GUILD STRUCTURE AND SEASONAL DISTRIBUTION OF INSECTS ASSOCIATED WITH *AMARANTHUS HYBRIDUS* UNDER DIVERSE CULTIVATION PRACTICES IN THE CENTRAL FREE STATE

by

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FRONTISPIECE

A stand of the dynamic new crop, *Amaranthus hybridus*.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 MAJOR CROPS VERSUS ALTERNATIVE CROPS

Agricultural systems in human history tended to be much more diverse than on present-day farms. At the beginning of the century, most farms in South Africa had a varied crop base and kept some native vegetation in place (Myers, 1998). Today agriculture utilizes relatively few plant species. The ten most important crops consumed by humans (in order of production by weight of agricultural product) include sugarcane, rice, wheat, maize, potato, sugar beet, cassava, barley, sweet potato and soybean. There may be 350 000 plant species of which about 80 000 are edible (Janick, 1998). Presently only about 150 species are actively cultivated and of these 30 produce 95% of human calorie and protein requirements (Janick, 1998). About half of our food derives from only four plant species *i.e.* rice, maize, wheat and potato and three animal species (cattle, swine and poultry) (Janick, 1998). With the worldwide increasing population, one might expect that the number of edible species should increase also. But in fact fewer species account for more of our food. Even George Washington said that if his managers "have the smallest discretionary power allowed them, they will fill the land with corn." (Jolliff, 1998). The reasons for this diminution of food crop diversity include the lack of marketing options and the extensive research support for the major crops so that these crops have overcome or compensated for many of their deficiencies and increased their adaptation (Myers, 1998). Most governments over the world protect major crop growers with subsidies and support them indirectly with research funds and marketing assistance (Janick, 1998).

Biodiversity is a non-detachable part of the concept of sustainability. Biodiversity is essential for agricultural production, as agriculture should be for biodiversity conservation (Heywood, 1998). As more and more land is used for agriculture, it is there where biodiversity protection is essential. Big monocultures are detrimental for diversity in terms of plant life and other life forms. It is therefore very important to promote agricultural biodiversity (agrobiodiversity). Agrobiodiversity embraces units (such as cultivars, pure lines and strains) and habitats (agroecosystems). It can be considered at three main levels – those of ecological diversity, organism diversity and genetic diversity (Heywood, 1998). The reliance on only a few species poses special hazards and risks due to biotic hazards (Janick, 1998). To enhance diversity, agriculture must diversify in crop production and exploit under-utilized crops.

Food crops may be classified on the basis of their economic importance (Janick, 1998). Major crops, such as grains, are cultivated worldwide in adapted areas and have high economic value and are associated with high genetic input. Specialty crops, *e.g.* spices, are niche crops that, while economically important, have small markets that can be filled by relatively few growers. Underutilized crops, *e.g.* oilseeds such as sesame and safflower, were once more widely grown, but are now falling into disuse due to various agronomic, genetic, economic or cultural factors. Neglected crops are maintained by socio-cultural preferences and traditional uses, whilst agricultural research and genetic conservation have largely ignored them. New crops are plants that have not yet been domesticated or that are adapted to new climates, cropping systems or areas. This also includes plants that give rise to new products (Swart, 1998). *Amaranthus,* the crop under investigation, can be classified as both underutilized and new.

About 60% of the world's agriculture consists of traditional subsistence farming systems in which there is a high diversity of crops and species, cultivated in a polycropping or intercropping manner (Heywood, 1998). The expansion of underutilized or new crops offers many benefits, including production diversification, providing a hedge for financial and biological risks, national economic advantages by increasing exports and decreasing imports, improvement of human and livestock diets and the improvement of economic development in rural areas (Janick, 1998). Although traditional agriculture may not produce marketable surpluses, it does make a major contribution to food security. Traditional cropping systems provide as much as 20% of the world's food supply (Heywood, 1998). These crops cannot compete economically with major crops, but many of the species have the potential of becoming economically viable (Janick, 1998).

Many neglected and underutilized crops are locally well-adapted and constitute an important part of the local diet, culture and economy. These crops are usually adapted to a wide range of growing conditions, contribute to food security especially under stress conditions and are important for a well-balanced diet (Janick, 1998). Traditional agricultural research in developed countries has, however, hitherto paid little attention to these crops. The long term high-risk nature of new crop development is a common barrier, discouraging the attraction and interest of the private sector (Jolliff, 1998). Getting support for cultivating new and under-utilized crops will mainly depend on providing evidence of success stories. One such a story is that of soybean. Soybean developed as a new crop in the United States (US) between 1920 and 1970. It has contributed to the generation of farm-gate wealth and rural prosperity. Furthermore, improved the US balance of trade and reduced government commodity program payments by providing an alternative crop to a surplus crop such as maize. The biological control of pests improved as a result of interruptions caused in the maize monoculture and there was a transition towards more environmentally friendly and renewable resource use. By 1996, soybean was no longer considered a new crop (Jolliff, 1998).

South Africa has a rich plant diversity, with more than 22 000 plant species known to occur within its boundaries. This represents 10% of the world's known species, even though this land surface comprises less than 1% of that of the earth (Coetzee, Jefthas & Reinten, 1998). Despite the enormous richness in plant species, relatively few of these plants are economically utilized. The use of indigenous plants is mostly low-key and restricted to medicinal, cultural and ornamental uses. Only a few of the plant species are used as edible food and these include amaranth, buchu, honeybush tea and cowpea (Coetzee *et al.*, 1998). Recently, however, more attention has been given to new and underutilized food crops, since profit margins of major crops have come under pressure (Nell & Cronje, 2000). Furthermore, subsistence farmers are increasingly selecting well-adapted, stable crop varieties and cropping systems in which two or more crops are grown simultaneously (Abate, Van Huis & Ampofo, 2000).

1.2. BACKGROUND OF *AMARANTHUS*

The plant *Amaranthus* L. is an important new crop, both as a vegetable and grain commodity. It is, however, actually a new crop with an ancient history. *Amaranthus* species were grown as the principle grain crop by the Aztecs and Incas 5000 – 7000 years ago, prior to the disruption of South American civilization by the Spanish conquistadors. As a vegetable, *Amaranthus* was already cultivated 2000 years ago (Stallknecht & Schulz-Schaeffer, 1993). Amaranth originated either in the Andes region of South America or Mexico and has now spread to most tropical regions. At present it is cultivated in India, Malaysia, Indonesia, Burma, Filippines, Taiwan, China, Africa, Central and South America, Nepal, Greece, Italy and Russia (Whitbread & Lea, 1982). This is due to the ability of these plants to adapt readily to new environments and extremely broad climatic zones, as well as their hardy, competitive ability. As a crop it permits utilization with minimum crop management and is therefore an easy crop to cultivate and domesticate (Allemann, Van der Heever & Viljoen, 1996).

The genus *Amaranthus* consists of approximately 60 species, but only a limited number show potential for cultivation. Most are considered to be weedy species of which *A. retroflexus* L. is considered to be one of the worst weeds in the world (Stallknecht & Schulz-Schaeffer, 1993). *Amaranthus* species can be divided into four groups according to their uses, *i.e*: ornamentals, weeds, grain and leaf amaranth (Anonymous, 1996). There is no distinct separation between the vegetable and grain type since the leaves of young grain type plants can be eaten as greens as well. The three principle species used for grain production include *A. hypochondriacus* L., *A. cruentus* L. and *A. caudatus* L.. The major species used for vegetable production include *A. tricolor* L., *A. dubius* Mart. & Thell., *A. lividus* L. and *A. hybridus* L. (Stallknecht & Schulz-Schaeffer, 1993).

Amaranthus is a warm-season crop. It is a C_4 plant and is one of the few dicots in which the first product of photosynthesis is a four carbon compound. The peculiar combination of the anatomical features of amaranth and its C_4 metabolism results in increased efficiency to utilize CO_2 under a wide range of temperature and moisture stressed environments (Whitbread & Lea 1982). This contributes to the plant's wide geographic adaptability and occurrence. *Amaranthus* thus has the potential to provide a valuable source of food in areas with hot and dry climates.

In South Africa, a country with self-sufficiency and food exports, malnutrition still prevails in many rural areas. At least 3 million people under the age of 15 suffer from malnutrition (Allemann *et al.*, 1996). Vegetables help to alleviate this problem by contributing to the amount of calories and other nutrients in the diet. South Africa has a relatively low agricultural potential due to inadequate or unreliable rainfall and crop production takes place under extremely variable agro-ecological conditions. Besides the fact that amaranth is suited for cultivation under harsh climatic conditions, it also has high nutritional value. Compared to other leafy vegetables, such as spinach, cabbage and lettuce (Table 1), it has the highest protein, iron and vitamin A content. These two factors offer excellent possibilities for improving human nutrition in Third World countries (Early, 1985).

Table 1. Comparison of nutritional value of five different leafy vegetables per 100 g edible food (*re* Langenhoven, Kruger, Gouws & Faber, 1991).

Component	***A.hybridus***	Spinach	**Cabbage**	**Lettuce**
Water content (%)	78.7	91.2	92.5	95.9
Kilojoules	254	95	99	53
Proteins (g)	5.2	1.2	1.2	1
Carbohydrates (g)	9.6	3.2	3.2	1.1
Fat (g)	0.5	0.3	0.2	0.2
Fiber (g)	2.7	2.2	2.2	1
Calcium (mg)	58	136	47	19
Iron (mg)	11.5	3.6	0.6	0.5
Phosphorus (mg)	45	56	23	20
Sodium (mg)	20	70	18	9
Vit. A (ret.ekv)	970	819	13	33
Vit. C (mg)	16	10	47	4

Overall, grain amaranth has received significantly more research attention than vegetable amaranth (Stallknecht & Schulz-Schaeffer, 1993), but the importance of vegetable amaranth has recently come strongly to the fore. Allemann *et al.* (1996) tested different *Amaranthus* varieties for yield and *A. hybridus* (Brits variety) had the highest average yield measured over five cuts (leaves were harvested five times) (Table 2).

Table 2. Fresh matter yields over five cuts of five *Amaranthus* varieties (Allemann *et al.*, 1996)

Variety	**$\bar{x}$ Yield (g/plant)**
A. hypochondriacus	263.73
A. tricolor	80.77
A. cruentus	214.01
A. hybridus (Brits)	263.91
A. hybridus (Mayfords)	206.8

1.3. IMPORTANCE OF RESEARCH

The world population is still growing, consequently more food will have to be produced. Presently there is enough food for all six billion people on earth, but in reality there are still countries where people are starving. Why these contradictory statements? Firstly the world's food resources are unevenly distributed. Secondly insects consume on average 10% of the earth's plant resources. With 400 000 herbivorous insects species feeding on about 300 000 vascular plant species (Schoonhoven, Jermy & Van Loon, 1998), insects are strong rivals of man in terms of energy consumption from plants (Louw, 1998). Thus, acceptable crop yield depends to a large extent on the influence of insects. Increases in plant material movement (export and import) also introduce new pests that contribute to this problem. Pest problems are also expected to increase during the next decades, as more intensive production is needed for the growing population (Abate, *et al.*, 2000). Pest management must therefore be an integral part of agriculture and the most common solution is to apply pesticides. Economic and social constraints, however, have kept pesticide use in Africa the lowest among all world regions (Abate, *et al.*, 2000). Subsistence farmers simply cannot afford the high cost of chemicals for insect control and the limited crop value in traditional farming systems does not economically justify the use of pesticides. Toxic residues on crop products, amongst others, also pose a serious threat to human health. Research to find alternative methods for pest management is thus very important and a long-term solution must be found.

The worldwide trend is to reduce the application of chemicals and to substitute it with other methods of control or to combine it with other methods. Alternative methods for plant protection such as biological control, genetic manipulation and cultivation (agricultural) methods are incorporated into agricultural practice. A combination of these methods is known as Integrated Pest Management (IPM), where IPM is regarded as the discreet use of a combination of control methods to keep pest populations below injury levels (Arnold, 1992). The main focus of developing and implementing IPM is to build IPM programs around the traditional pest management approaches that are used in small-scale agriculture (Abate, *et al.*, 2000).

Pest management strategies in Africa between 1972 and 1992 constituted: biological control using natural enemies (34%), chemical control (27%), scouting monitoring (15%), host plant resistance (13%) and cultural practices (11%) (Abate, *et al.*, 2000). Two important aspects are thus cultural practices and biological control and a combination of these two methods should give significant results in terms of pest management.

Cultural practices include mixed cropping or intercropping and are based on the premise that more diverse habitats support more natural enemies. Flying insect pests are also less efficient in finding and identifying their host plants than is the case in a big monoculture (Armstrong & Mckinlay, 1997). A monoculture, on the contrary, reduces a complex natural plant system to a single species community. This can lead to decreased insect diversity and rapid growth of a single or very few insect species that can in turn develop pest status (Stamps & Linit, 1998). Diversity in agroecosystems may favour reduced pest pressure and enhanced activity of natural enemies (Landis, Wratten & Gurr, 2000). Staggered planting dates are another example of an agricultural practice. Plants that are planted early are already past the stage where too much damage can be inflicted when pest populations rise to injury levels. Plants that are planted late in the season can escape the peak of pest population densities in that particular life-cycle of the pests, as they have already been completed. Most of the pest insects may already, for example, be in the overwintering stage.

Biological control is the management of biological agents (predators, parasitoids and microbial organisms) and their products to keep pest population numbers in check (Arnold, 1992). The advantages above chemical control, are that the beneficial insects are very selective, they are already present, they have got the ability to seek and find the pest insects, they can multiply and spread by themselves and the pest can not develop resistance against the control. The disadvantages, on the other hand, are that the control is slow, it does not exterminate the pest population and it is difficult to apply (Van der Westhuizen, 1996). Ongoing research is necessary for effective biological control.

Indigenous pest management knowledge is site-specific and should be the basis for developing IPM techniques. Farmers often lack the biological and ecological information necessary to develop better pest management. Information about the biology and ecology of pests must be available and therefore research must be done (Abate, *et al.*, 2000). Research about the arthropod community composition, guild structure and the interactions between these guilds in an ecosystem is essential to determine if IPM methods are viable in a certain setup. This study was based on such an approach. Although insects and arachnids were sampled, this study mainly concentrated on the different aspects of the insect community. The following questions were asked:

1. How does the arboreal, terrestrial and alate insect community diversity compare in a monoculture, mixed cropping and staggered planting date setup of *A. hybridus?*

2. What are the dominance structures and what is the insect guild composition of the arboreal, terrestrial and alate insects in a monoculture, mixed cropping and staggered planting date setup of *A. hybridus?*

3. What is the diversity in border areas, fallowland and refugia and do these insects have an influence on the diversity and insect composition found on and amongst the cultivated *A. hybridus*?

4. Is a combination of agricultural practices and biological control viable and applicable for cultivation of *A. hybridus*, and can the environment be manipulated to enhance the survival and fecundity of natural enemies thereby increasing their effectiveness?

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CHAPTER 2

MATERIAL AND METHODS

2.1 STUDY AREA AND CROP

This study was conducted at the experimental site of the Department of Soil Science of the University of the Free State, near the Tempe Airport, 20 km northwest of Bloemfontein (SE 2926Aa) in the Free State. This province is a semi-arid region. Sustainability is an especially relevant question to agriculture in semi-arid regions. Such regions have four unique characteristics: *i.e.* 1. No growing season will have the same amount, kind or range of precipitation as the previous season and the temperature average, range and extremes will also be different; 2. Crops cannot be planned or managed in the same manner from season to season; 3. From a sustainability point of view the soil recourse base and water holding capacity does not remain the same over a long period; 4. Abundant sunshine and cloud-free days induce rapid growth when moisture conditions are favourable, but these conditions cannot be sustained throughout the season, since semi-arid regions only receive substantial precipitation for a few months of the year at most, and water management is necessary (Steward & Robinson, 1997). Due to these reasons the plants used in this study were irrigated regularly throughout the season and fertilizer was applied at the beginning of the growing season.

Amaranthus hybridus is a difficult crop to establish when cultivated directly from the seed. Seeds are small and must be planted in shallow seedbeds to ensure germination. Since they are planted very close to the surface, rain or irrigation can easily wash them out (Mposi, 1998). To side-step this problem, seeds were cultivated in seedtrays in a greenhouse. When seedlings were about six weeks old, they were transferred to the field and planted in a previously weeded and ploughed plot. *A. hybridus* thrives in low acidity soil, with a previous study finding that *A. hybridus* planted in soil with pH 6.4 producing the highest yield (Singh & Whitehead, 1993). In this study the pH was not measured.

Another aspect that received attention is the spacing between plants. In previous studies by Singh & Whitehead (1993), tall, lanky plants were produced when closely spaced (4, 8 and 16 cm apart), whilst the highest leaf number and maximum leaf area were obtained in widely spaced plots (24, 32 and 40 cm apart). Thus, plants grown at low density exhibited more lateral growth than plants grown at high density because of intraspecific competition, mainly for sunlight and space (Knezevic & Horak, 1998). Farmers prefer spacing that results in the highest yield and thus plant the plants in wider rows. To exploit these conditions, the plants in this study were planted in rows 30 cm apart and with a spacing of one meter between rows. Density of plant stands may also affect the distribution and abundance of insect species, albeit these effects on phytophages may be due to quality difference of host plants and variability of microclimate too. The abundance of predators and parasitoids on the other hand is determined by microclimate and abundance of prey and thus also indirectly by host plant diversity (Honěk, 1988). More sunlight reaches the ground surface in sparse stands and thus the ground surface temperature is higher than in dense stands. Running activity of insects increases with temperature (Honěk, 1988) and thus more insects should be caught in pitfalls in sparse stands. Plots were weeded regularly and no herbicides or pesticides were used, thereby ensuring a natural insect diversity.

2.1.1. Monoculture

This part of the study was conducted from January to May 1997, as well as from February to May in 1998 (Appendix 1). The monoculture of *A. hybridus* in 1997 (consisting of *c.* 1000 plants) was bordered by a monoculture of maize, natural field and a dirt road (Fig. 2.1). The plants were in a good condition. The monoculture of 1998 (consisting of *c.* 250 plants) in combination with the mixed crop setup, was basically the same (Fig. 2.2).

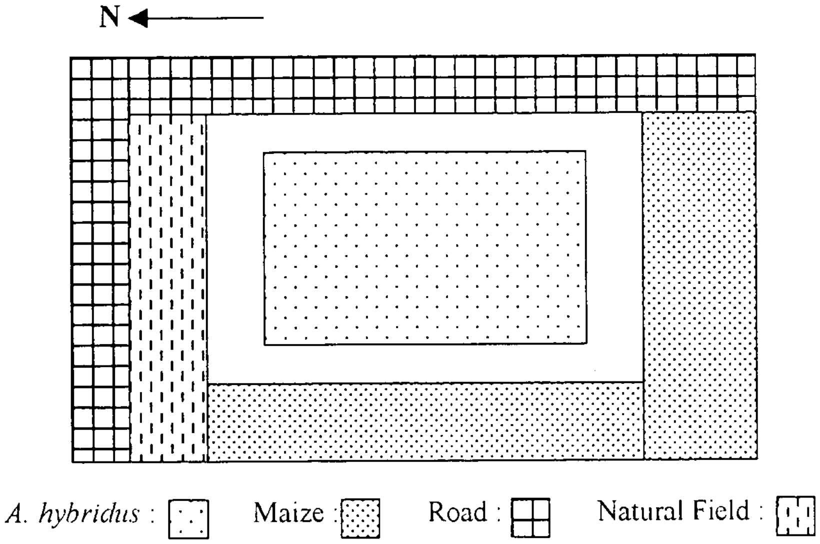

Fig. 2.1. The experimental setup in the 1997 season with a monoculture of *Amaranthus hybridus*

The general method of farming in the Free State is big monocultures and high production. However, hand in hand with these go the application of large quantities of pesticide and herbicide, necessitating expensive application equipment. A monoculture reduces a complex natural plant system to a single species community that leads to a decrease in insect diversity. This in turn promotes rapid population growth of a single or few phytophagous insect species that more likely than not develop into pests (Stamps & Linit, 1998). Overall agricultural intensification leads to a narrow genetic base of crop varieties (often grown in monoculture), reduction in natural areas around crops (depriving natural enemies of their natural habitat) and more pest-susceptible plants due to soil fertility decline (Abate, Van Huis & Ampofo, 2000).

2.1.2. Mixed cropping

In 1998 *A. hybridus* was planted in a mixed crop setup together with sunflower, maize and pumpkin in a random block design (Fig. 2.2). The plots were about a meter and a half apart. A monoculture of *A. hybridus* and maize were also included in the study.

