and February.

Unlike in the sugarcane-bean intercrop, there was no predator population decline accompanying the *E. saccharina* decline at the beginning of the project, instead there were great fluctuations in combined predator populations. This suggests lack of stability in predator population resulting from lack of floral diversity in the control plot.

6.3 Conclusions and management recommendations

The stages in the life cycle of *E. saccharina*, which feed on sugarcane and also the age of sugarcane which becomes more vulnerable to *E. saccharina* attack, are important factors in determining the efficacy of the companion crop that be intercropped with sugarcane. This section deals with the *E. saccharina* biology as it pertains to its life in sugarcane, successes and failures shown by the bean crop in the context of pest control, alternatives to bean crop and intercropping within Integrated Pest Management (IPM).

6.3.1 *E. saccharina* biology in sugarcane

E. saccharina larvae penetrate the sugarcane stalk when they are sufficiently robust, about 10 days after hatching (Betbeder-Matibet, 1981). The larvae feed on sugarcane until they pupate (Carnegie 1974). The larval period varies between 20 to 60 days (Carnegie, 1974). This variation in larval period is within individuals as well as between seasons (Carnegie, 1974). While all stages of the sugarcane are subject to *E. saccharina* attack (Carnegie and Smaill, 1982), it seems as though most damage occurs when nodes have been formed and sucrose synthesised (Betbeder-Matibet, 1981). Attack by the borer reduces the sucrose content and purity of the juice extracted (Betbeder-Matibet, 1981). Invasion of the sugarcane internode by pathogenic agents is also facilitated by *E. saccharina* attack (Betbeder-Matibet, 1981). Some of these pathogenic agents facilitate inversion of sucrose into glucose (Betbeder-Matibet, 1981). Contrary to expectation, in both the sugarcane-bean intercrop and control plots highest *E. saccharina* infestation occurred during the first three months of sugarcane stalk sampling for pest infestation in the present study (Figures 23 and 24). Sugarcane was five to nine months old during this period. However, these infestation levels were low (below 10 per 100 stalks) for any appreciable predation (Leslie and Boreham, 1981) to have occurred. Further, there was a marked decrease in infestation as the study progressed, so that there were no larvae collected during the month of October 1996, thus suggesting some pest population suppression. Predators may have been responsible for the decline in infestation levels in the sugarcane-bean intercrop. This is indicated by the concomitant decrease in predator populations, suggesting interdependence. However, the decline occurred when there were no beans present in the sugarcane-bean intercrop (Chapter 4), suggesting a residual effect of predators on *E. saccharina*, which cannot be explained in terms of bean intercropping (Altieri 1993).

6.3.2 The bean crop as a companion crop in sugarcane

Row intercropping of the bean crop in sugarcane

Results show that the decline in *E. saccharina* populations during the initial stages of the project was accompanied by a decline in combined predator populations in the sugarcane-bean intercrop, suggesting predator/prey populations. In contrast, there were great fluctuations in predator populations in the control plot during the same period. This predator population instability in the control plot seems to indicate that there was no predator/ prey relationship there, instead there were factors other than *E. saccharina* populations that influenced the fluctuations.

It is thus suggested that bean intercropping in the sugarcane-bean intercrop resulted in a relatively more stable predator population, which preyed on *E. saccharina*, resulting in a decline in infestation levels during the initial stages of the project. However, fluctuations in *E. saccharina* and predator population from October onwards, in the sugarcane-bean intercrop, seem to be independent of each other, suggesting lack of continued bean crop influence on predator populations. This lack of continued bean crop influence on predator populations was expected because the bean crop dried out so that there was no trace of it from August onwards. This observation combined with the lack of increased foliage associated arthropods in the sugarcane-bean intercrop, despite the significantly higher arthropod populations there, suggest that the bean crop as an intercropping companion in sugarcane has some limitations.

The first is the short life span (three months) of the bean crop in relation to that of sugarcane (15 months) (Chapter 3). This means that the food resources such as pollen and nectar, microhabitats, higher humidity conditions near the ground and the visual and olfactory changes that beans might have provided in sugarcane, are limited in time. The bean crop had flowered when the second arthropod sample was taken in May 1996 and pod formation had taken place when the third sample was taken. In addition, beans had dried out by August, thus the influence of flowers, pods and bean height that the bean crop might have had on arthropod populations were limited to the April to August 1996 period. The assumption, that the host plant and non-host plant always overlap in time and space, is one of Altieri's (1993) criticisms of Root's (1973) hypotheses (Chapter 2) which attempt to explain arthropod dynamics in diverse agroecosystems. According to *E. saccharina*) these hypotheses cannot explain the residual reductions in herbivore load, in diverse habitats, six months after harvest of one of the companion crops. Results of the present study seem to indicate that pest populations were reduced during the last stages of the project (Figures 23 and 24), an observation that cannot be explained in terms of bean intercropping, according to Altieri (1993).

Two generally accepted hypotheses (Skovgård and Päts, 1996) have been proposed by Root (1973) to explain differences in herbivore populations in simple and diverse habitats. First, the resource concentration hypothesis predicts that oligophagous herbivores will locate and build up populations in a monoculture, because the host plants are concentrated in time and space. That is, many herbivores, especially those with narrow host ranges are more likely to find hosts that occur in dense or nearly pure stands. Those species whose entire life requirements are met in this simple environment will remain the longest and reproduce. On the other hand, species with broad ranges will drift out of that habitat to feed on other plants. Similarly, species that must regularly use some special resources (e.g., shelter, nectar and pollen) not available in pure stands, will tend to emigrate. In South African sugarcane context (as pointed out in Chapter 1) *E. saccharina* is polyphagous, but its entire life requirements are met in sugarcane monoculture. Further, the study site of the present project was not surrounded by *E. saccharina* alternate hosts, suggesting that *E. saccharina* found in sugarcane was likely to remain there.

The second hypothesis, the natural enemies hypothesis, postulates an increase in number, searching and foraging activity by predators and parasitoids in diverse habitats due to a supply of alternate prey, food and refugia, which leads to a reduction in herbivore populations. That is, relatively stable populations of generalised predators and parasitoids can persist in these habitats because they can exploit the wide variety of herbivores, which become available. Similarly, specialised predators and parasitoids are less likely to fluctuate widely, because the refuge provided by the complex environment enables the natural enemy's prey/host species to escape widespread destruction by generalist predators and parasitoids. This natural enemies hypothesis can explain the observed fluctuations in *E. saccharina* and predator populations in the sugarcane-bean intercrop during the initial stages of the project. As shown in Figures 23 and 24, relatively stable populations of predators occurred in the sugarcane-bean intercrop when compared to the control plot. These stable predator populations occurred because there was an abundance of alternate prey in the sugarcane-bean intercrop as indicated by the significantly higher epigeal arthropod populations in that treatment (Chapter 5). However, the stability in predator populations beyond September was not obvious, suggesting failure of the bean crop to sustain its influence on arthropods.

The second limitation of the bean crop is its low height in relation to sugarcane, combined with the late planting of beans that occurred, in this study. Beans were planted three months after the previous sugarcane harvest leading to them becoming shaded by sugarcane. In this way, beans were unlikely to bring visual changes to the sugarcane that would attract arthropods, or inhibit colonisation of sugarcane stands by herbivores. Altieri (1993), citing many other authors, has shown that predatory coleopterans, which are normally found in large numbers in bean monocultures, avoid feeding in shaded beans in a maize/bean intercrop, thus accounting for lower numbers of coleopterans in the intercrop.

In the light of the results of this study, it is concluded that the bean crop, as a companion crop in sugarcane has potential management value in *E. saccharina* control. Firstly, predators such as Acarina and *D. helvolus* were significantly increased in the sugarcane-bean intercrop when compared to the control plot. Secondly, the pest population decreased during the last stages of the study. However, further investigations may be required because predators differ in importance from field to field and from year to year, hence spatial replication and at least two full years of field research are often necessary (Whitcomb, 1974). Therefore, fourteen months of arthropod sampling, in the current study, may not have been enough to make meaningful conclusions. A large database on the influence of within-crop habitat management, on *E. saccharina* control in sugarcane, is still to be collected. The present study, which is an extension of the preliminary work done by Conlong (1995), is the first in that regard.

It is therefore recommended that similar studies should be conducted, with the view to spatial and temporal replication and improving the limitations of the bean crop. Further, combination of intercropping with other programmes in the Integrated Pest management (IPM) may be desirable to enhance the effect of intercropping. Improving the limitations of the bean crop would include avoiding shading by sugarcane by timing the date of its planting in relation to that of sugarcane, or strip cropping of bean crop within sugarcane. An alternative crop should be sought for intercropping in sugarcane as another option to improve the bean crop limitations.

Strip intercropping of the bean crop in sugarcane

Strip cropping, the culture of multiple-row patterns of crops (Capinera *et al.*, 1985) could provide an alternative to row intercropping that leads to shading of beans by sugarcane. Small stands of plants have been used in pest control within the context of the equilibrium theory of island biogeography (Levins, 1986). The results of these studies seem to indicate that for some insect species, recruitment occurs from within small stands of plants and is then followed by competitive exclusion, which forces emmigration into plant stands of the other crop. This form of cropping would also allow for relay cropping, thus solving the short life span nature of the bean crop. In other words, a second bean crop could be planted immediately after the harvest of the previous one.