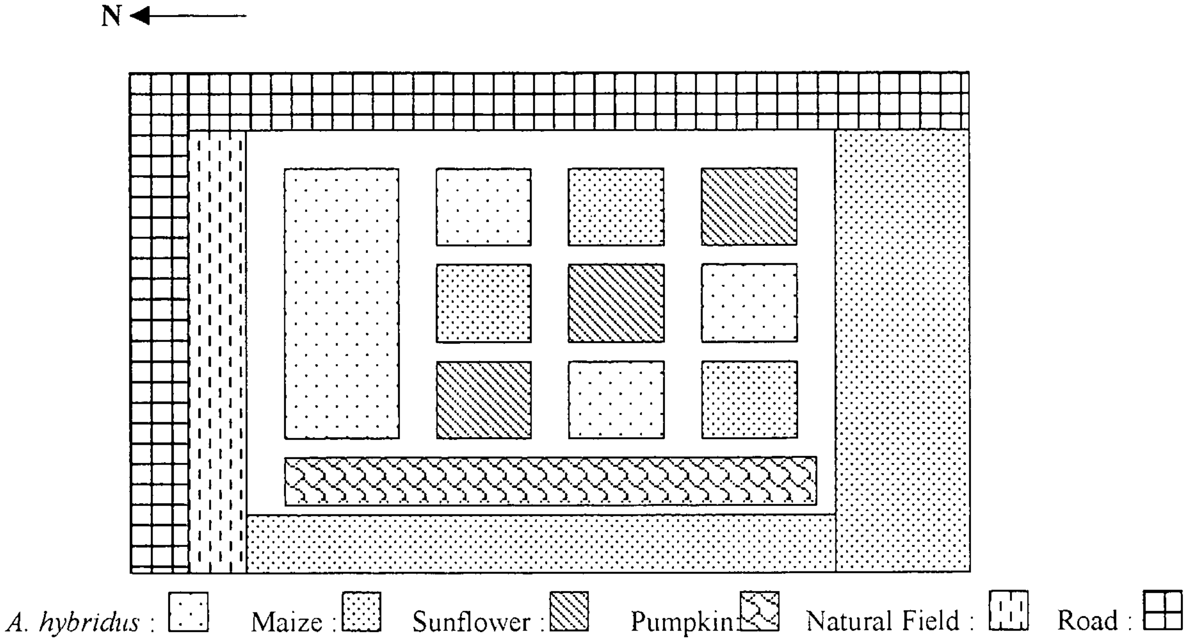

Fig. 2.2. The experimental setup in the 1998 season with *Amaranthus hybridus* in mixed cropping and monoculture.

The monoculture *A. hybridus* consisted of 250 plants and the plots in the mixed crop setup of 50 plants each. Plants in this year were healthy and in a good condition throughout the growing season. The plots were bordered with natural field and a dirt road. Sampling was done from February to May 1998 (Appendix 1).

Increased plant diversity and thus increased niche diversity should lead to an increase in insect species richness. This includes both phytophages and their natural enemies, thus decreasing the probability that a single herbivore species will dominate the community (Stamps & Linit, 1998). Mixed cropping provides a wide range of visual and chemical stimuli for phytophages. Consequently flying insect pests are less efficient at finding their host plants in a mixed crop setup (Arnold, 1992). This practice, although discouraged in favour of monocropping, meets the agronomic, socio-economic and nutritional needs of the small-scale farmer better. This includes better food security, optimal use of soil and space, maintenance of soil fertility, better erosion control and a reduction in the need for weeding (Abate *et al.*, 2000).

2.1.3. Staggered planting dates

Three plots of *A. hybridus* were planted on successive dates, *i.e.* 30 November 1998, 30 December 1998 and 30 January 1999 (labeled A-plot, B-plot and C-plot, respectively). Each plot consisted of 120 amaranth plants. The plots were adjacent to a monoculture of maize, a border area of natural field and a dirt road (Fig. 2.3). The border area was included in the study to determine the influence of its fauna on insect incidence and diversity. A plot with other *Amaranthus* species was also planted on 30 December 1998, but it was not included in this study. Sweeping and beating sampling began on 29 January for the A-plot, 10 February for the B-plot and 8 April for the C-plot and was continued until 21 May (Appendix 1). Pitfall sampling began on 17 December 1998 for the A-plot, 10 February for the B-plot and 11 March for the C-plot and was continued until 4 June (Appendix 1). The plants experienced fungal root rot and the fungi species responsible for this were *Fusarium oxysporum* and *F. sambucinum* (Chen & Swart, 1999). This is known to happen when plants are planted for three successive years on the same soil. The plants were thus in a relatively poor condition.

Adjusting planting or harvesting time to escape pest damage is one of the important strategies in Africa of keeping pest damage below economic levels. Early planting is a very effective manner of control against certain pests, since pest population peaks can be avoided. Early planting also helps to maximize yield. The crop benefits from a full season's rainfall and soil nitrate fluxes and suffers less from weed competition (Abate, *et al.*, 2000).

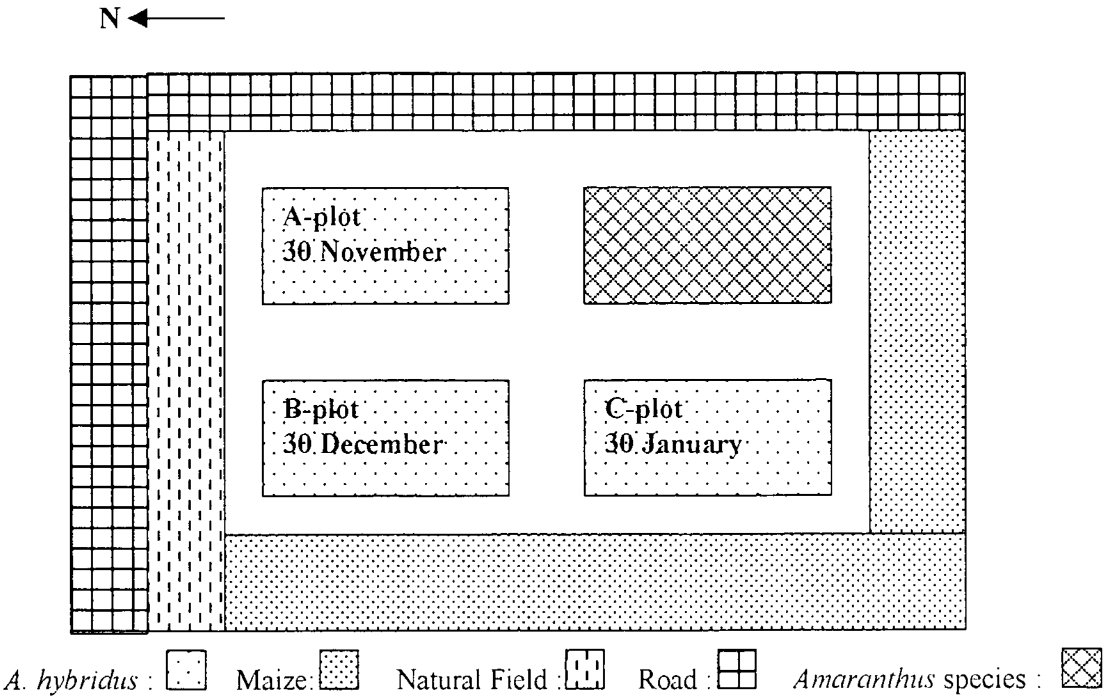

Fig. 2.3. The experimental setup in the 1998-1999 season with *Amaranthus hybridus* plots planted at monthly intervals.

2.2. TECHNIQUES

Sweeping and beating methods were used to sample the arboreal insect fauna in 1998 and 1999. This sampling method was used in the *A. hybridus* monoculture in 1998, the mixed cropping culture and the staggered planting dates culture. This was done every second week. Aspirators were used to sample the small insects from the sweeping nets and beating sheets. Quantitative sampling was done and the insects were killed with ethyl acetate and then preserved in 70% ethanol. Care was taken to sample the same number of plants with more or less the same biomass in the different plots.

Terrestrial insect sampling was by pitfall trapping, conducted in 1997, 1998 and 1999. Aluminum tins (11 cm in height and 6 cm in diameter) were randomly placed in the soil of the plots with the rim at the level of the ground surface. The tins were screened from rain, irrigation water, debris and direct sunlight by white rooflike protectors. No bait was used. The tins were half-filled with ethylene glycol ($CH_2OH.CH_2OH$). The pitfalls were emptied every second week and the insects were preserved in 70% ethanol. Pitfall catches sample the groundliving (terrestrial) fauna, as well as insects that fall from the plants and are thus just temporarily on the ground. Pitfall catches can be treated as indicators of insect activity and population density (Honěk, 1988).

A malaise trap was used in 1999 to sample all flying insects (especially pollinators and parasitoids). In this manner only data for the staggered planting dates culture was thus collected. The trap was placed in the flight path of the insects for the best results (between the B- and C-plot). Insects were thus sampled that were flying in and out of the cultivated *Amaranthus* land. The insects were also preserved in 70% ethanol.

Although insects and arachnids were sampled, the main aim of this study was the investigation of the different aspects of the insect community. Insects were counted and identified at least to family level and a reference collection was compiled. The identification keys in Borror, Tripplehorn & Johnson (1992) and Scholz & Holm (1996) were used. The voucher reference collection stands in the Department of Zoology and Entomology of the University of the Free State.

2.3. INDICES

One problem associated with diversity measurement is knowing what sample size to adopt for purposes of reliability. The cumulative species index is generally applied and the point at which the line graph reaches an asymptote indicates the minimum viable sample size (Magurran, 1988).

Indices were developed to give diversity a succinct numerical dimension (Samways, 1984). Diversity remains a central theme in ecology and measures of diversity can be seen as indicators of the well-being of ecological systems (Magurran, 1988).

2.3.1. Alpha diversity

Alpha diversity is a single within-habitat measure of species diversity (Jennings, 1996). The alpha species diversity measures can be divided into three main categories, *i.e.* species richness indices, species abundance models and the proportional abundance of species (Magurran, 1988).

2.3.1.1. Species richness indices : Margalef index

The first property of a community to be considered is the number or abundance of species it contains. Five major factors can determine the number of species in a community (Price, 1984). First is the historical factor, which is the time the commodity has been available for colonization. In agriculture there is not much time for colonization, due to relatively short growing periods. Then there are two external factors, namely the number of potential colonizers, that is the size of the species pool from which colonization can occur, and the distance of the colonizers from the source. The insect species in this study come mainly from the surrounding natural fields and cultivated lands. Two internal factors relate to the structural diversity of the biotype, namely the size of the biotype, and the interaction between species that leads to the extinction of some and the survival of others. In part these two factors depend on the structural diversity.

The Margalef (D_{mg}) index represents the relative abundance of species. The formula is as follows:

$$D_{mg} = (S-1)/\ln N$$

where S is the number of species recorded and N is the total number of individuals summed over all S species (Magurran, 1988). This index is also subject to sampling intensity.

2.3.1.2. Species abundance models

Not all species in a community are equally common. A few species would be very abundant, some would have medium abundance, while most would be represented by only a few individuals. There are four models for these different situations (Magurran, 1988). Rank abundance plots determine the relationship between number of species and number of individuals.

a) Geometric series.

A few species are dominant with the remainder fairly uncommon. This occurs in species poor communities under harsh conditions. High dominance occurs.

b) Log series

Species of intermediate abundance become more common.

c) Lognormal distribution

This distribution occurs mostly in large, species rich, stable communities (Magurran, 1988). The lognormal is the most widely applied of all species-abundance distributions. The lognormal distribution results from the summation of three or more underlying groups of species. The first group contains many species which are rare, the second group contains a smaller number of moderately common species and the third group an even smaller number of species with high abundance (Gray, 1987). There is thus not high dominance.

d) Broken stick model

All species are more or less equally abundant.

2.3.1.3. Proportional abundance of species

a) Shannon index (H) and evenness (E)

This is the most widely used index (Samways, 1984). The formula is:

$$H = -\sum p_i \ln p_i$$

where the quantity p_i is the proportion of individuals found in the ith species. P_i is estimated as n_i/N where n_i is the number of a single species and N is the total number of individuals (Magurran, 1988). The value of this index is usually between 1,5 and 3,5 and only rarely surpasses 4,5. This index is most strongly affected by species in the middle of the sequence. The richer the community, the less expressive the measurement, for H asymptotically approaches a maximum of around 5 (Whittaker, 1972).

Although the Shannon index takes into account the evenness of the abundance of species, it is possible to calculate a separate additional measure of evenness (E):

$$E = H/\ln S$$

where H is the Shannon index and S the number of species (Magurran, 1988).

E is constrained between 0 and 1 with 1 representing a situation in which all species are equally abundant (Magurran, 1988). A value near to 1 shows that species in a community are evenly distributed and that there is thus not high dominance. When the value is nearer to 0 the community exhibits high dominance.

b) The Berger-Parker index (d)

This is a dominance measure. It expresses the proportional importance of the most abundant species. The formula is:

$$d = N_{max}/N$$

where N_{max} is the number of individuals in the most abundant species and N is the total of all individuals (Magurran, 1988).

The reciprocal form is usually adopted (1/d), so that an increase in the value represents an increase in diversity and a reduction in dominance. This index is independent of the number of species (S), but is influenced by sample size (Magurran, 1988).

2.3.2. Beta diversity

Beta diversity is the change in diversity among different communities of a landscape. It is an index of between-habitat diversity (Jennings, 1996). The index in this section is a similarity index. This measure investigates the similarity of pairs of sites.

2.3.2.1. The Bray-Curtis index (C_N)

The formula is:

$$C_N = 2{}_jN/({}_aN+{}_bN)$$

where ${}_aN$ is the number of individuals in site A; ${}_bN$ is the number of individuals in site B, and ${}_jN$ is the sum of the lower of the two abundances of species which occur in the two sites (Magurran, 1988).

This index is designed to equal 1 in cases of complete similarity and 0 if the sites are dissimilar and have no species in common. The data is then further analysed through cluster analysis starting with a matrix giving the similarity between each pair of sites. The two most similar sites in this matrix are combined to form a single cluster. The analysis proceeds until all are combined in a single dendrogram (Magurran, 1988).

2.4. FEEDING GUILDS

The different feeding guilds of the insects sampled were determined. The four main feeding guilds found were phytophages (herbivores), predators, parasitoids and scavengers or detritivores. The relationship among these guilds was established. Material was identified at least to family level and the tendencies in the dominant species were determined.

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Appendix 1

Sampling dates in the different years (1997, 1998 and 1999).

	1	2	3	4	5	6	7	8	9	10	11	12
1997												
Monoculture												
Terrestrial	09/01	21/01	04/02	18/02	04/03	01/04	15/04	13/05				
1998												
Mixed crop												
Arboreal	03/02	19/02	06/03	18/03	01/04	15/04	29/04	15/05				
Terrestrial	19/02	06/03	18/03	01/04	15/04	29/04	15/05	27/05				
Monoculture												
Arboreal	03/02	19/02	06/03	18/03	01/04	15/04	29/04	15/05				
Terrestrial	19/02	06/03	18/03	01/04	15/04	29/04	15/05	27/05				
1998 - 1999												
A-plot												
Arboreal	29/01	10/02	25/02	11/03	23/03	08/04	30/04	21/05				
Terrestrial	17/12	31/12	13/01	29/01	10/02	25/02	11/03	23/03	08/04	30/04	21/05	04/06
B-plot												
Arboreal	10/02	25/02	11/03	23/03	08/04	30/04	21/05					
Terrestrial	10/02	25/02	11/03	23/03	08/04	30/04	21/05	04/06				
C-plot												
Arboreal	08/04	30/04	21/05									
Terrestrial	11/03	23/03	08/04	30/04	21/05	04/06						
Border area												
Arboreal	29/01	10/02	25/02	11/03	23/03	08/04	30/04	21/05				
Terrestrial	17/12	31/12	13/01	29/01	10/02	25/02	11/03	23/03	08/04	30/04	21/05	04/06
Malaise trap	11/03	23/03	08/04	30/04	21/05							

CHAPTER 3

DIVERSITY OF ARBOREAL INSECTS IN THREE DIFFERENT CULTIVATION PRACTICES

3.1 INTRODUCTION

Biodiversity, defined as the variety of life forms, the ecological roles they play and the genetic diversity they contain (Odum, 1993), is an important and central theme in ecology. The question may arise what the importance of biotic diversity really is and why it must be studied and conserved. Firstly there is the notion of interdependence in nature. Each species is part of an interdependent, holistic ecosystem, which implies that the loss of one part leads to instability. Secondly, the more species in a community, the greater its ability to recover after disturbance, and thirdly, redundancy in an ecosystem. Where more than one species or groups of species are capable of carrying out major functions, or act as major links in the food web, is considered an ecological asset. Thus, conserving species is important for the maintenance of everyday life support systems (Odum, 1993).

Species can become endangered if population sizes become small and a genetic bottleneck develops. Increasing numbers of species are either endangered or becoming extinct due to the destruction of habitat, or the fragmentation of habitats into isolated patches, as a result of human activities (Odum, 1993). As humans use more and more land for agriculture (more food must be produced for the increasing population), more habitats are destroyed. A new trend in world agriculture, however, is to increase biodiversity (Heywood, 1998) and call for a focus on biodiversity conservation. The diversity, and influences on the diversity, of insects in a cultivated field is very different to that of natural veld. Annual cropping systems are especially variable in time and space. The timing and sequence of habitat availability and suitability relative to the timing of population processes and the ability of the insects to move among patches of vegetation, determine the dynamics of the pest population. There are high risks and uncertainties associated with living in an annual cropping system (Kennedy & Storer, 2000). Agricultural cropping systems are thus an island both in space and time from the viewpoint of the organisms colonizing them. Flying insects, when approaching a monoculture of a cultivated crop, receive many more visual and chemical stimuli to descend upon it, than from a more diverse ecosystem. Colonization can be rapid, but the resource is only available for a short period. As the crop nears the end of its growing season the insects must seek alternative resources. The reduced competition, otherwise found under favourable conditions, results in a low insect diversity and subsequent pest outbreaks in cultivated crops.

Diversity is thus an index of ecosystem well-being. There are two components of diversity, namely the richness or variety component and the relative abundance component (Odum, 1993). Two communities could have the same number of species, but be very different in terms of the relative abundance or dominance of each species. Indices were developed to give diversity numerical substance (*re* Samways, 1984) and can be divided into three categories, namely: species richness indices, species abundance models and indices based on the proportional abundance of species (Magurran, 1988).

Because the current trend in world agriculture is to focus on maintaining or increasing biodiversity, this was the underlying aim of this study concerning insect communities on amaranth. In this chapter the overall arboreal insect diversity found whilst employing different cultural practices of *Amaranthus hybridus*, was measured using different indices. The questions asked were:

1. How does the insect diversity encountered in different agricultural practices, *i.e.* monoculture, mixed crop setup and staggered planting dates, compare?
2. What aspects influence the diversity of insects on amaranth plants?

3.2 MATERIAL AND METHODS

Insects were sampled from plants using beating sheets, sweeping nets and aspirators and then killed with ethyl acetate. Intensive sampling was done on 20 plants per plot. In 1998 sampling was done on the amaranth in monoculture and in the mixed crop plots (Fig. 2.2). Samples were also taken from the other crops (sunflower, maize and pumpkin) in the mixed crop setup. In 1999 sampling was done on the staggered planting date crops. These plots were planted 30 November, 30 December and 30 January and were named A-plot, B-plot and C-plot, respectively (Fig. 2.3). The insects were identified and counted in the laboratory and then preserved in 70% ethanol. These data were processed and the following indices were calculated: diversity indices for each individual sample (Appendix 1.1); mean diversity indices including all the individual samples by working with a factor equal to the number of samples taken at a site (mixed crop, monoculture and A-plot =8; B-plot = 7; C-plot = 3) (Appendix 1.2); and diversity indices for the first three samples taken from each of the plots in the staggered planting dates setup (Appendix 1.3). The latter was done to compare data of plants at more or less the same growth stage. The phenology of the first three samples from plots A, B and C was uniform.

An important factor to consider is the test for the correct sample size. Cumulative species were counted to calculate this (Fig. 3.1).

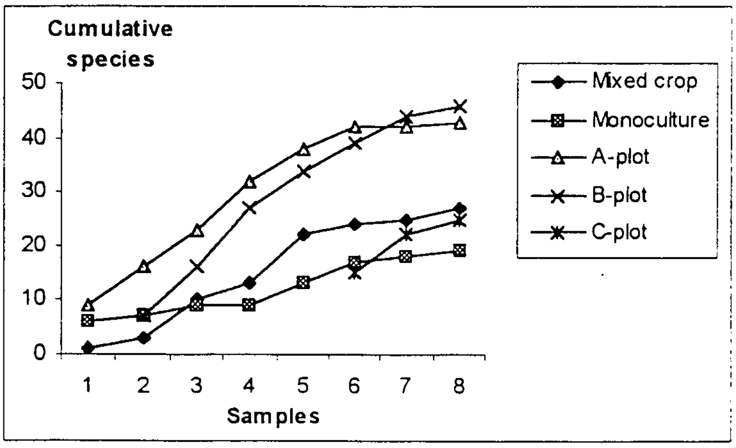

Fig. 3.1 Cumulative arboreal species in five different plots (mixed crop, monoculture, A-plot, B-plot and C-plot).

The minimum sample size on *A. hybridus* in the mixed crop setup was five samples, indicated by the graph leveling off at sample 5. The minimum sample size for the monoculture was six samples, so too for the A-plot and the B-plot. Too few samples were taken in the C-plot and consequently the graph does not level off. The minimum sample size can thus be determined at at least six samples. In future studies a minimum of six samples must be taken.

3.3. RESULTS AND DISCUSSION

3.3.1. Species richness

In community analysis the first aspect to consider is the number or abundance of species it contains. The Margalef (D_{mg}) index represents the relative abundance of species. For the first three samples taken in 1999 (Appendix 1.3), the A-plot (D_{mg}= 4.402) had the highest abundance value followed by the B-plot (D_{mg}= 4.401) (Fig. 3.2). The C-plot (D_{mg}= 4.139) had the lowest abundance. The 1998 season had a lower relative abundance of species overall than in 1999 (Fig. 3.3). As mentioned earlier, the plants in the 1999 season were in a bad condition, while the plants in the 1998 season were in a very much better condition. The fact that the plants in the 1999 season support more insects favours the ‘plant-stress hypothesis’. This hypothesis proposes that phytophagous insect abundance can be higher on hosts under stressful conditions (Cornelissen, Madeira, Allain, Lara, Araujo & Fernandes, 1997). Stressed plants decrease protein synthesis and there is an increase in total nitrogen in the aerial plant parts (Price, 1997). Chemical defenses in the stressed plants can also decrease (Cornelissen, *et al.*,1997). These conditions are favorable for pest development.

The data in Fig. 3.4 corresponds to the theory that colonization is rapid at first and then drops rapidly to more or less a state of equilibrium (Price, 1984). As the growing season of plants in the plot nears its end, the insect species in the plot either die (after completion of their reproductive cycle) or emigrate to the next colonizable plot (another plot of amaranth or the natural field). This can be seen, for example, at sample 7 in the A-plot where the species abundance drops while the abundance values in the B- and C-plot increase at sample 7 as the plants in those plots reach their peak growth stage. In 1998, as the amaranth growing season neared its end, the insects were found to either migrate to the natural field, go into their overwintering phase, or die.

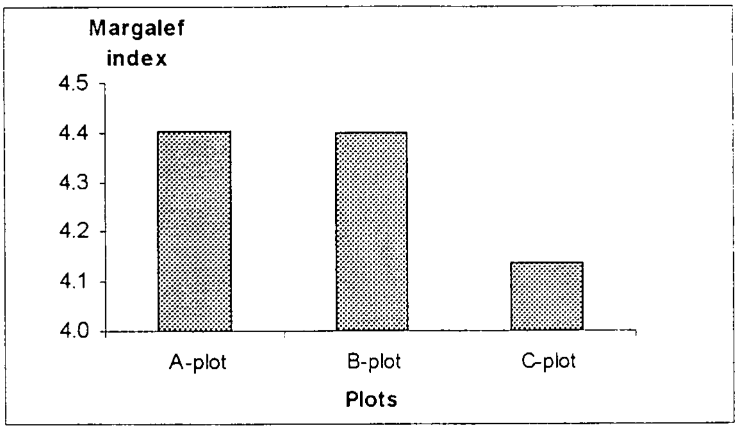

Fig. 3.2. Margalef (D_{mg}) index for arboreal insects indicating the mean of the first three samples of each plot in the staggered planting dates culture (A-plot, B-plot and C-plot), 1999 (SE: 0.088).

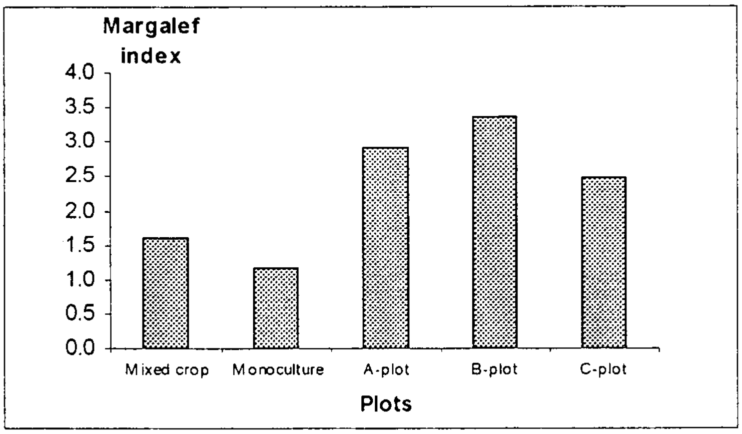

Fig. 3.3. Mean Margalef (D_{mg}) index of the total number of arboreal insects collected in 1998 (mixed crop and monoculture) and in 1999 (staggered planting dates) (SE: 0.383).

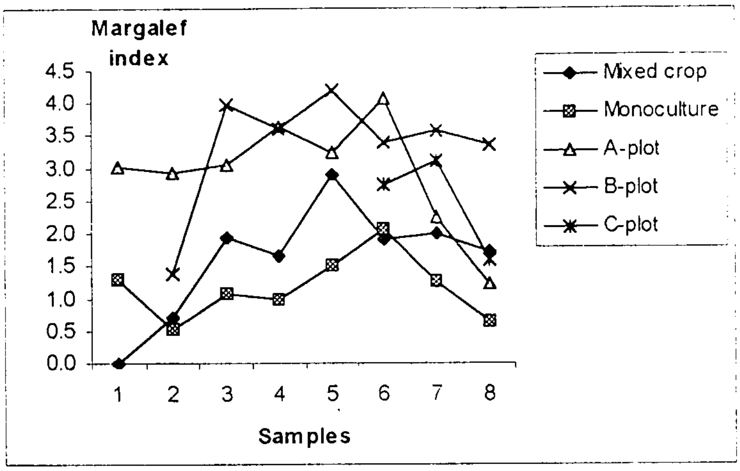

Fig. 3.4. Margalef (D_{mg}) index for arboreal insects in five different plots (mixed crop, monoculture, A-plot, B-plot and C-plot).

3.3.2. Rank abundance

There are four types of rank abundance plots, *i.e.* the geometric series, the log series, the lognormal distribution and the broken stick model. The rank abundance plots of the arboreal insects in this study fit the lognormal model. There was thus not high dominance in any of the five sites, *i.e.* mixed crop (Fig. 3.5), monoculture (Fig. 3.6), A-plot (Fig. 3.7), B-plot (Fig. 3.8) and the C-plot (Fig. 3.9). The insect community is composed of more or less 65% rare species, 25% species of intermediate incidence and 10% of very abundant species.

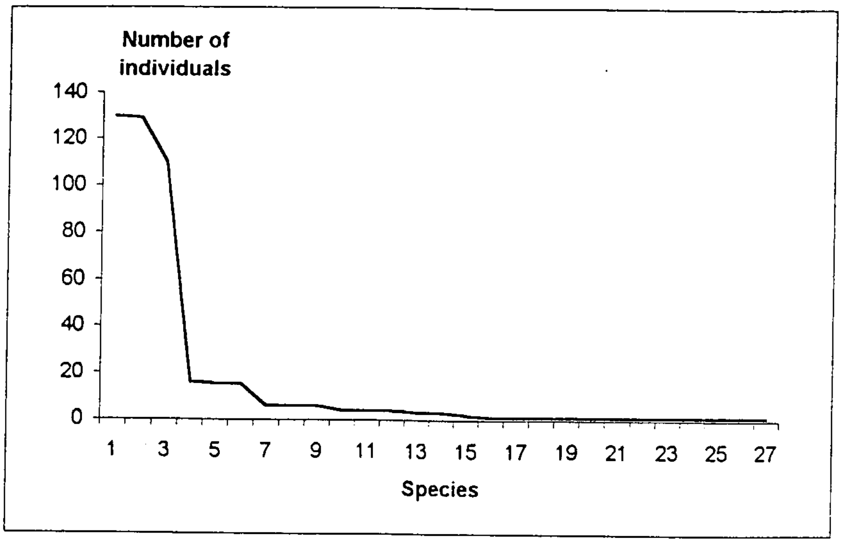

Fig. 3.5. Rank abundance plot of the arboreal insects in the mixed crop setup.

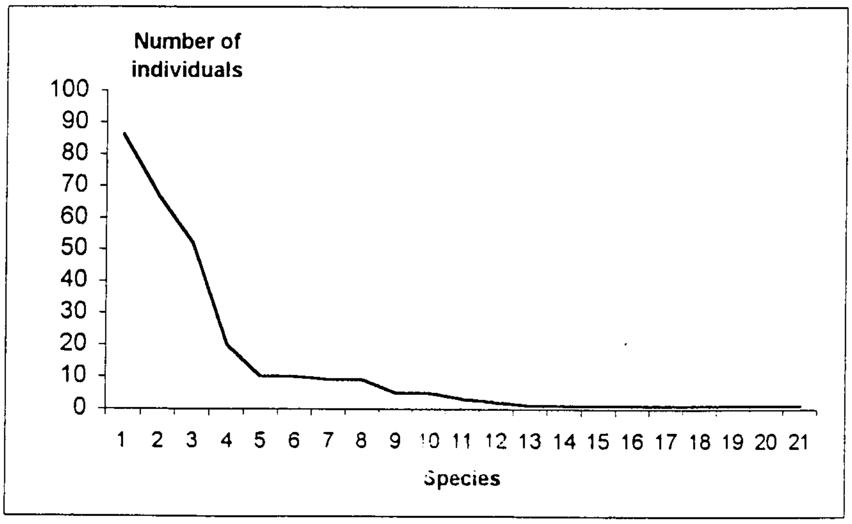

Fig. 3.6. Rank abundance plot of the arboreal insects in the monoculture.

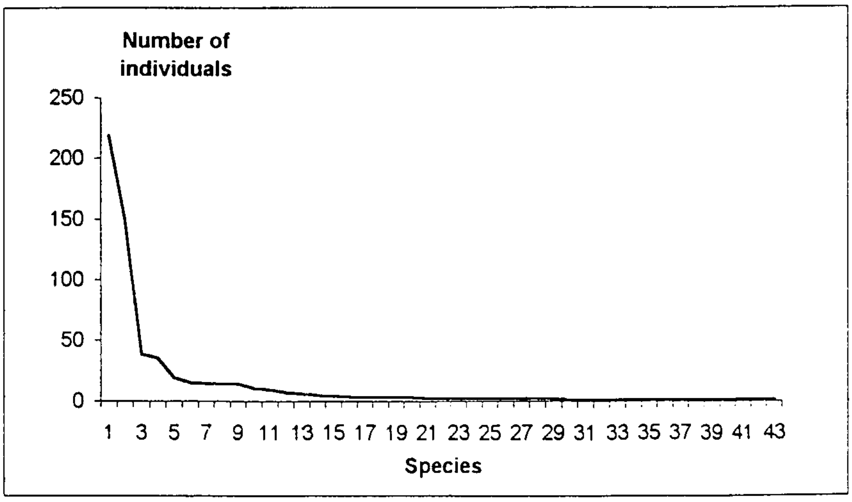

Fig. 3.7. Rank abundance plot of the arboreal insects in the A-plot.

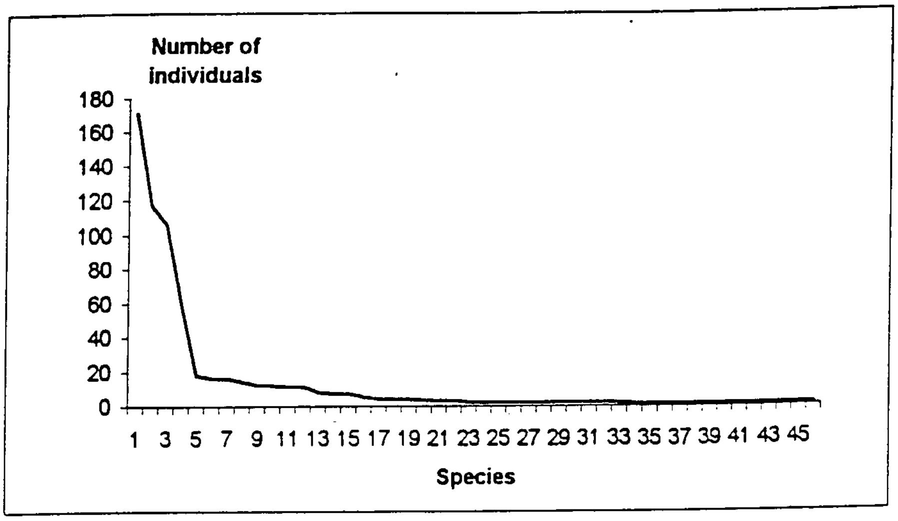

Fig. 3.8. Rank abundance plot of the arboreal insects in the B-plot.

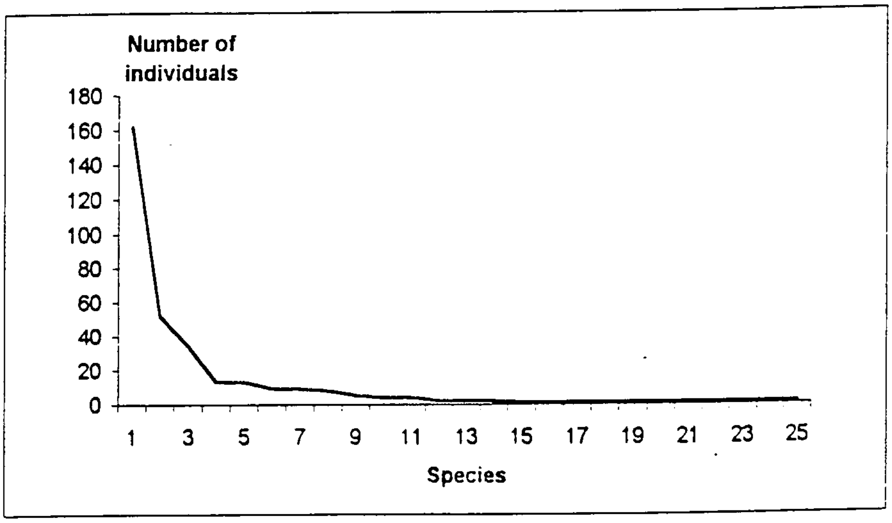

Fig. 3.9. Rank abundance plot of the arboreal insects in the C-plot.

3.3.3. Proportional abundance of species

3.3.3.1. Diversity

Diversity is a very important aspect in ecology. The Shannon index is an indicator of the diversity in a community. Host plants present themselves to insects as 'islands' in a 'sea' of other vegetation (Stamps & Linit, 1998). The 'recourse concentration hypothesis' proposes that a net movement of insects onto large and out of small patches of vegetation would produce a pattern of increasing insect diversity with patch size (Matter, 1997).

Three aspects of recourse concentration are important, *i.e.* the density of host plants, the patch size and the patch diversity (Stamps & Linit, 1998). The more space, and thus niches, available, the greater the colonization rate of organisms and the extinction rate becomes less, resulting in greater species diversity. This is especially true for flying insects. The greater the patch, the more visual and chemical stimuli are available for the flying insect to react upon. The patches in the 1999 season (staggered planting dates) were larger than that of the mixed crop in 1998. More insects, and thus a greater diversity, were found in the 1999 season (Fig. 3.10) implying that a higher migration rate from the surrounding maize- and natural fields occurred in 1999, when the larger patches of amaranth were present.

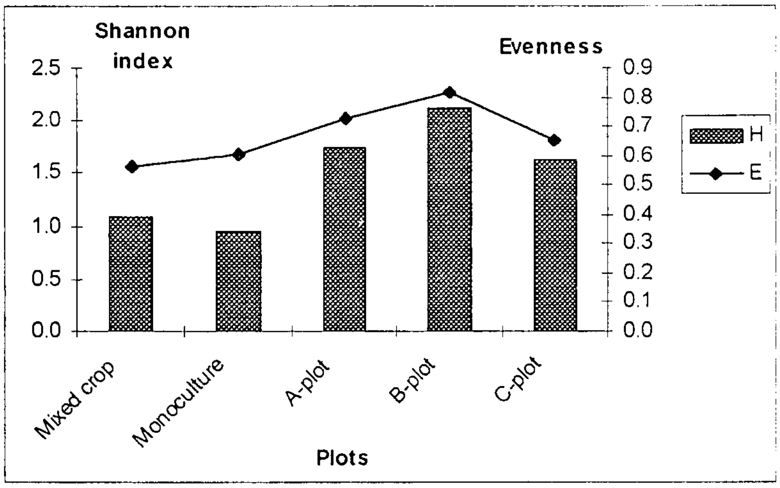

Fig. 3.10. Mean Shannon index (H) and Evenness (E) for the total number of arboreal insects collected in 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (SE (H): 0.215; SE (E): 0.046).

Stamps & Linit (1998) also suggest that plants are less apparent or attractive to insects in a multispecies plant environment than in a single species environment. Flying insect pests are thus less efficient in finding and reacting to their host plants in mixed crop than in monoculture agriculture. When looking, however, at overall diversity between the monoculture (H= 0.945) and mixed crop (H= 1.084) setups, the mixed crop setup had a higher diversity (Fig. 3.10). This diversity encompasses phytophages, predators and parasitoids and the mixed crop setup enhances the abundance of the latter two (see also Chapter 4).

Small patches of plants in a heterogeneous habitat are islands from the point of view of the insects colonizing them. The equilibrium theory of island biogeography states that the number of species on an island is determined by a balance between immigration and extinction and that this balance is dynamic, with species continually going extinct and being replaced (through migration) by the same or different species (Begon, Harper & Townsend, 1990). This theory thus proposes that for each 'island' there will be an immigration rate of species arriving on the island per unit time. The immigration rate of species will decline because the more species that become established, the fewer niches are available for occupation (Fig. 3.11). The line will be steep at first, but the rate slowly declines until the point P is reached (P is the optimum number of species that can reach the island, since that is all the species that the outside source supports). The emigration curve (extinction) has an exponential shape and a positive slope, since as more species arrive there is a greater chance of some becoming extinct, *e.g.* competition between species will increase and population sizes may be reduced, both accelerating the rate of extinction (Price, 1984) (Fig. 3.11). Overall these opposing factors will act to eventually produce an equilibrium number of species on any given island (Price, 1984). The number of species where the lines cross (s) (Fig. 3.11) is a dynamic equilibrium and should be the characteristic species richness for the 'island' (Begon, *et al.*, 1990).

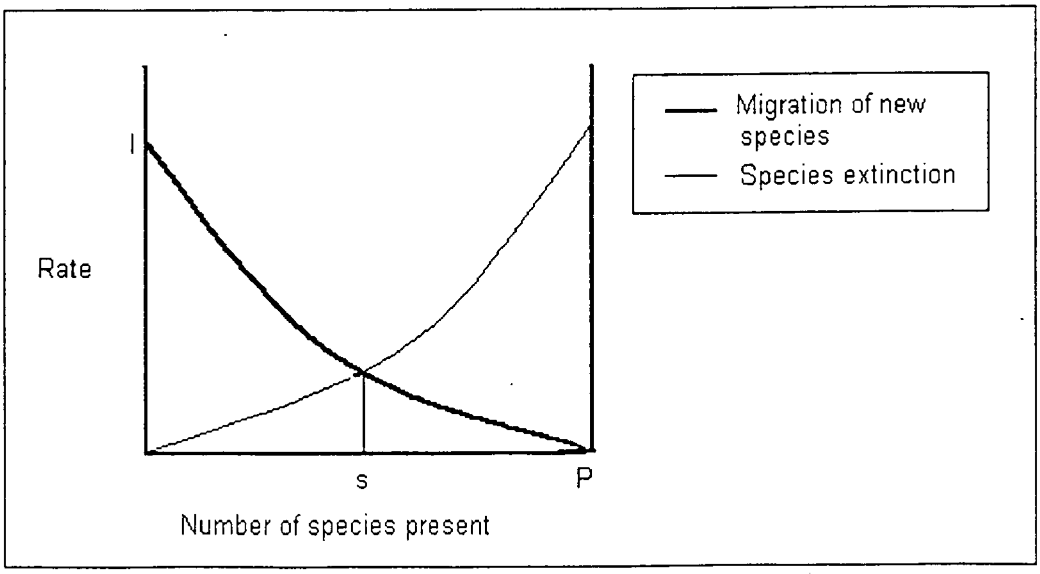

Fig.3.11. The relationship between migration to and extinction rates on an island that leads to an equilibrium number of species, s, on the island. I is the initial migration rate and P the total number of species in the source of colonizers (redrawn from Price, 1984).

This theory is a bit different for annual cropping systems. These systems can only be an island for a short period of time and are thus temporally restricted with an equilibrium that cannot be established over a lengthy time-span. The resource is only available and suitable for the insect for a short time. Many insect species are also only adapted to a specific growth stage of the plant. When that stage passes, the insect species move on to another island with plants in the favourable growth stage. The availability of niches can also determine if a community will reach equilibrium. If all niches are occupied, there is no space for other species that utilize the same niche. There can then be two outcomes, *i.e.* either competition can develop or stasis will be maintained until the plants die at the end of the growing season.

The island theory is complicated in the staggered planting dates scenario, because there are now consecutive islands in time within a close range. The B-plot has the highest diversity (Fig. 3.12) (Appendix 1.3), since the B-plot's growing season (*i.e.* mid-summer) coincides with peak insect populations. The species in the A-plot did not reach P, because later in its growing season the insects rather moved to the B-plot where the plants were greener. The B-plot had the highest immigration rate, because its peak growth stage coincides with peak insect populations. Many niches were thus available for colonization. The C-plot did not attract many insects. This plot was planted late in the season when many insect species had already completed their life-cycle or were already in an overwintering stage. An immigration-emigration scenario was thus non-existent in spite of niche availability.