6.3.3 Alternatives to beans

An alternate crop to bean crop for intercropping is another option to avoid shading and short life span. Sunflower has several qualities that would make it a suitable companion crop in sugarcane. The stalk length of commercial sunflower varies from 0.5 to 5 meters and there are semidwarf hybrids that have been developed with a stalk length of between 1.2 to 1.5 meters (Seiler, 1997). Thus it has cultvars that would suit intercropping in different sugarcane varieties and conditions with different stalk heights. In this way shading by sugarcane would be avoided.

The phenological development of sunflower further suggests that it can be cultivated in South African sugarcane growing areas. For example, the minimum temperature for germination is 6^0C, while the maximum is 40^0C (Connor and Hall, 1997). Optimum temperature for emergence, floral initiation, anthesis and maturity is 28^0C 40^0C (Connor and Hall, 1997). All these temperature parameters lie within the LTM temperatures shown in Chapter 4.

Similarly, germination is more sensitive in loam soils with the water threshold varying between –0.7 and –2.2 Mpa, which translates to between 7% and 12% soil moisture (Connor and Hall, 1997). For instance, 7% moisture means that there is 7 mm of water in 100 mm of soil. The minimum LTM monthly rainfall was 30 mm, which can easily make the requisite 7% soil moisture.

Further, sunflower is either annual as are most sugarcane varieties or perennial, thus enabling it to exert its influence on arthropod populations throughout the sugarcane growth period (Seiler, 1997). Seiler and Rieseberg (1997) list 15 annual sunflower species. In addition, sunflower head diameter, which is measured by including the area of the disk flowers, varies from 6 to 75 cm (Seiler, 1997), which could allow it attract pollinators as well as other insects.

The most important attribute of sunflowers in habitat management with the view to increasing and enhancing predator foraging activity in sugarcane, is the diversity of insects that visit its stands. Over 80 insect species attack sunflower as potential pests or as pests in

Africa (Charlet *et al.,* 1997). They include root, stalk, foliage and head feeding species. In addition, there are other insects that are attracted to nectar and pollen in the flowers of sunflower, which serve the pollination function. Thus greater abundance and diversity of arthropods that visit sunflower could provide alternate prey for generalist predators and so retain them in sugarcane.

There are other benefits that may be derive from intercropping or strip cropping, other than habitat management for pest control purposes (Chapter 1). Sunflower is no exception. Crops used in strip cropping or intercropping may influence the total farm economy in other ways other than serving as natural enemy reservoirs. They may be sold for cash income in which case they would be complementary and supplementary to the primary crop. Or they may be destroyed when the natural enemy purpose has been served, in which case they are sacrificial to the total farm economy and the cost is absorbed by the primary crop (Laster, 1974). Additional benefits from bean intercropping were outlined in Chapter 1. Sunflower is an excellent source of nutrients for many livestock species because of high levels of oil and protein, as well as moderate fibre content (Dorrell and Vick, 1997). In addition, it is the source of well known household products such as cooking oil, margarine and lecithin (Dorrell and Vick, 1997). Thus these attributes of sunflower warrant further investigation for their use in sugarcane habitat management for *E. saccharina* control.

6.3.4 Intercropping in Integrated Pest Management (IPM) context

The proponents of IPM (a combination of two or more pest control strategies; Levins, 1986), argue that there is no single method of control that can be expected to provide an acceptable solution to all insect pest problems (Knipling, 1979). *E. saccharina* in the South African sugarcane industry is no exception, as indicated by its present economic importance despite the variety of control methods against it (Chapter 1). One such combination of control methods, which showed positive results in the *E. saccharina* situation, has been chemical control and pre-trashing (Heathcote, 1984). It is therefore suggested that habitat management, in the form of intercropping be investigated within the IPM context. This would include application of habitat management in fields where either least susceptible sugarcane varieties or selective pesticides are also used. The same should apply with parasitoid field releases. Currently there is an ongoing research on all of these programmes at SASEX, and more often than not the programmes are mutually exclusive.

However, Morse and Buhler (1997) have recently criticised IPM as being complex and technical, which make it difficult to implement. These difficulties have also led to IPM not being adopted by farmers, particularly in developing countries (Morse and Buhler, 1997). Because of the mounting evidence that the success of IPM is site and pest specific these authors have also questioned universal application of the programme. Caution, should therefore, be exercised when the programme is implemented in the South African sugarcane situation.

In conclusion the potential shown by the bean crop in attracting arthropod predator populations during the initial stages of the this project demands further investigation as predator importance varies from year to year and from field to field (Whitcomb, 1974). With the necessary precautions taken into account, the feasibility of integrating intercropping in sugarcane within the broader IPM should also be investigated. In addition, an alternate crop that would overcome the limitations of the bean crop as a companion crop in sugarcane should also be considered.

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