Species were more evenly distributed in 1999 than in 1998 (Fig. 3.10). The distribution of species in the B-plot was the most even at 0.817, while the distribution of the other plots ranges between 0.561 and 0.731 (Appendix 1.2). There was thus less dominance in the B-plot than in the other plots. A figure of around 0.6 is, however, still low and does show a certain degree of dominance. The species in the C-plot were the most unevenly distributed in the first three samples (Fig. 3.12), which implies that the plot, which was planted late was inclined to attract pest species.

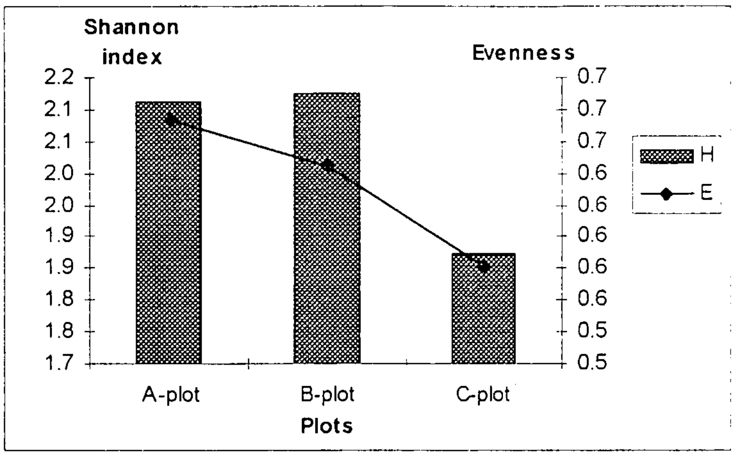

Fig. 3.12. Shannon (H) index and Evenness (E) for arboreal insects indicating the mean of the first three samples in each of the different plots in the staggered planting date culture (SE (H): 0.082; SE (E): 0.027).

3.3.3.2. Dominance

The Berger-Parker index is an indicator of the dominance in a community. The diversity increases and the dominance in the insect community decreases when the inverse value of the index (1/d) increases. The dominance in all plots over eight samples was very similar (Fig. 3.13) (Appendix 1.1) except in the B-plot where the dominance decreases rapidly towards the end of the season. The plants in the B-plot were the most stressed, especially towards the end of the season, and thus attracted many phytophagous insects during this time. The B-plot also had the lowest dominance (1/d= 3.573) and thus the highest diversity of species over the first three samples (Fig. 3.14) (Appendix 1.3). The B-plot growth stage and niche availability coincides with peak insect populations in mid-summer. The C-plot showed high dominance (1/d= 2.037), which may imply that this plot, which was planted late, was favourable for pest populations (Fig. 3.14).

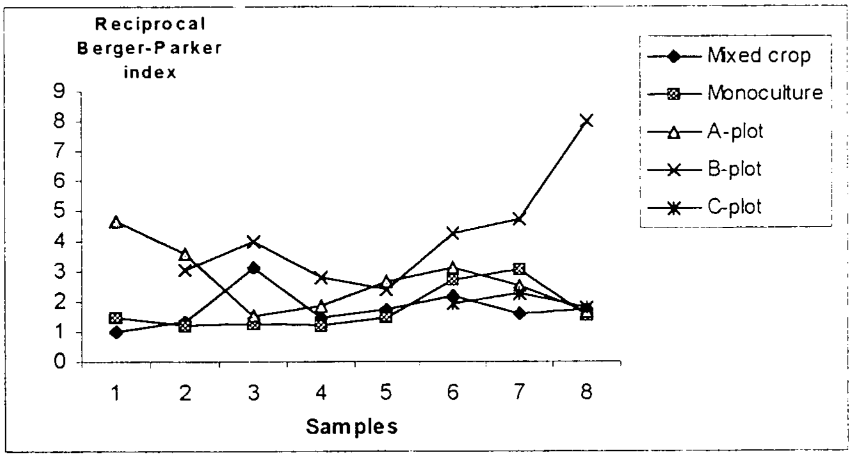

Fig. 3.13. Inverse of Berger-Parker (1/d) index for arboreal insects in five different plots (mixed crop, monoculture, A-plot, B-plot and C-plot).

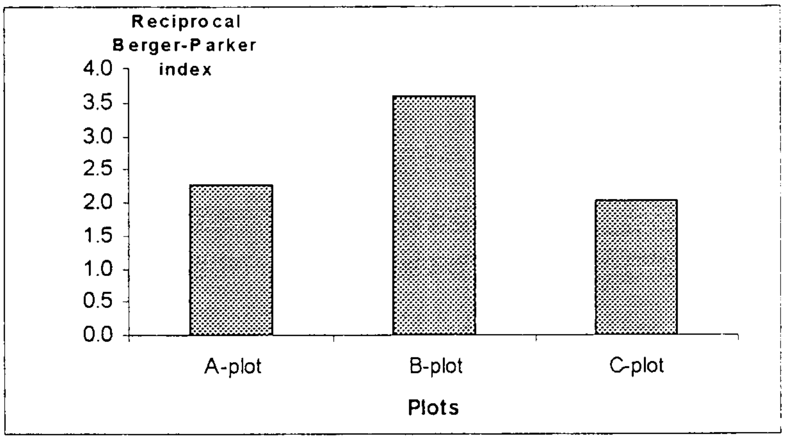

Fig. 3.14. Inverse of Berger-Parker (1/d) index for arboreal insects indicating the mean of the first three samples of each plot in the staggered planting dates setup (SE: 0.477).

The 1999 season had lower dominance than the 1998 season (Fig. 3.15) (Appendix 1.2). This can be attributed to the 'plant-stress hypothesis' that insect populations on stressed plants are more diverse (the plants in 1999 were stressed and those in 1998 not). Alternatively, because the plots were bigger in 1999 than in 1998, they could have attracted a higher insect diversity (if the 'resource concentration hypothesis' is supported) (Matter, 1997).

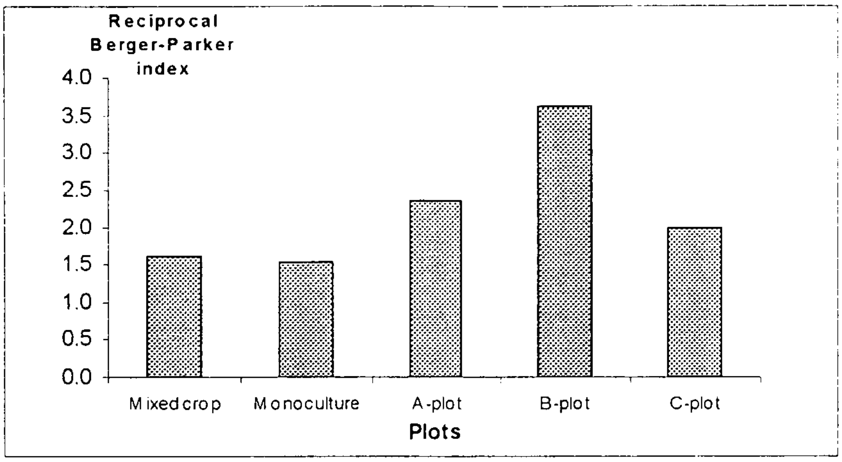

Fig. 3.15. Mean inverse of Berger-Parker (1/d) index for the total number of arboreal insects collected in 1998 (mix crop and monoculture) and in 1999 (staggered planting dates) (SE: 0.383).

To be dominant animals must possess adaptations that are general in nature and will promote their survival in every environment they invade. To occupy a large area, be competitively superior, or an effective colonizer, a species must have accumulated a large number of general adaptations (Price, 1984). The most dominant groups seem to evolve in the largest areas with the most favourable climate.

3.3.4. Similarity

The Bray-Curtis index calculated the insect similarity between all the plots (Table 1) and this was then processed into a dendrogram (Fig. 3.16) via a matrix (Appendix 2). The monoculture and the A-plot were the most similar (0.539), followed by the B-plot and C-plot (0.396) (Table 1, Fig. 3.16). The mixed crop was the most dissimilar at 0.245 (Table 1, Fig. 3.16).

Table 1. Bray-Curtis indices for the first three samples in each of the five different plots (1 as the most similar and 0 the most dissimilar).

	Monoculture	Mixed crop	A-plot	B-plot	C-plot
Mixed crop	0.377	*	0.229	0.33	0.045
Monoculture	*	0.377	0.539	0.278	0.245
A-plot	0.539	0.229	*	0.515	0.369
B-plot	0.278	0.33	0.515	*	0.411
C-plot	0.245	0.045	0.369	0.411	*

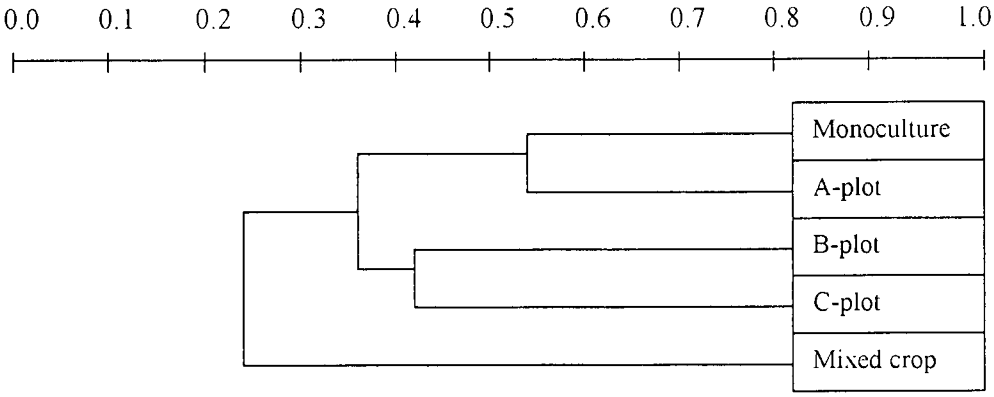

Fig. 3.16 Bray-Curtis index dendrogram to show the most similar plots.

This index formulates the most similar sites closer to 1 and the most dissimilar sites closer to 0. Thus, all the plots are relatively dissimilar from each other. The first three samples of the monoculture and the A-plot were similar because they were planted at the same time (November) in 1997 and 1998. The plants were also in very much the same condition for the first three samples. The diversity in the B- and C-plot was similar because plant conditions were more or less the same for the first three samples taken. An important cluster occurs between the mixed crop and the pure amaranth stands, which clearly shows the difference between a single plant species stand (in this case amaranth) and a more diverse plant stand (amaranth, maize, sunflower and pumpkin). The mixed crop was thus the most dissimilar, due to smaller patches in a diverse plant agroecosystem.

3.4. CONCLUSION

Annual cropping systems are variable in time and space. Flying insects see these systems as islands. The greater the island or patch of vegetation, the greater the immigration rate. It is probable that this is the reason why the 1999 season had a higher insect abundance and diversity than in 1998 with the smaller vegetation patches. The B-plot in the staggered planting date setup coincides with peak insect populations and thus had a more diverse fauna. Comparing the monoculture and mixed crop setup, the mixed crop had a higher diversity of insects. Thus, a more diverse habitat seemingly supports a more diverse insect fauna.

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Appendix 1

(S: Species; N: Total number of insects; Dmg: Margalef index; H: Shannon index;
E: Evenness; d: Berger-Parker index)

1.1. Diversity indices of individual samples in five different plots.

	1	2	3	4	5	6	7	8
1998	**03/02**	**19/02**	**06/03**	**18/03**	**01/04**	**15/04**	**29/04**	**15/05**
Mixed crop								
S	1	2	7	8	14	9	10	9
Cum. S	1	3	10	13	22	24	25	27
N	1	4	22	68	89	64	89	106
Dmg	0.000	0.721	1.941	1.659	2.896	1.924	2.005	1.715
H	0.000	0.562	1.664	1.215	1.567	1.423	1.224	1.019
E	0.000	0.811	0.855	0.584	0.594	0.648	0.532	0.464
d	1.000	0.750	0.318	0.676	0.573	0.453	0.618	0.585
1/d	1.000	1.333	3.143	1.478	1.745	2.207	1.618	1.710
Monoculture								
S	6	2	5	4	6	9	6	3
Cum. S	6	7	9	9	13	17	18	19
N	46	7	41	21	28	47	52	21
Dmg	1.306	0.514	1.077	0.985	1.501	2.078	1.265	0.657
H	0.958	0.410	0.814	0.567	1.087	1.636	1.318	0.773
E	0.534	0.592	0.506	0.409	0.606	0.745	0.735	0.704
d	0.696	0.857	0.780	0.857	0.679	0.362	0.327	0.667
1/d	1.438	1.167	1.281	1.167	1.474	2.765	3.059	1.500
1999	**29/01**	**10/02**	**25/02**	**11/03**	**23/03**	**08/04**	**30/04**	**21/05**
A-plot								
S	9	12	15	19	17	20	10	3
Cum. S	9	16	23	32	38	42	42	43
N	14	43	97	140	142	107	56	5
Dmg	3.031	2.925	3.060	3.643	3.229	4.066	2.236	1.243
H	2.107	2.009	1.437	1.575	1.743	2.284	1.780	0.950
E	0.959	0.808	0.531	0.535	0.615	0.763	0.773	0.865
d	0.214	0.279	0.660	0.543	0.373	0.318	0.393	0.600
1/d	4.667	3.583	1.516	1.842	2.679	3.147	2.545	1.667

Appendix 1 (continued)

B-plot

S		7	16	21	21	16	16	8
Cum. S		7	16	27	34	39	44	46
N		73	44	251	119	85	66	8
Dmg		1.398	3.964	3.620	4.185	3.376	3.580	3.366
H		1.709	2.360	1.784	2.145	2.264	2.446	2.079
E		0.878	0.851	0.586	0.705	0.816	0.882	1.000
d		0.329	0.250	0.355	0.420	0.235	0.212	0.125
1/d		3.042	4.000	2.820	2.380	4.250	4.714	8.000

C-plot

S						15	16	7
Cum. S						15	22	25
N						164	125	41
Dmg						2.745	3.107	1.616
H						1.700	1.848	1.292
E						0.628	0.666	0.664
d						0.512	0.440	0.561
1/d						1.952	2.273	1.783

1.2. The mean of diversity indices of insects sampled in 1998 (mixed crop and monoculture) and in 1999 (staggered planting dates).

	S	N	Dmg	H	E	d	1/d
Mixed crop	27	465	1.608	1.084	0.561	0.622	1.608
Monoculture	19	277	1.173	0.945	0.604	0.653	1.531
A-plot	43	606	2.929	1.736	0.731	0.422	2.367
B-plot	46	646	3.356	2.112	0.817	0.275	3.635
C-plot	25	330	2.489	1.613	0.653	0.504	1.983

1.3. Diversity indices of the first three samples in the staggered planting dates culture.

	S	N	Dmg	H	E	d	1/d
A-plot	23	148	4.402	2.112	0.674	0.439	2.277
B-plot	27	368	4.401	2.124	0.644	0.280	3.573
C-plot	25	330	4.139	1.873	0.582	0.491	2.037

APPENDIX 2

Matrixes of the Bray-Curtis index for 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) on which the Bray-Curtis index dendrogram (Fig. 3.16) is based.

(Mixed crop= M, Monoculture= MC, A-plot= A, B-plot= B, C-plot= C)

MATRIX 1

	M	MC	A	B	C
M		0.377	0.229	0.33	0.045
MC			0.539	0.278	0.245
A				0.515	0.369
B					0.411
C					

MATRIX 2

	MC/A	M	B	C
MC/A		0.303	0.396	0.307
M			0.33	0.045
B				0.411
C				

MATRIX 3

	MC/A	B/C	M
MC/A		0.352	0.303
B/C			0.187
M			

MATRIX 4

	MC/A/B/C	M
MC/A/B/C		0.245
M		

Values of the different clusters in the Bray-Curtis index dendrogram (Fig. 3.16) derived from the matrixes.

MC/A	0.539
B/C	0.411
MC/A/B/C	0.352
MC/A/B/C/M	0.245

CHAPTER 4

FEEDING GUILDS AND DOMINANCE STRUCTURES OF ARBOREAL INSECTS IN THREE DIFFERENT CULTIVATION PRACTICES

4.1. INTRODUCTION

The functioning of an ecosystem depends on the interaction of its different elements (Odum, 1993; Louw, 1998). Green plants fix the sun's energy and as producers form the basis of a food web. Plants provide nutrition for insect herbivores (phytophages). The phytophages in turn provide nutrition for predators and parasitoids (natural enemies of phytophagous insects). Other elements, amongst others, include hyperpredators and hyperparasitoids that make the ecosystem even more complex.

The plant (primary producer) can be a very complex structure with different niches and can modify the interactions between the different components in an ecosystem. The *Amaranthus* plant has a complex architecture with a wide variety of niches, *i.e.* roots, stem, leaves and seed heads, all of which are utilised by an array of insect species. Of these the seed heads of the amaranth plant attract the highest diversity of insect species (personal observation). It is not only the different niches on the plant that affect the number of species or colonisation rate of phytophages, but also the size, shape, texture and nutritional value of the plant. Overall the food source will affect the size, survivorship, development time and density of the phytophagous species on the crop (Bottrell, Barbosa & Gould, 1998).

Phytophages are killed by a taxonomically and ecologically diverse range of natural enemies which includes insect predators, parasitoids, nematodes, fungi, protists, bacteria and viruses (Hawkins, Cornell & Hochberg, 1997). Natural enemies are an important source of herbivore mortality. Predators are free-living and usually larger than their prey, which serve as an energy source but not as a habitat. Predation plays an important role in the economy of nature, and it is beneficial to human economy as well when it comes to the control of insects (Odum, 1993). A parasitoid adult is a free-living insect and it deposits its eggs or larvae inside another organism (host). These immature stages live in or on the host and eventually kill it. Biological control with parasitoids is feasible for they are sometimes specific for the species one wishes to control. Such a parasite constantly keeps at work and can quickly adjust to increases and decreases in host numbers. In contrast, a pest usually can not be controlled by the introduction of a general predator, which may in itself become a pest if it spreads its attack to species other than the intended target (Odum, 1993). There are also many factors in a crop field that affect the colonisation and efficiency of natural enemies. Plants may influence the natural enemies directly by releasing behaviour modifying chemicals or indirectly by affecting their hosts or prey. Other plant effects include plant morphology, like texture (e.g. slippery leaves, trichomes) and plant structure that may influence the natural enemies' searching efficiency (Bottrell, *et al.*, 1998). Because all phytophages derive their nutrition from plants, the natural enemies using them as host or prey indirectly obtain their nutrition from the plants. Just as the food source affects the phytophages, so it also indirectly affects the natural enemies that feed on the phytophages (Bottrell *et al.*, 1998).

Many agroecosystems are unfavourable environments for natural enemies due to high levels of disturbance. These systems are, however, favourable for pests. The need for habitat management is therefore directly linked to the biology of specific pests and natural enemies (Landis, Wratten & Gurr, 2000). Acceptable crop yield is, amongst other factors, dependent upon the influence of insects. In this chapter the insect trophic interactions on amaranth were studied and the influence of cultivation methods on these interactions was also determined. Such an IPM approach is important in successful crop production.

The following questions were asked in this part of the study :

1. How do the feeding guilds in three different practices, *i.e.* monoculture, mixed crops and staggered planting dates, compare?

2. How does the alate insect community compare with the arboreal insect community?
3. Which are the dominant insect groups and what are the tendencies observed in them?
4. Is there any correlation between the tendencies in the dominant phytophage, predator and parasitoid groups?

4.2. MATERIAL AND METHODS

As far as possible, all insects were collected from the plants with beating sheets, sweeping nets and aspirators and then killed with ethyl acetate. Intensive collecting was done on 20 plants per plot. Sampling was done in 1998 on the monoculture amaranth and also in the mixed crop plots (Fig. 2.2). Samples were also taken from the other crops (sunflower, maize and pumpkin) in the mixed crop setup. In 1999 sampling was done on the staggered planting date crops. The plots were planted 30 November, 30 December and 30 January and were named A-plot, B-plot and C-plot, respectively (Fig. 2.3). The insects were identified to family level at least and counted in the laboratory, before being preserved in 70% ethanol. The different insect feeding guilds and the relationship between them were determined for all the samples in the mixed crop and monoculture in 1998 (Appendix 1.1) and for the first three (Appendix 1.2) and last three samples (Appendix 1.3) in each plot of the staggered planting date setup in 1999. The first three samples were taken to compare plants in more or less the same growth stage. The last three samples were used to coincide with the sampling conducted with the malaise trap. The dominant families were calculated by the number of individuals of an insect species expressed as a percentage of the total number of individuals in the sample (Appendix 1.1 and 1.2) (Wassner, 1994). Following the results in Appendix 1.1 and 1.2 dominant species were taken as comprising more than 2% for the predators and more than 20% for the phytophages (marked with an arrow ←). The tendencies in these species were then followed.

A malaise trap was used to sample insects in 1999, especially the parasitoids, that moved in and out of the cultivated land. Data was collected in this manner during the staggered planting date trial only (Appendix 2). The parasitic category included all species that were either parasitic in the adult stage, or parasitic as immatures regardless their of adult diet, known to mainly consist of nectar, pollen and/or host fluids (*sensu* Siemann, Tilman, Haarstad & Ritchie, 1998).

4.3. RESULTS AND DISCUSSION

Crops grown in monoculture systems often suffer from severe pest problems. Monoculture reduces a complex natural plant system to a single-species community. This can lead to decreased insect diversity and can promote rapid population growth of a single or very few insect species. Multi-species cropping systems increase plant diversity and decrease the possibility of pest problems, but increase the diversity of phytophages. In a review of 209 studies on 287 species of phytophages, approximately 52% of the species had lower densities in polycultural, compared to monocultural, cropping systems. Only 15% had higher densities (Stamps & Linit, 1998). The results of this study correspond with these findings. In the mixed crop setup (Fig. 4.1) a slightly lower abundance of phytophagous species can be seen compared to that in the monoculture (Fig. 4.2). These data support the resource concentration hypothesis, which suggests that plants are less apparent or attractive to phytophagous insects in multispecies plant environments. Phytophages are more likely to locate and remain on hosts occurring in large dense stands compared to plants that occur in association with other plant species (Stamps & Linit, 1998).

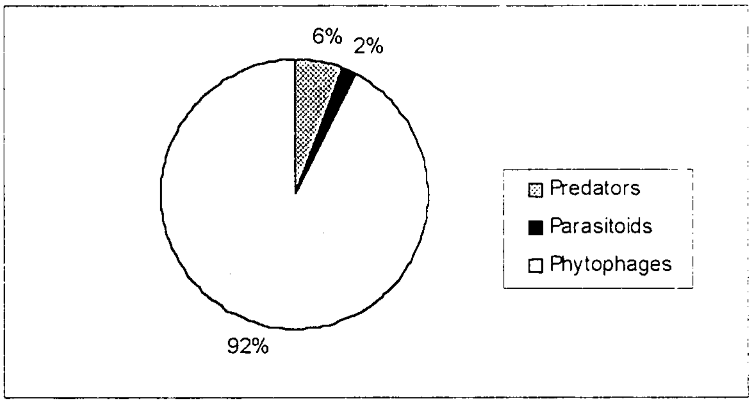

Fig. 4.1. Arboreal insect guilds on *Amaranthus hybridus* determined over eight samples in the mixed crop setup, 1998.

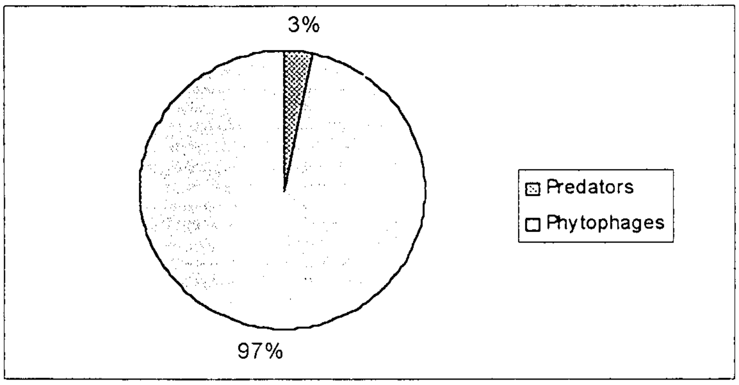

Fig. 4.2. Arboreal insect guilds on *Amaranthus hybridus* determined over eight samples in the monoculture, 1998.

The 'enemy hypothesis' predicts that natural enemies will be more abundant in complex than in simple plant systems and that their action will result in lower herbivore population densities (Verkerk, Leather, & Wright, 1998), explaining the lower abundance of phytophages in the mixed crop. By increasing the plant diversity, niches are also diversified and consequently the diversity of phytophages will increase. A higher diversity of phytophages will in turn maintain a higher diversity of parasitoids and predators. Increased plant diversity could also increase the diversity of higher trophic levels directly by increasing the diversity of floral resources that many parasitoids and predators utilise or require (Siemann, *et al.*, 1998). It can also be added that the presence of C_4 plants tends to increase herbivore species richness (Siemann, *et al.*, 1998), *Amaranthus* being a C_4 plant.

In the 1999 season the A-plot had the highest incidence of natural enemies, followed by the C-plot and the B-plot (Fig. 4.3). The plants in 1999 experienced root diseases, and were thus in a bad condition, especially in the B-plot. For the first three samples the A-plot was in a more or less healthy condition and the C-plot was planted too late to experience the full impact of the diseases. The fact that the B-plot had the highest incidence of phytophages corresponds with what the 'plant-stress hypothesis' predicts. This hypothesis suggests that herbivore abundance is higher on hosts under stressful conditions. This happens due to decreased chemical defences in stressed host tissue (Cornelissen, Madeira, Allain, Lara, Araujo & Fernandes, 1997). Phytophagous species on stressed plants are more likely to become pests than the same species on vigorous plants (Price, 1997).

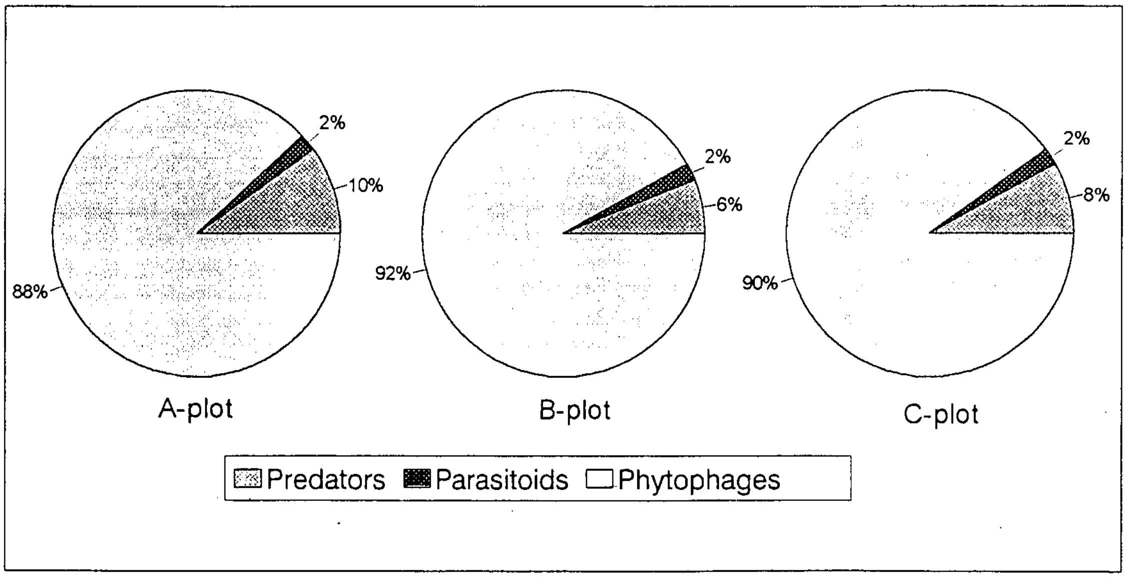

Fig.4.3. Arboreal insect guilds on *Amaranthus hybridus* determined over the first three samples in each plot of the staggered planting date setup, 1999.

The colonisation of a crop field depends in part on flying insects migrating from other plant plots. To monitor these insects, a malaise trap was used (Appendix 2). These insects may be established on the plants (and are then called arboreal) and are totally dependent on the plant, while other insects fly around in the amaranth environment, just occasionally landing on the plant. An example of such a group is the parasitoids. These insects are difficult to monitor on the plants, because the adult only stays a short time (just to deposit her eggs or larvae). In previous studies it was found that parasitoids kill more immature herbivores than do either predators or pathogens (Hawkins, Cornell, Hochberg, 1997). It is apparent that the ratio of phytophage/predator/parasitoid is very different for insects flying into and out of a particular ecosystem (Fig. 4.4) than for arboreal insects caught during the same time interval in the same ecosystem (last three samples of each plot (Fig. 4.5) (Appendix 1.3). This is indicative of the fact that the phytophagous insects depend on their host plant. They will stay on the plant till they have completed their life cycle and then fly out of the system, or die. On the other hand, beneficial insects like parasitoids and to a lesser degree predators, have greater freedom of movement as they have to hunt for their prey. Predators in this study were mostly terrestrial and consequently only the few flying predator species were caught by the malaise trap. The data of the last three samples in each of the staggered planting dates plots were used for comparative reasons - this was more or less the same time that the malaise trap was in use.

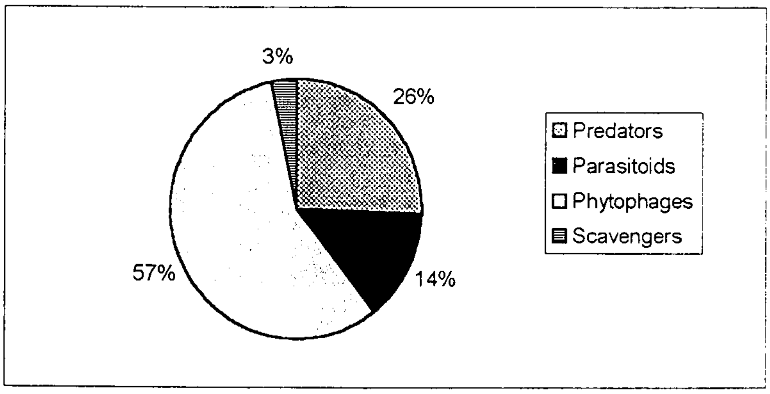

Fig. 4.4. Alate insect guilds collected by the malaise trap over three samples, April – May 1999.

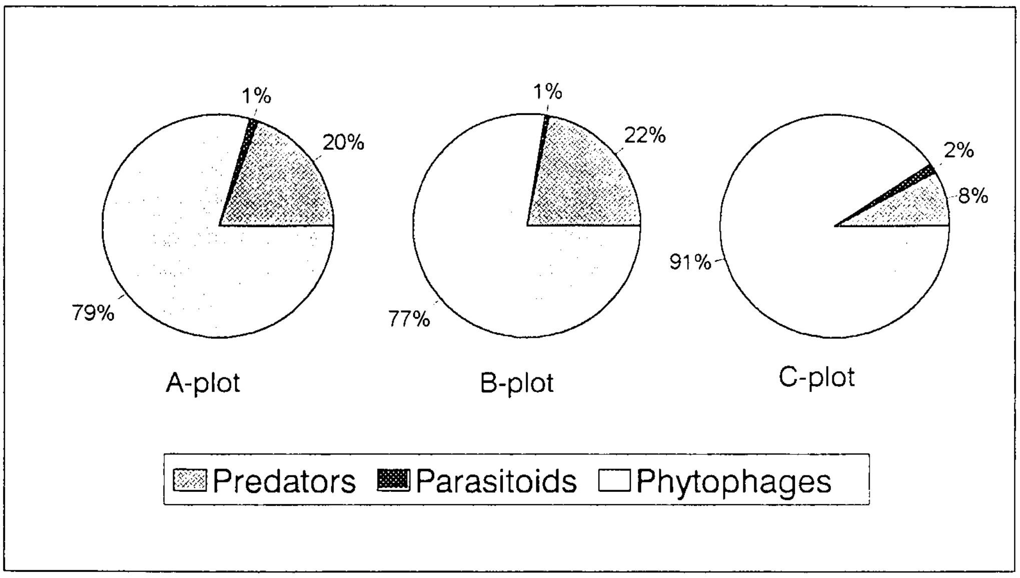

Fig. 4.5. Arboreal insect guilds on *Amaranthus hybridus* determined over the last three samples in each plot of the staggered planting date setup, April – May 1999.

The dominant arboreal families can have a major influence on crop yield. Species were expressed as a percentage of the total (Appendix 1.1 and 1.2) and then the dominant species were taken on more than 2% for predators and more than 20% for phytophages. The main predator families were Araneae (spiders) and Coccinellidae (Coleoptera) (Table 1). The dominant phytophage families on *A. hybridus* were Melyridae (Coleoptera), Miridae (Hemiptera), Aphididae (Homoptera) and Thripidae (Thysanoptera) (Table 1). There was no apparent correlation between the numbers of the phytophagous community and the numbers of the predator populations. Thus, here it would seem that an increase in the phytophage community does not necessarily induce an increase in the natural enemy community.

Table 1. Dominant arboreal families in different cultivation practices of *Amaranthus hybridus*, 1998 (mixed crop and monoculture, over eight samples) and 1999 (staggered planting dates, over first three samples) with the families expressed as a percentage of the total.

	Mixed	Crop	Monocu	lture	A-	plot	B-	plot	C-	plot
	Total	%	Total	%	Total	%	Total	%	Total	%
Predators										
Araneae spp	4	0.86	1	0.36	7	4.73	4	1.09	17	5.15
Coccinellidae sp	19	4.09	6	2.17	1	0.68	11	2.99	5	1.52
Phytophages										
Melyridae sp1	110	23.66	86	31.05	65	43.92	93	25.27	52	15.76
Miridae sp1	130	27.00	52	18.77	3	2.03	57	15.49	162	49.09
Aphididae spp	129	957.00	67	24.19	26	17.57	46	12.50	9	2.73
Thripidae sp1	16	3.44	10	3.61	13	8.78	103	27.99	13	3.94

Spiders (Araneae) (Fig. 4.6) are one of the most common predator groups found in agro-ecosystems. They have special adaptations towards a predatory way of life. Most spiders feed on a variety of prey and predation on adult prey, eggs and immature stages occurs. Spiders are thus potentially important predators that can be used in an IPM programme.

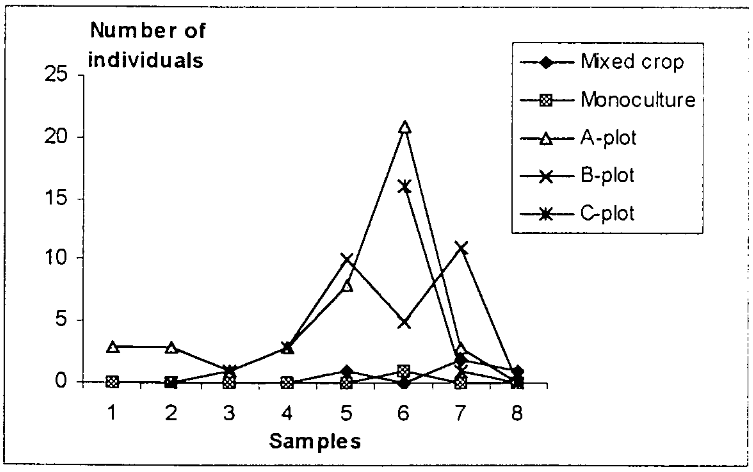

Fig. 4.6. Araneae sampled on *Amaranthus hybridus* in five different plots, 1998 and 1999.

Spiders are also exceptionally well-adapted to adverse environmental conditions (Van den Berg & Dippenaar-Schoeman, 1999). This can be the reason why they were less apparent in 1998 (healthy plants) compared to numbers in 1999 (stressed plants) (Fig.4.6). Especially towards the end of the season (sample 5-7) when the plants were really in a weak condition there was an increase in the number of spiders. Spiders were probably better adapted than other predators for these conditions and due to increasing phytophage numbers (stressed plants) spiders had an advantage and could increase in numbers. The other predators could have moved to border areas at the end of the season, but the spiders prevailed. Consequently more of them were sampled.

Coccinellidae are important predators of aphids. Five different Coccinellidae species were sampled, of which *Hippodamia variegata* and a *Scymnus* sp. were the most abundant. An increase in the aphid population does not induce an increase in Coccinellidae numbers. Thus, there is no correlation, except perhaps in the C-plot (Fig. 4.7), where a lot of aphids were sampled in the first sample. In the second sample Coccinellidae numbers increased.

Coccinellidae must search for specific prey, and plant architecture has a major influence on their searching efficiency. *A. hybridus* has a complex architecture that makes searching for and finding prey difficult. Aphids feed in concealed places, due to reasons such as escaping from prey and desiccation (Larsson, Häggerström & Denno, 1997). Plant architecture is thus an important component in determining the predation risk of aphids (Clark & Messina, 1998). Because it is difficult to find prey on amaranth, Coccinellidae beetles prefer plants with a less complex architecture such as maize, as was the case in 1998 in the mixed crop setup (Fig. 4.8). Although there were fewer aphids on the maize, less time was spent in searching for them, which was thus more advantageous in terms of energy economy.

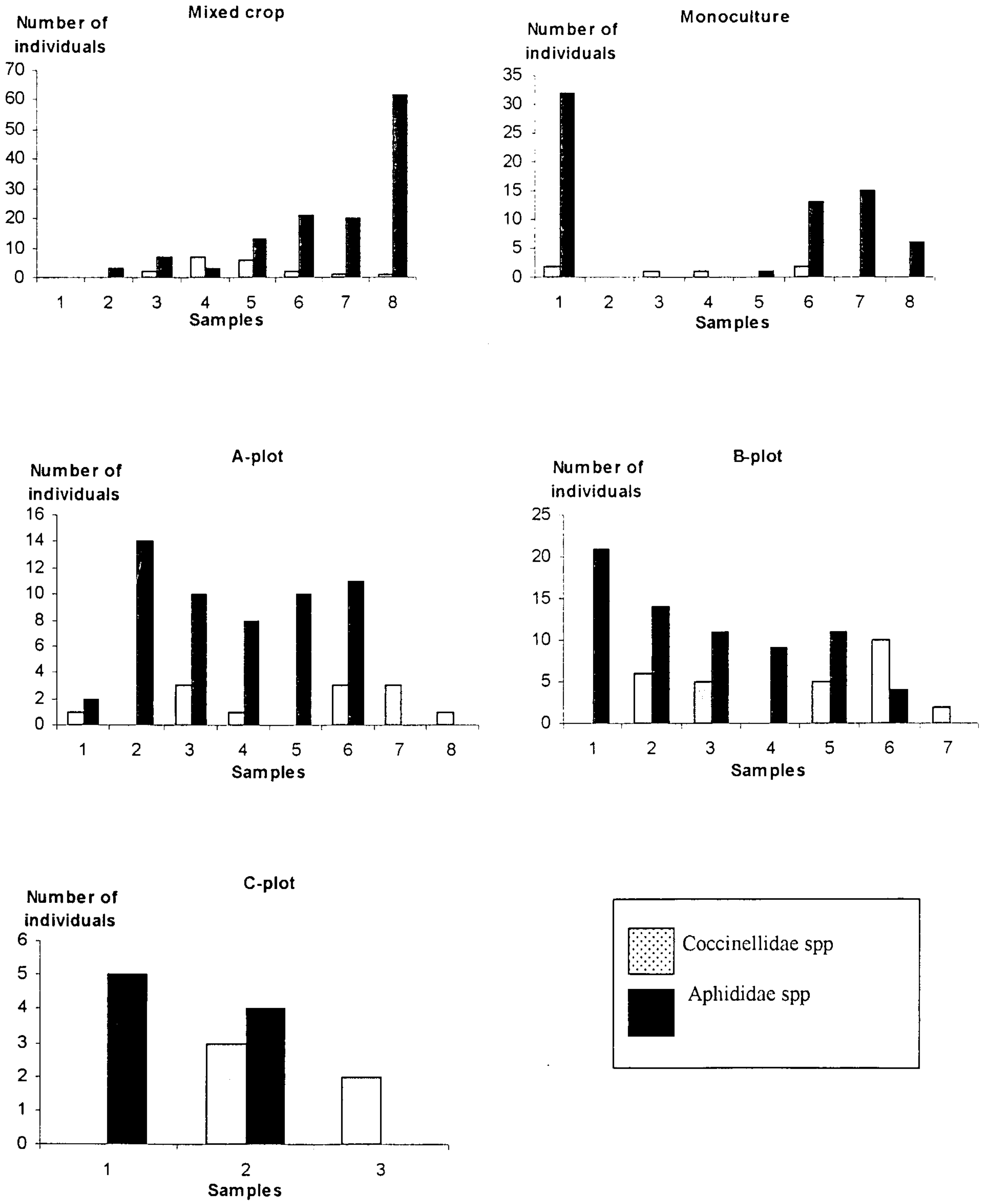

Fig. 4.7. Coccinellidae and Aphididae sampled on *Amaranthus hybridus* in 1998 (mixed crop and monoculture) and 1999 (staggered planting dates).

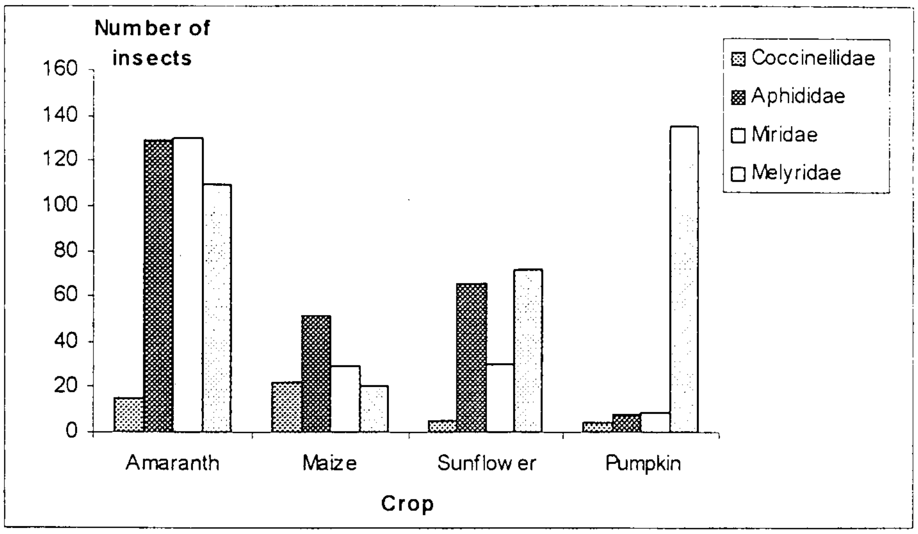

Fig. 4.8 Dominant phytophagous families on other crops in the mixed crop setup (maize, sunflower and pumpkin) compared to amaranth, 1998.

Although Coccinellidae beetles have been used to control aphids, they are rarely effective in reducing aphid abundance. Aphids have very high rates of increase and are very sensitive to changes in the qualities of their host plants. Aphid colonies rarely last for more than a month. It is thus a very unstable and unreliable food source for predators (Hemptinne & Dixon, 1997). There is also evidence of intraguild predation where Coccinellidae eat the eggs of another aphidophagous insect, the green lacewing (Chrysopidae) or the larval instars of the latter attack the larvae of Coccinellidae (Lucas, 1998). Factors like these thus also influence the effectiveness of Coccinellidae as predators.

Astylus atromaculatus (Melyridae) is a pollen feeder, and thus is more abundant at the beginning of the growing season, coinciding with pollen formation and shedding (Fig. 4.9). The numbers in 1998 are lower than in 1999, because these insects rather preferred the pumpkin that was part of the mixed crop setup (Fig. 4.8).

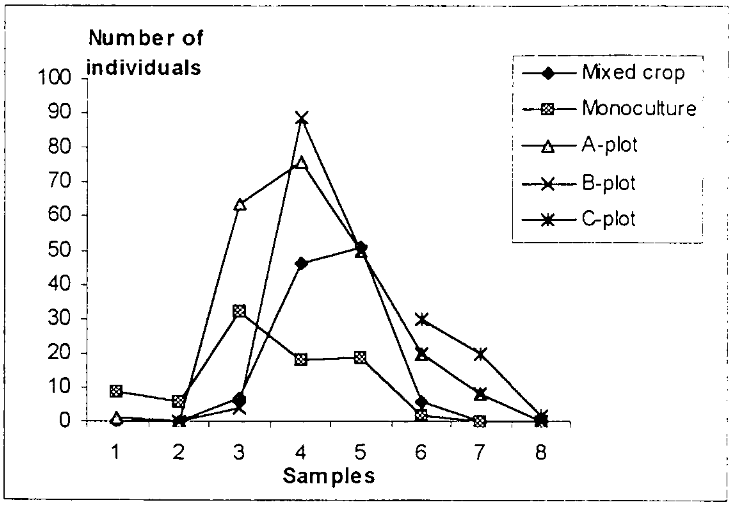

Fig. 4.9. *Astylus atromaculatus* (Melyridae) sampled on *Amaranthus hybridus* in five different plots, 1998 and 1999.

The shift of *A. atromaculatus* from one plot to the following as the different growing stages follow one another, can be seen in the staggered planting dates experiment (Fig. 4.9). From the A-plot they immigrated to the B-plot and then to the C-plot. In the C-plot, high numbers were not achieved, because all the plants did not reach the pollen-shedding stage. The plants in this plot were planted too late, and at a certain time, the plants just stopped growing when their photosynthesis pumps shut down.

Lygus sp. (Miridae) is a major pest of *Amaranthus* and especially of grain *Amaranthus* (Whitbread & Lea, 1982). This is a seed-sucking insect, and thus occurred nearer to the end of the growing season, when the seed-sucking niche was available (Fig. 4.10). In 1998, the insects mainly immigrated from the sunflowers that were in die back and went to the maturing seeds of the *Amaranthus*. Note that the C-plot in 1999 had a very high abundance at the end of the season. This is very interesting because the plants in this plot never reached the seed-forming stage. This plot was probably only used as a refugium before the insects went into their overwintering phase, or died.

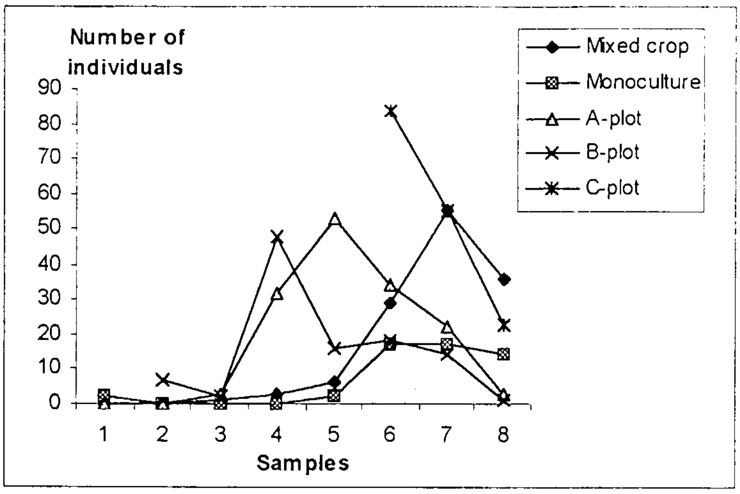

Fig. 4.10. *Lygus* sp. (Miridae) sampled on *Amaranthus hybridus* in five different plots, 1998 and 1999.

The Aphididae consisted mainly of two species, *i.e. Rhopalosiphum padi* and *R. maidis*. There were more aphids in 1999 than in 1998. These results correspond with results from other studies where sap sucking pests performed better on stressed plants than chewing insects did (Koricheva, Larsson & Haukioja, 1998). Sampling of aphids is impeded due to them feeding in concealed places and thus sampling was intensified in 1999. In the monoculture the number of Aphididae first disappeared, then reappeared and increased before decreasing towards the end of the study (Fig. 4.7). The mixed crop had a low abundance of aphids in the beginning of the study, but an increase towards the end. Most aphids were located on sunflower, but as the sunflowers come to the end of their growing season, the aphids migrated to the greener amaranth from sample 5 onwards (Fig. 4.7). This was also the case with the aphids on the monoculture. This aphid number increase was towards the end of the amaranth growth phase even though the plants were in die back. The aphids collected during this period were located mostly on the lower parts of the plants where they were more protected against the cold or in association with the greener growth around the seedheads. In 1999 the B-plot had the highest incidence of Aphididae (Fig. 4.7). The plants in this plot were stressed and thus promoted the development of pest populations. The C-plot had a low aphid incidence. These plants were planted too late and could not really be a food source for an extended period. The aphids found on them were probably just using them as refugium.

A small number of species may become very abundant on *A. hybridus* (Table 1). However, the overwhelming majority of species are never abundant and many are rare (Appendix 1). Interactions of the few abundant species with their host plants are expected to be harmful. There are, however, phytophagous species of high abundance, which exert only a low, if any, impact on their host. There is thus little or no impact on the condition of the host plant. Possibly only competition holds these populations in check (Bauer, 1998). The family Thripidae contains such species (Fig. 4.11).

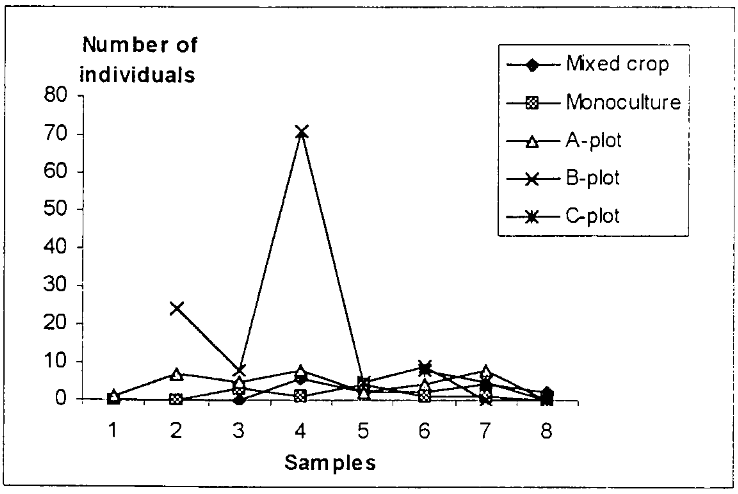

Fig. 4.11. Thripidae sampled on *Amaranthus hybridus* in five different plots, 1998 and 1999.

Thripidae did not show major peaks during the study except in the B-plot where they had a very high abundance, especially at sample 4 (Fig. 4.11). The B-plot's plants were more stressed than the plants in the other plots and the conditions were thus favourable for rapid population growth *re* 'plant stress hypothesis' (Price, 1997). Although this species from this family may have a low impact on the plant, it can act as vector of certain viral pathogens to the plants.

4.4. CONCLUSION

Phytophagous arboreal insects are directly linked to the plant and influence the plant accordingly. In turn natural enemies influence the arboreal phytophagous insects. The phytophages and consequently also the natural enemies were more diverse in the mixed crop setup compared to the monoculture. Better control of phytophages can probably be achieved. In 1999 the natural enemies were more abundant in the A-plot, the plot that was planted first in the staggered planting dates culture. It thus seems more advantageous to plant early and in a polycultural setup. Two of the dominant families surveyed were predators and the other four were phytophages. No correlation was made between the numbers in the phytophagous community and the predatory community. Thus, in this survey an increase in phytophagous insects does not appear to have induced an increase in the predatory insects. Many beneficial insects such as parasitoids and predators actively fly around in the amaranth environment. The arboreal insects fly in and settle on plants, whereas parasitoids and predators are less predictable. Some predators, however, are terrestrial and do not fly. All in all cultural practices are therefore important, enhancing the abundance of beneficial insects, and consequently also important in biological control.

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Appendix 1

1.1. Arboreal insects sampled on amaranth over eight samples in the mixed crop and monoculture setup in 1998 with each species expressed as a percentage of the total (dominant species indicated with an arrow)

		Total	Percentage	
Mixed crop				
Predators		**27**	**5.80**	
Reduviidae sp1		1	0.22	
Staphylinidae sp1		1	0.22	
Cleridae sp1		1	0.22	
Coccinellidae larva		4	0.86	
Coccinellidae sp	*Hippodamia variegata*	15	3.23	←
Tabanidae sp3		1	0.22	
Araneae sp	Salticidae sp1	4	0.86	
Parasitoids		**8**	**1.70**	
Chalcididae sp1		1	0.22	
Chalcidoidea sp10		3	0.65	
Diapriidae sp1		4	0.86	
Phytophages		**430**	**92.50**	
Onychiuridae sp1		1	0.22	
Entomobryidae sp1		6	1.29	
Neelidae sp2		15	3.23	
Miridae sp1	*Lygus* sp1	130	27.96	←
Scutteleridae sp1		1	0.22	
Pentatomidae sp1		3	0.65	
Aphididae sp1	*Rhopalosiphum padi*	129	27.74	←
Thripidae sp1		16	3.44	
Melyridae sp1	*Astylus atromaculatus*	110	23.66	←
Nitidulidae sp1		6	1.29	
Phalacridae sp2		1	0.22	
Chrysomelidae sp1		1	0.22	
Apionidae sp1		1	0.22	
Chironomidae sp1		2	0.43	
Syrphidae sp1		1	0.22	
Lepidoptera larva 1		6	1.29	
Apidae sp	*Apis mellifera*	1	0.22	
Total		**465**		
Monoculture				
Predators		**9**	**3.30**	
Staphylinidae sp1		1	0.36	
Coccinellidae larva		1	0.36	
Coccinellidae sp	*Hippodamia variegata*	5	1.81	
Sphecidae sp1		1	0.36	
Araneae sp	Salticidae sp1	1	0.36	

Appendix 1 (continued)

Parasitoids		**1**	**0.40**		
Chalcididae sp1		1	0.36		
Phytophages		**267**	**96.40**		
Onychiuridae sp1		10	3.61		
Entomobryidae sp1		3	1.08		
Neelidae sp2		1	0.36		
Miridae sp1	*Lygus* sp1	52	18.77		
Lygaeidae sp1		1	0.36		
Scutteleridae sp1		9	3.25		
Pentatomidae sp1		20	7.22		
Aphididae sp1	*Rhopalosiphum padi*	67	24.19	←	
Thripidae sp1		10	3.61		
Melyridae sp1	*Astylus atromaculatus*	86	31.05	←	
Chrysomelidae sp1		1	0.36		
Apionidae sp1		2	0.72		
Lepidoptera larva1		5	1.81		
Total		**277**			

1.2. Arboreal insects sampled on amaranth in the first three samples of each plot in the staggered planting date setup in 1999 with each species expressed as a percentage of the total (dominant species indicated with an arrow).

		Total	Percentage		
A-plot					
Predators		**14**	**9.50**		
Lygaeidae sp	Geocorinae sp1	1	0.68		
Cleridae sp1		1	0.68		
Coccinellidae larva		1	0.68		
Anthicidae sp	*Anthicus* sp1	2	1.35		
Anthicidae sp	*Anthicus* sp2	2	1.35		
Araneae sp	Salticidae sp1	3	2.03	←	
Araneae sp7		2	1.35		
Araneae sp14		2	1.35		
Parasitoids		**3**	**2.00**		
Diapriidae sp1		3	2.03		
Phytophages		**131**	**88.50**		
Onychiuridae sp1		1	0.68		
Tingidae sp1		4	2.70		
Miridae sp1	*Lygus* sp1	3	2.03		
Lygaeidae sp1		1	0.68		
Rhophalidae sp1		1	0.68		
Cicadellidae sp1		1	0.68		
Aphididae sp1	*Rhopalosiphum padi*	9	6.08		
Aphididae sp2		17	11.49		
Thripidae sp1		13	8.78		
Melyridae sp1	*Astylus atromaculatus*	65	43.92	←	

Appendix 1 (continued)

Phalacridae sp1		1	0.68		
Chrysomellidae sp	Galerucinae sp2	1	0.68		
Culicidae sp1		1	0.68		
Lepidoptera larva1		13	8.78		
Total		**148**			
B-plot					
Predators		**23**	**6.30**		
Lygaeidae sp	Geocorinae sp1	1	0.27		
Chrysopidae larva		1	0.27		
Chrysopidae sp1		2	0.54		
Cleridae sp1		2	0.54		
Coccinellidae larva		5	1.36		
Coccinellidae sp	*Hippodamia variegata*	6	1.63		
Anthicidae sp	*Anthicus* sp1	2	0.54		
Araneae sp2		1	0.27		
Araneae sp14		3	0.82		
Parasitoids		**5**	**1.40**		
Chalcididae sp1		2	0.54		
Scelionidae sp1		3	0.82		
Phytophages		**340**	**92.40**		
Neelidae sp1		2	0.54		
Tingidae sp1		11	2.99		
Miridae sp1	*Lygus* sp1	57	15.49		
Rhophalidae sp1		2	0.54		
Scutteleridae sp1		2	0.54		
Pentatomidae sp1		1	0.27		
Cicadellidae sp1		1	0.27		
Aphididae sp1	*Rhopalosiphum padi*	7	1.90		
Aphididae sp2		39	10.60		
Thripidae sp1		103	27.99	←	
Melyridae sp1	*Astylus atromaculatus*	93	25.27	←	
Phalacridae sp1		1	0.27		
Curculionidae sp	*Baris dodonis*	3	0.82		
Diptera sp4		1	0.27		
Lepidoptera larva1		15	4.08		
Lepidoptera larva3		2	0.54		
Total		**368**			
C-plot					
Predators		**26**	**7.90**		
Lygaeidae sp	Geocorinae sp1	1	0.30		
Meloidae sp1		1	0.30		
Cleridae sp1		1	0.30		
Coccinellidae sp	*Scymnus* sp1	5	1.52		
Sphecidae sp17		1	0.30		
Araneae sp	Salticidae sp1	4	1.21		
Araneae sp22		13	3.94	←	

Appendix 1 (continued)

Parasitoides		**5**	**1.50**	
Braconidae sp3		1	0.30	
Chalcididae sp1		1	0.30	
Chalcidoidea sp3		2	0.61	
Chalcidoidea sp18		1	0.30	
Phytophages		**299**	**90.60**	
Tingidae sp1		1	0.30	
Miridae sp1	*Lygus* sp1	162	49.09	←
Lygaeidae sp1		34	10.30	
Rhophalidae sp1		2	0.61	
Cicadellidae sp1		1	0.30	
Aphididae sp2		9	2.73	
Thripidae sp1		13	3.94	
Melyridae sp1	*Astylus atromaculatus*	52	15.76	
Phalacridae sp1		4	1.21	
Chrysomelidae sp	Galerucinae sp2	2	0.61	
Curculionidae sp	*Microlarinus angustulus*	8	2.42	
Curculionidae sp	*Baris dodonis*	9	2.73	
Diptera sp4		1	0.30	
Diptera sp12		1	0.30	
Total		**330**		

1.3. Arboreal insects sampled on amaranth in the last three samples of each plot in the staggered planting date setup, 1999

		Total	Percentage
A-plot			
Predators		**33**	**19.60**
Chrysopidae larva		1	
Chrysopidae sp1		1	
Coccinellidae sp	*Hippodamia variegata*	1	
Coccinellidae sp	*Scymnus* sp1	6	
Araneae sp	Salticidae sp1	6	
Araneae sp14		9	
Araneae sp22		9	
Parasitoids		**2**	**1.20**
Diapriidae sp1		1	
Chalcidoidea sp11		1	
Phytophages		**133**	**79.20**
Tettigoniidae sp1		1	
Miridae sp1	*Lygus* sp1	59	
Lygaeidae sp1		10	
Rhophalidae sp1		5	
Cicadellidae sp1		2	
Aphididae sp2		8	
Aphididae sp3		3	
Thripidae sp1		12	

Appendix 1 (continued)

Melyridae sp1	*Astylus atromaculatus*	28	
Phalacridae sp1		1	
Curculionidae sp	*Microlarinus angustulus*	1	
Curculionidae sp	*Baris dodonis*	2	
Diptera sp4		1	
Total		**168**	
B-plot			
Predators		**35**	**22.00**
Carabidae sp	Trechiinae sp1	1	
Carabidae sp4		1	
Coccinellidae sp	*Hippodamia variegata*	5	
Coccinellidae sp	*Scymnus* sp1	12	
Araneae sp	Salticidae sp1	7	
Araneae sp14		3	
Araneae sp22		6	
Parasitoids		**1**	**0.60**
Chalcidoidea sp4		1	
Phytophages		**123**	**77.40**
Miridae sp1	*Lygus* sp1	33	
Lygaeidae sp1		8	
Rhophalidae sp1		1	
Cicadellidae sp1		7	
Cicadellidae sp2		1	
Aphididae sp1	*Rhopalosiphum padi*	4	
Aphididae sp2		11	
Thripidae sp1		9	
Melyridae sp1	*Astylus atromaculatus*	28	
Chrysomelidae sp1		1	
Chrysomelidae sp	Galerucinae sp2	1	
Apionidae sp1		1	
Curculionidae sp	*Microlarinus angustulus*	1	
Curculionidae sp	*Baris dodonis*	10	
Curculionidae sp	*Hypolixus* sp1	4	
Diptera sp4		1	
Diptera sp12		1	
Lepidoptera larva1		1	
Total		**159**	
C-plot			
Predators		**26**	**7.90**
Lygaeidae sp	Geocorinae sp1	1	
Meloidae sp1		1	
Cleridae sp1		1	
Coccinellidae sp	*Scymnus* sp1	5	
Sphecidae sp17		1	
Araneae sp	Salticidae sp1	4	
Araneae sp22		13	

Appendix 1 (continued)

Parasitoides		**5**	**1.50**		
Braconidae sp3		1			
Chalcididae sp1		1			
Chalcidoidea sp3		2			
Chalcidoidea sp18		1			
Phytophages		**299**	**90.60**		
Tingidae sp1		1			
Miridae sp1	*Lygus* sp1	162			
Lygaeidae sp1		34			
Rhophalidae sp1		2			
Cicadellidae sp1		1			
Aphididae sp2		9			
Thripidae sp1		13			
Melyridae sp1	*Astylus atromaculatus*	52			
Phalacridae sp1		4			
Chrysomelidae sp	Galerucinae sp2	2			
Curculionidae sp	*Microlarinus angustulus*	8			
Curculionidae sp	*Baris dodonis*	9			
Diptera sp4		1			
Diptera sp12		1			
Total		**330**			

Appendix 2

2.1. Alate insects sampled by malaise trap in the last three samples of the study, 1999.

		Total	Percentage
Predators		**113**	**25.70**
Labiduridae sp1		2	
Chrysopidae sp1		1	
Ciccindellidae sp	*Lophyra* sp1	1	
Staphylinidae sp1		1	
Cleridae sp3		2	
Coccinellidae sp	*Adonia* sp1	1	
Coccinellidae sp	*Exochomus* sp1	2	
Coccinellidae sp	*Hippodamia variegata*	58	
Coccinellidae sp	*Scymnus* sp1	16	
Coccinellidae sp1		1	
Meloidae sp1		5	
Anthicidae sp	*Anthicus* sp2	1	
Tabanidae sp3		2	
Sphecidae sp2		2	
Sphecidae sp3		6	
Sphecidae sp13		4	
Pompilidae sp1		2	
Formicidae sp5		1	
Formicidae sp12		1	
Araneae sp8		2	
Araneae sp13		2	
Parasitoids		**61**	**13.90**
Braconidae sp2		1	
Braconidae sp3		7	
Ichneumonidae sp2		2	
Ichneumonidae sp4		1	
Ichneumonidae sp5		3	
Ichneumonidae sp6		21	
Chalcidoidea sp3		5	
Chalcidoidea sp4		3	
Chalcidoidea sp6		13	
Diapriidae sp1		2	
Scelionidae sp1		2	
Vespidae sp1		1	
Phytophages		**252**	**57.30**
Acrididae sp1		4	
Miridae sp1	*Lygus* sp1	7	
Lygaeidae sp1		3	
Cicadellidae sp1		42	
Melyridae sp1	*Astylus atromaculatus*	24	
Apionidae sp1		3	
Curculionidae sp	*Hypolixus* sp1	1	
Diptera sp1		22	

Appendix 2 (continued)

Diptera sp2		3			
Diptera sp5		33			
Diptera sp6		8			
Diptera sp7		2			
Diptera sp9		1			
Diptera sp12		38			
Diptera sp15		10			
Diptera sp19		21			
Diptera sp23		4			
Diptera sp24		2			
Diptera sp28		1			
Culicidae sp1		11			
Trichoptera sp1		2			
Pieridae sp1		1			
Noctuidae sp1		5			
Colletidae sp1		4			
Scavengers		**14**	**3.20**		
Muscidae sp1		4			
Calliphoridae sp1		2			
Calliphoridae sp2		8			
Total		**440**			

CHAPTER 5

DIVERSITY OF TERRESTRIAL INSECTS IN THREE DIFFERENT CULTIVATION PRACTICES

5.1 INTRODUCTION

In a cultivated land the insect community does not only consist of the arboreal and alate insect community, although these species have a major impact on crop yield. The terrestrial insect community also constitutes a major part of the total insect community in the ecosystem. These 'terrestrial' insects are not all groundliving *per se*, some, for example, fall off plants to escape predators, while others are tourists, temporarily using the ground as an extension of their habitat. As terrestrial insects move across the landscape, they encounter a wide variety of habitats that differ in resource availability, microclimate and shelter. This has consequences for processes shaping the communities and the success of certain species (Bommarco, 1998).

Terrestrial insects face many different biotic and abiotic factors to arboreal insects. Variation in the density of plant cover and the resulting fluctuation in microclimate on the soil surface are important aspects in the life cycle of a terrestrial insect (Honek, 1997). Other management and habitat characteristics that influence terrestrial insects, include crop type, organic manure applications, insecticide use, the presence of refugia such as field borders (Clark, Gage & Spence, 1997) and ploughing (Baguette & Hance, 1997). Different species have different ecological requirements depending on their size, larval life cycle and food (Baguette & Hance, 1997). Different insects are thus influenced differently by certain factors, for example, some terrestrial insects prefer dense plant stands with much canopy cover, while others prefer more open plant stands where more sunlight reaches the soil surface (Honĕk, 1988). To further complicate matters there are high risks and uncertainties associated with living in an annual cropping system (Kennedy & Storer, 2000), especially for terrestrial insects since they are generally not good flyers and can thus not migrate very far to new plants after the growing season. Refugia during the time when no crop is cultivated are important to maintain a terrestrial insect community. Terrestrial insects are not influenced so much by or as dependent on plants. Consequently the different hypotheses that are applicable for arboreal insects like the recourse concentration, enemy, and island hypotheses cannot be applied to terrestrial insects (Stamps & Linit, 1998).

Determining the biodiversity of this part of the ecosystem is also very important. Increasing numbers of species are becoming endangered or have become extinct due to the destruction of habitat or the breaking up of habitats into isolated patches as a result of human activities (Odum, 1993). As more and more land is used for agriculture, to feed the fast growing population, it is important that biodiversity must be conserved even in agriculture (Heywood, 1998). In fact, studies concerning this matter are essential to eventually enhance biodiversity in the agricultural landscape as such diversity is regarded an index of ecosystem well-being. In this part of the study the diversity of the terrestrial insects was monitored. Although these insects do not live on the plant and seemingly do not have a big influence on crop yield, many terrestrial insects are important predators. This makes them important biological control agents and their conservation is therefore, essential. They attack prey that fall from the plants and so constitute to the overall predator complex (arboreal, alate and terrestrial). More detail concerning the predators is presented in Chapter 6. Terrestrial insects are also influenced by cultural practices and consequently this aspect was also included in the study.

The questions asked were:

1. How does the insect diversity encountered in different agricultural practices, *i.e.* monoculture, mixed crop setup and staggered planting dates of *Amaranthus hybridus*, compare?
2. What aspects influence the diversity of the terrestrial insect community?

5.2 MATERIAL AND METHODS

Insects were collected using a pitfall-trapping program. Pitfall trapping is a widely used method for investigating the activity and occurrence of terrestrial insects (Honek, 1997). Sampling was done in the monoculture of 1997 (Fig. 2.1), the mixed crop and monoculture of 1998 (Fig. 2.2) and the staggered planting date setup in 1999 (30 November = A-plot; 30 December = B-plot and 30 January = C-plot) (Fig. 2.3). Aluminum tins were randomly placed in the soil with the rim at the level of the ground surface. The tins were screened from rain, irrigation water and the sun with white rooflike protectors. No bait was used, but they were half-filled with ethylene glycol ($CH_2OH.CH_2OH$). The pitfalls were emptied every second week and the insects were preserved in 70% ethanol. The dates that sampling was done differ in the different years (Chapter 2: Appendix 1). The data were processed and different indices calculated (Appendix 1.1). Calculations were done for every collection for the monoculture of 1997, the mixed crop and monoculture of 1998 and for each plot in the staggered planting date culture. To compare the data of the different plots the mean diversity indices for each plot were calculated with a factor equal to the number of samples taken at a site (monoculture 1997, mixed crop, monoculture 1998, B-plot, = 8; A-plot = 12; and C-plot = 6) (Appendix 1.2). An important factor to consider in an analysis of this kind is the correct sample size. The test for this is the cumulative species index. The point at which the curve reaches an asymptote indicates the minimum viable sample size (Magurran, 1988).

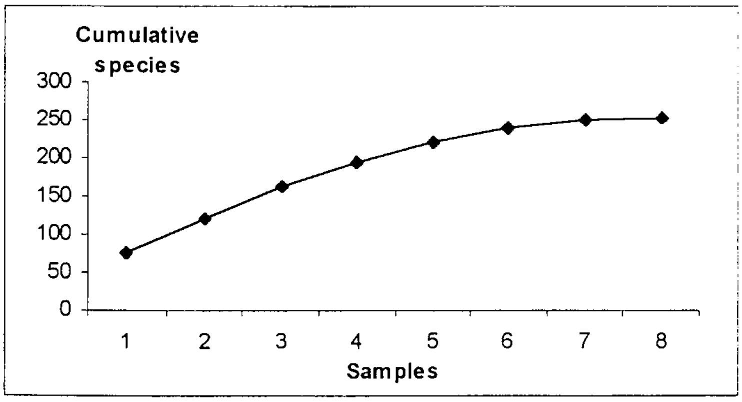

Fig. 5.1. Cumulative terrestrial species over eight samples in the monoculture, 1997.

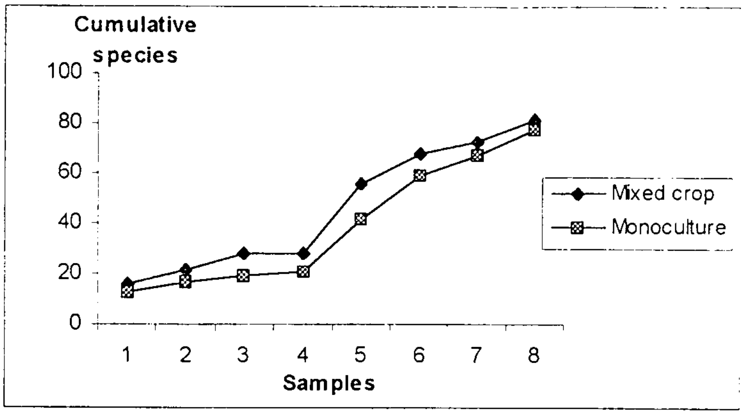

Fig. 5.2. Cumulative terrestrial species over eight samples in the monoculture and mixed crop setup, 1998.

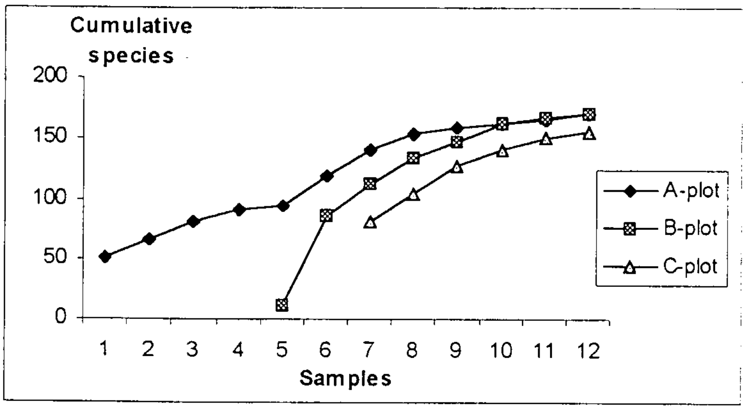

Fig. 5.3. Cumulative terrestrial species over twelve (A-plot), eight (B-plot) and six (C-plot) samples in the staggered planting date setup, 1999.

The minimum sample size in the monoculture of 1997 is six samples (Fig. 5.1). In 1998 no asymptote can be seen (Fig. 5.2). This is due to the greater variety of species that moved to the greener amaranth at sample five, which coincides with the end of the growing season of the other plants in the mixed crop setup (sunflower and maize). Species were probably still accumulating on the amaranth at sample 8, as they were migrating from the other plots. The staggered planting date setup in 1999 had a minimum sample size of ten for the A-plot, six for the B-plot and four for the C-plot (Fig. 5.3).

5.3 RESULTS AND DISCUSSION

5.3.1. Species richness

An important property of a community is the number or abundance of species it contains. The Margalef index (D_{mg}) represents the relative abundance of species (Appendix 1.1). In the monoculture of 1997 the highest abundance of species was found during the middle of the growing season at sample 4 (D_{mg}= 18.488) (Fig. 5.4). In 1998 the mixed crop had two peaks at the beginning (sample 2) and nearer to the middle of the growing season (sample 5) (D_{mg}= 12.907 and 6.293 respectively) (Fig. 5.5). The monoculture of 1998 had one peak in the middle of the growing season at sample 6 (D_{mg}= 5.644) (Fig. 5.5). The peak abundance in 1998 occurred later than that of the 1997 season. The insects in 1998 were supposedly first associated with the other crops in the mixed crop setup (sunflower, maize and pumpkin) that were at their peak growth stage with much more shelter for the groundliving insects. As these plant species neared the end of their growing season the insects moved to the greener and lush growing amaranth. In 1997 there was just an amaranth monoculture and no other plants to visit first.

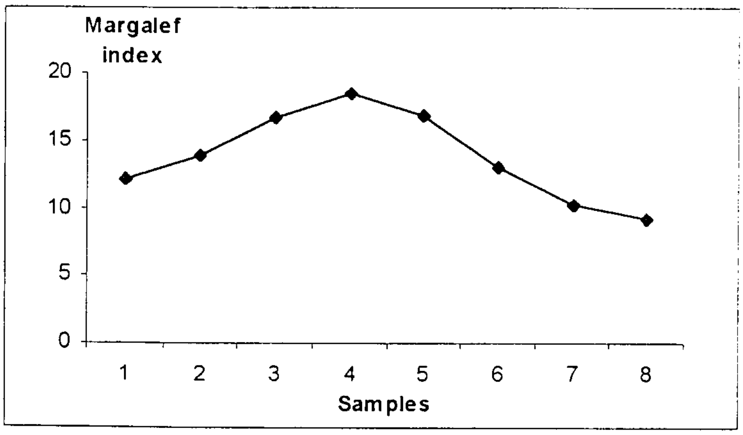

Fig. 5.4. Margalef index (D_{mg}) for terrestrial insects over eight samples in the monoculture, 1997.

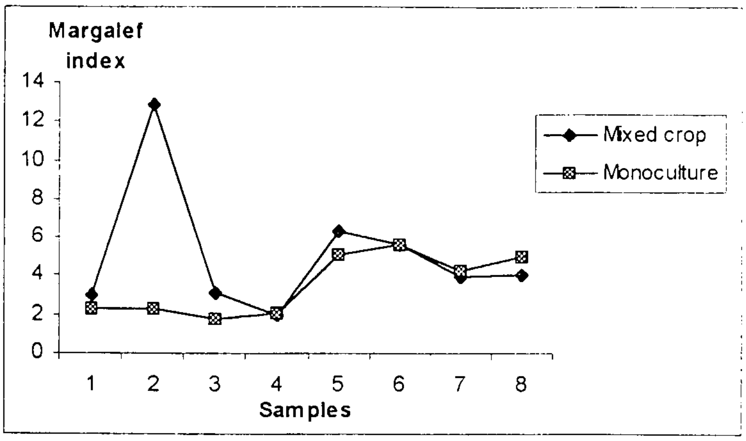

Fig. 5.5. Margalef index (D_{mg}) index for terrestrial insects over eight samples in the mixed crop and monoculture, 1998.

In the 1999 season (Fig. 5.6) the A-plot's species abundance peak was at sample 7 (D_{mg}= 12.977) and the abundance decreased as the species shifted to the greener B-plot that had a peak at sample 10 (D_{mg}= 13.151). The C-plot does not have major peaks (Appendix 1.1).

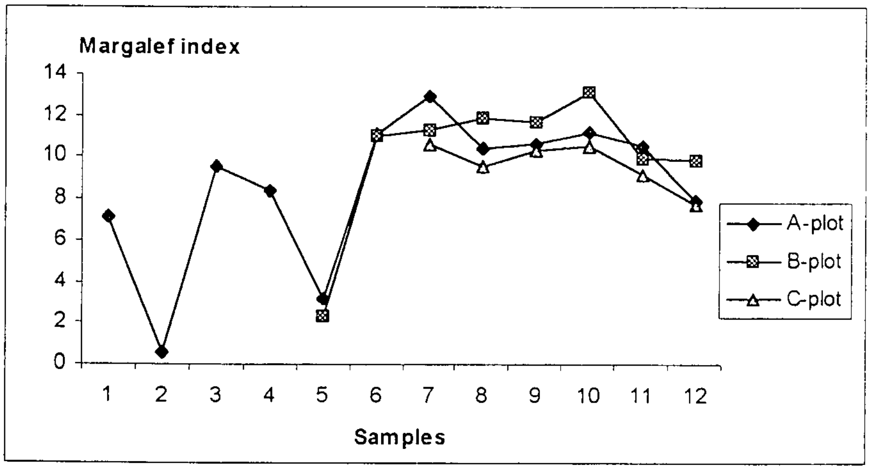

Fig.5.6. Margalef index (D_{mg}) for terrestrial insects over twelve (A-plot), eight (B-plot) and six (C-plot) samples in the staggered planting date setup, 1999.

Comparing mean diversity indices of the total abundance of insects from all the plots (Appendix 1.2), the monoculture of 1997 had the highest abundance of species (D_{mg}= 13.832) (Fig. 5.7), with the monoculture of 1998 not attracting as many species (D_{mg}= 3.556). In 1997 the plot was much bigger and had a denser plant cover compared to the plots of 1998. These factors contributed to optimum resource availability, microclimate and shelter (Bommarco, 1998) from the sun, wind and other abiotic factors. In 1998 there was more fallow soil area due to the setup of the mixed crop plots. There were thus more open spaces for the sun to reach the soil surface, which resulted in high soil temperatures. The insects preferred the large adjacent monoculture of maize or pumpkin, a more stable environment, where they were more sheltered and protected (Fig. 5.8). The maize monoculture and the pumpkin showed a higher abundance and diversity of insects in comparison with the mixed crop and monoculture in 1998 (Fig. 5.8).

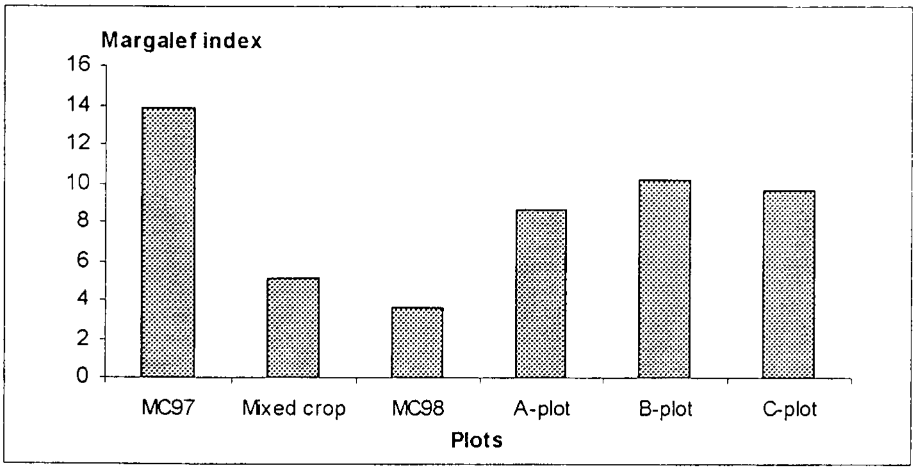

Fig. 5.7. Mean Margalef index (D_{mg}) for the total number of terrestrial insects collected in 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (MC = monoculture).

In 1999 the B-plot (D_{mg}= 10.130) had a higher abundance compared to the A-plot (D_{mg}= 8.623) (Fig. 5.7). The B-plot was adjacent to the large maize monoculture, while the A-plot was next to a dirt road. Species abundance in 1999 was less than that of 1997, but more than 1998 (Appendix 1.2). Slightly bigger plots were planted in 1999 than in 1998, but they were smaller than the plot in 1997.

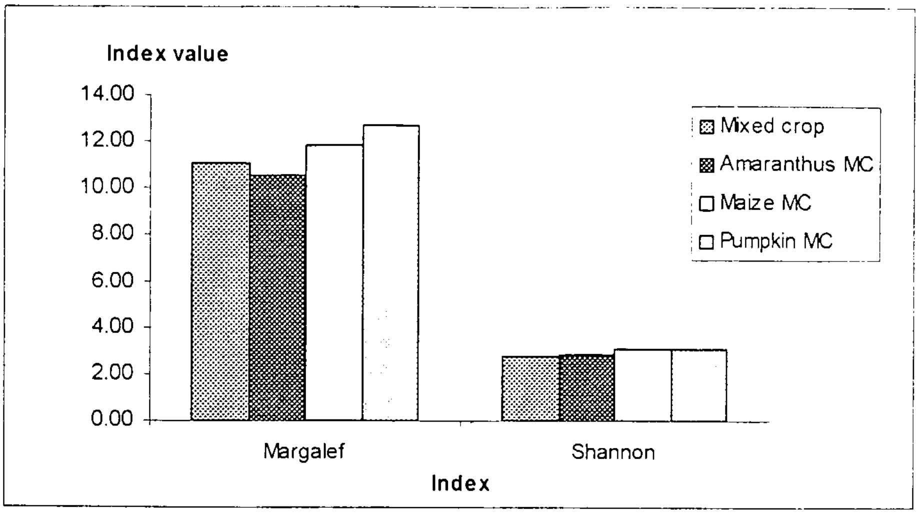

Fig. 5.8. Comparison of Margalef (D_{mg}) and Shannon (H) indices in amaranth mixed crop and monoculture setup and a maize and pumpkin monoculture (MC = monoculture), 1998.

5.3.2. Rank abundance

In any community all species are not equally common. This led to the development of species abundance models, *i.e.*: the geometric series, the log series, the log normal distribution and the broken stick model (Magurran, 1988). The rank abundance plots of the terrestrial insects in this study all equal the log normal distribution. There was thus not high dominance in any of the sites, *i.e.* the monoculture of 1997 (Fig. 5.9), mixed crop (Fig. 5.10), monoculture of 1998 (Fig. 5.11) and staggered planting dates of 1999 (A-plot - Fig. 5.12, B-plot - Fig. 5.13 and C-plot - Fig. 5.14). The insect communities are composed of rare species, species with intermediate population sizes and very abundant species. Rare species made up the majority in the insect communities surveyed and were mostly represented by only one or two individuals.

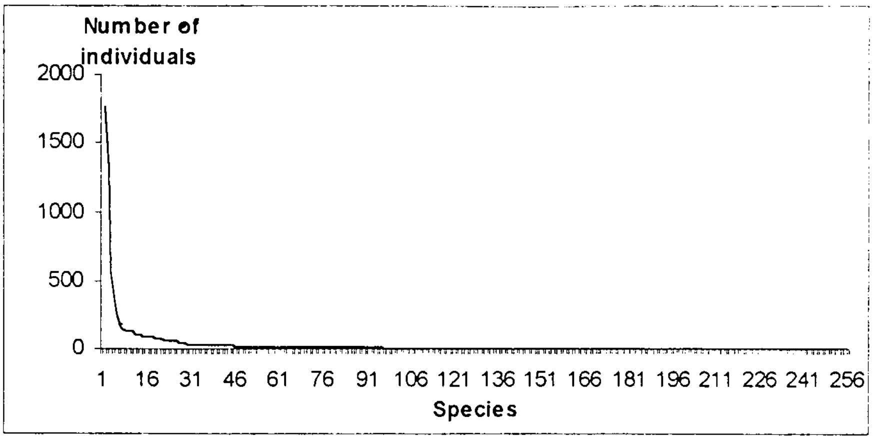

Fig. 5.9. Rank abundance plot of the terrestrial insects in the monoculture, 1997.

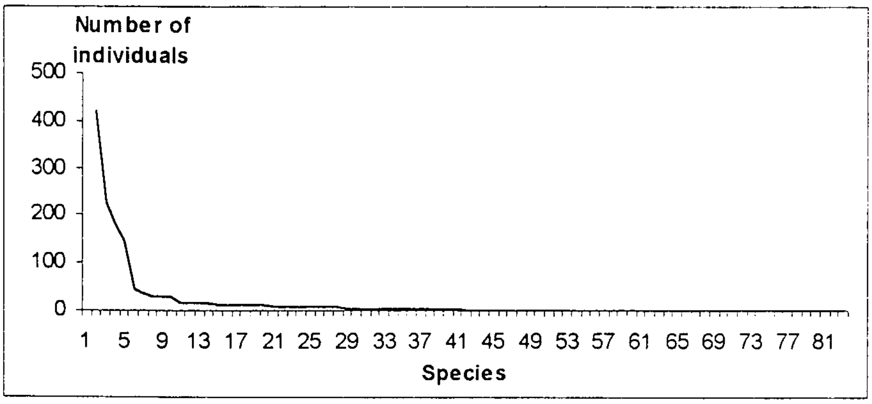

Fig. 5.10. Rank abundance plot of the terrestrial insects in the mixed crop setup, 1998

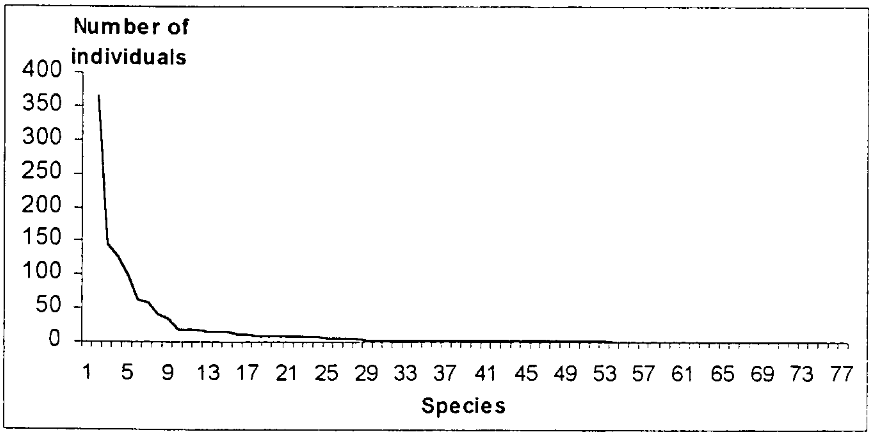

Fig. 5.11. Rank abundance plot of the terrestrial insects in the monoculture, 1998.

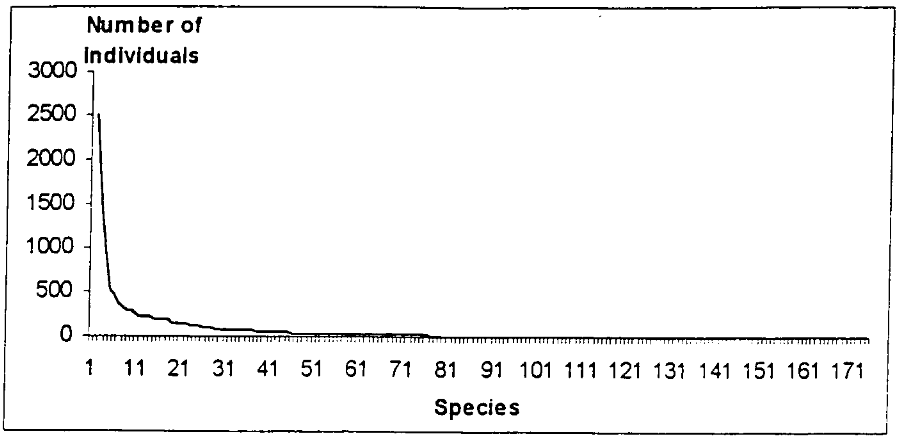

Fig. 5.12. Rank abundance plot of the terrestrial insects in the A-plot of the staggered planting date setup, 1999.

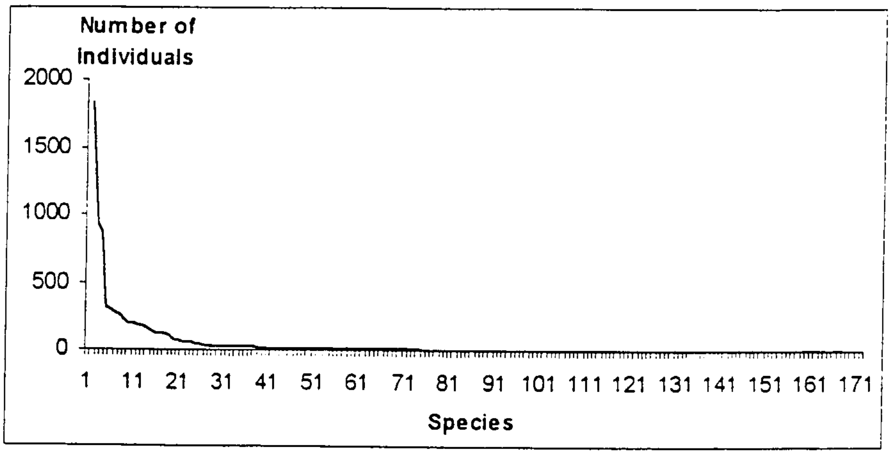

Fig. 5.13. Rank abundance plot of the terrestrial insects in the B-plot of the staggered planting date setup, 1999.

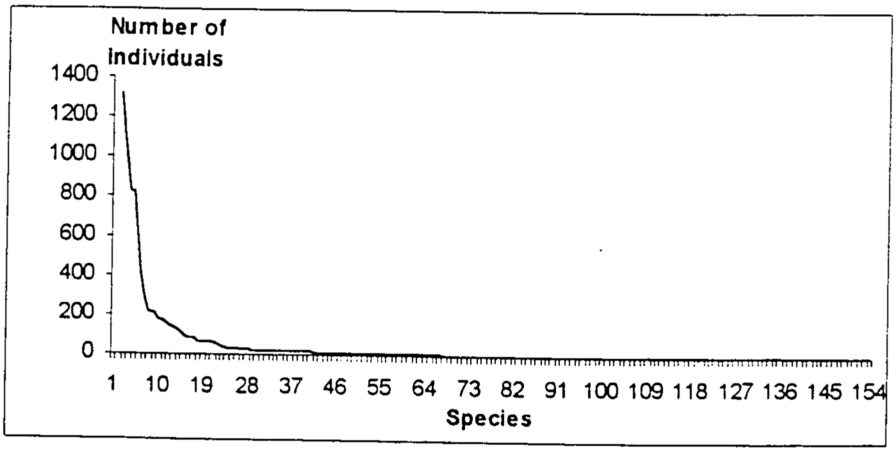

Fig. 5.14. Rank abundance plot of the terrestrial insects in the C-plot of the staggered planting date setup, 1999.

5.3.3. Proportional abundance of species

5.3.3.1. Diversity

The Shannon index is an indicator of the diversity in a community (Appendix 1.1). The diversity in the monoculture of 1997 peaks in the middle of the growing season at sample 4 (H= 3.861) (Fig. 5.15). In the 1998 season the mixed crop and the monoculture both peak in the middle of the growing season at sample 5 (H= 2.185 and 2.720 respectively) (Fig. 5.16). In the 1999 season no major peaks can be seen (Fig. 5.17). There is also no clear shift of insect peaks from one plot to another as the growing seasons of the successive plots follow one another.

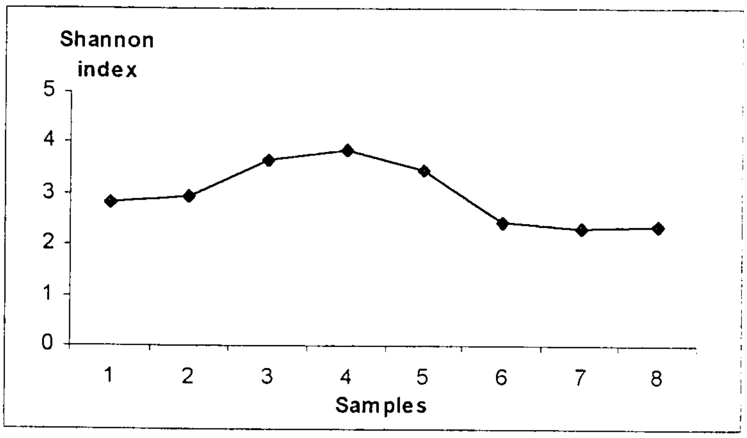

Fig. 5.15. Shannon index (H) of the terrestrial insects over eight samples in the monoculture, 1997.

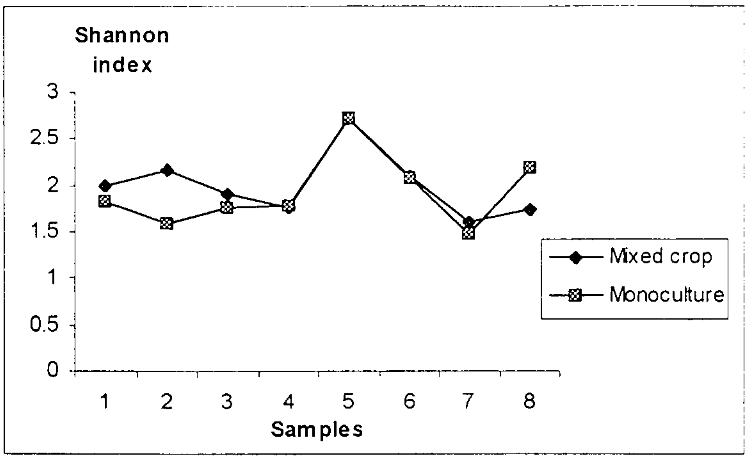

Fig. 5.16. Shannon index (H) for the terrestrial insects over eight samples in the mixed crop setup and monoculture, 1998.

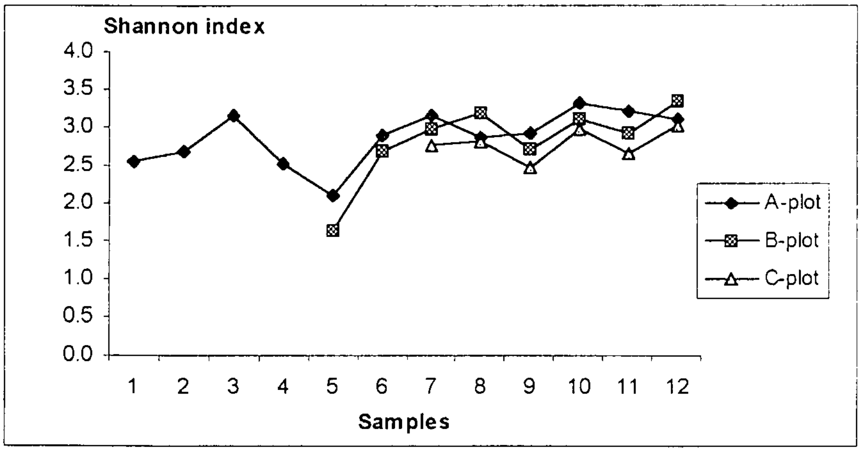

Fig.5.17. Shannon index (H) for the terrestrial insects over twelve (A-plot), eight (B-plot) and six (C-plot) samples in the staggered planting date setup, 1999.

Total numbers of species (Fig. 5.18) show that in 1999, the A-plot had the highest diversity followed by the B-plot (H= 2.874 and 2.816 respectively) (Appendix 1.2). This phenomenon is may be due to terrestrial insects migrating from the border areas to the A-plot soon after it was planted. Some species probably becoming established there, not risking moving over fallow ground to newly cultivated crops. Ecotones (a zone of transition between adjacent ecological systems) may serve either as barriers or corridors between populations. Because these ecotones represent unique habitats, they are favoured by some species and are inhospitable to others (Magura & Tothmeresz, 1997). Most species, however, probably still tend to randomly move between plots, especially on the scale of the experimental setup in this study. "New" insect species could also have moved to the B- and C-plots from the adjacent maize monoculture. The B- and C-plot were adjacent to the maize, but the A-plot was further away from it, next to a dirt road.

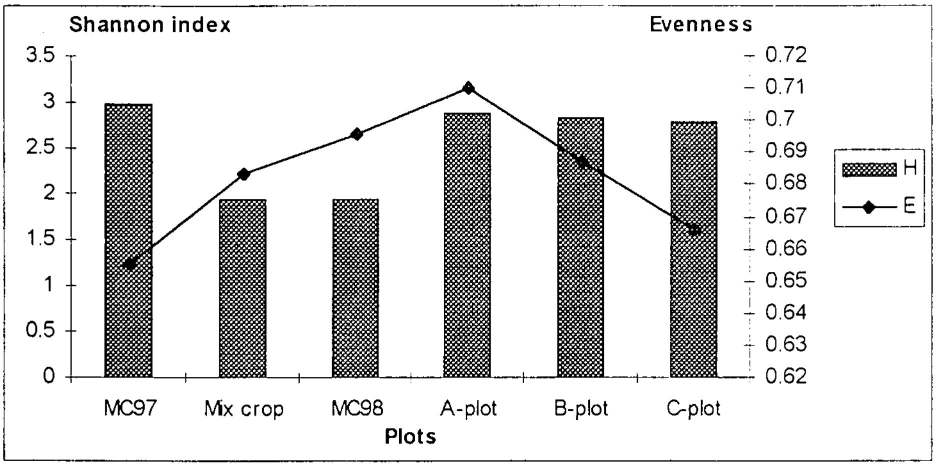

Fig. 5.18. Mean Shannon index (H) and Evenness (E) for the total number of terrestrial insects collected in 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (MC = monoculture).

In 1998 the amaranth in mixed crop setup had a slightly higher diversity (H= 1.930) than the monoculture (H= 1.926) (Appendix 1.2). As mentioned earlier, the 1998 plots had more fallow ground between the different plots of plants and insects preferred the more dense stands of maize and pumpkin (Fig. 5.8). Of all the plots, the monoculture of 1997 had the highest diversity (H= 2.987) (Fig. 5.18). This is because this plot was the largest stand of plants where there was much more shelter, protection and environmental homogeneity for the terrestrial insects. In other studies it has been found that the Shannon index increased as the cover of herbs and shrubs and the resulting relative air moisture increased (Magura & Tothmeresz, 1997).

Evenness (Fig. 5.18) ranges between the values of 0.656 (monoculture 1997) and 0.710 (A-plot). The nearer the values are to 1, the more evenly distributed the species are. Overall there is not a high evenness and thus species were not evenly distributed in the plots. A regression of evenness can be seen in the 1999 season. Species were more evenly distributed in the A-plot (E= 0.710), followed by the B-plot (E= 0.687). Terrestrial insects moved at random between plots, but possibly mostly returned to the plots with optimum conditions. It can thus be assumed that the A-plot had the most advantageous conditions that suited the highest number of insect species. The B-plot plants presented below optimum conditions and consequently only some insect species preferred this stand and because of less competition or better adaptability, increased in numbers. The same could have happened in the C-plot, but the C-plot was also planted late, the majority of insects was going into their overwintering phases or had already died. Only a few species remained at the end of the season.

5.3.3.2. Dominance

The Berger-Parker index (d) is an indicator of the dominance in a community. The diversity increases and the dominance in the community decreases when the inverse value of the index (1/d) increases (Magurran, 1988). Because the species with the highest number of individuals is used, the lower the number of individuals of that specific species, the lower the dominance and consequently the higher the diversity in the community as a whole.

In the 1997 season the dominance decreased visibly at sample 4 (1/d= 10.564) (Fig. 5.19). This corresponds with the diversity that increases at sample 4 (H= 3.861) (Fig. 5.15) (Appendix 1.1). In the 1998 season there was also a major decrease in dominance in the middle of the growing season (sample 5) in the mixed crop and the monoculture (1/d= 4.826 and 5.955 respectively) (Fig. 5.20). There was thus also an increase in diversity at sample 5 (Fig. 5.16). In 1999 there is a major decrease in dominance towards the end of the growing season in the A- and B-plot (Fig. 5.21).

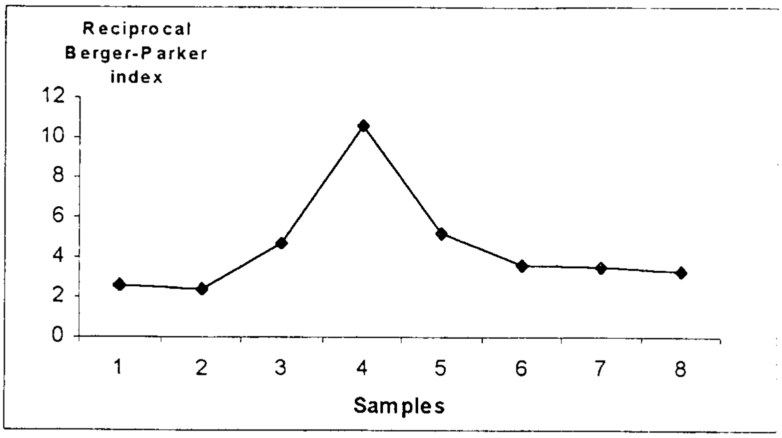

Fig. 5.19. Berger-Parker index (1/d) for the terrestrial insects over eight samples in the monoculture, 1997.

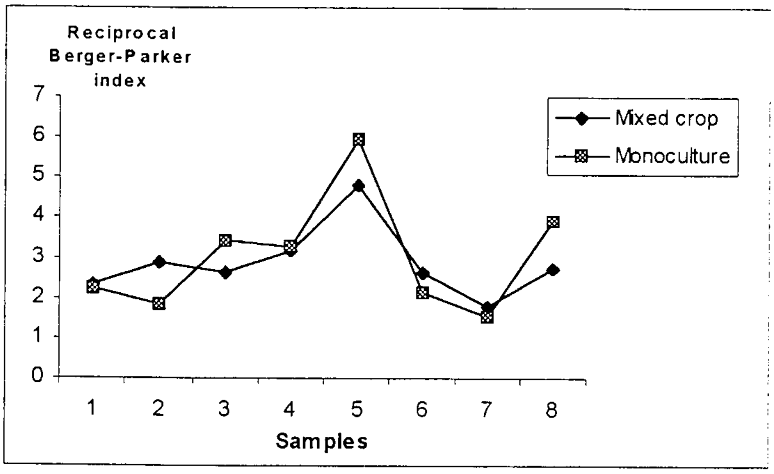

Fig. 5.20. Berger-Parker index (1/d) for the terrestrial insects over eight samples in the mixed crop setup and monoculture, 1998.

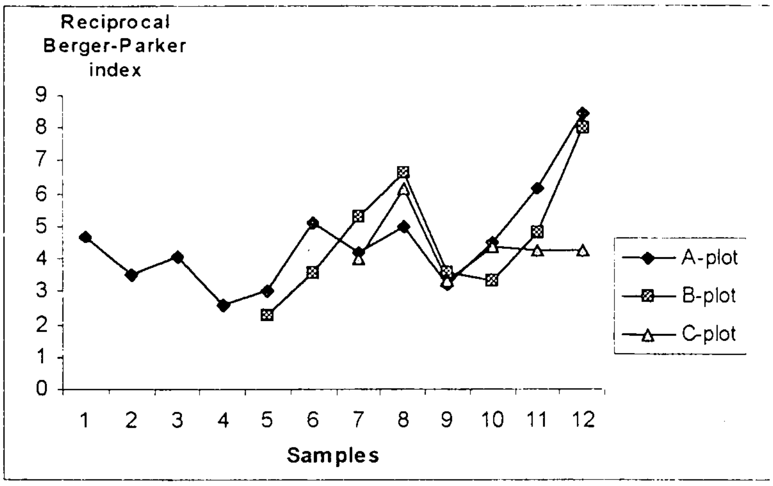

Fig. 5.21. Berger-Parker index (1/d) for the terrestrial insects over twelve (A-plot), eight (B-plot) and six (C-plot) samples in the staggered planting date setup. 1999.

In total in 1999 (Fig. 5.22) the C-plot (1/d= 4.254) had the lowest dominance followed by the A-plot (1/d= 4.118) and then the B-plot (1/d= 4.057). The B-plot's plants were in a bad condition and thus favourable for pest species development. Only a few species utilised or preferred this plot and due to less competition and better adaptability, increased in numbers.

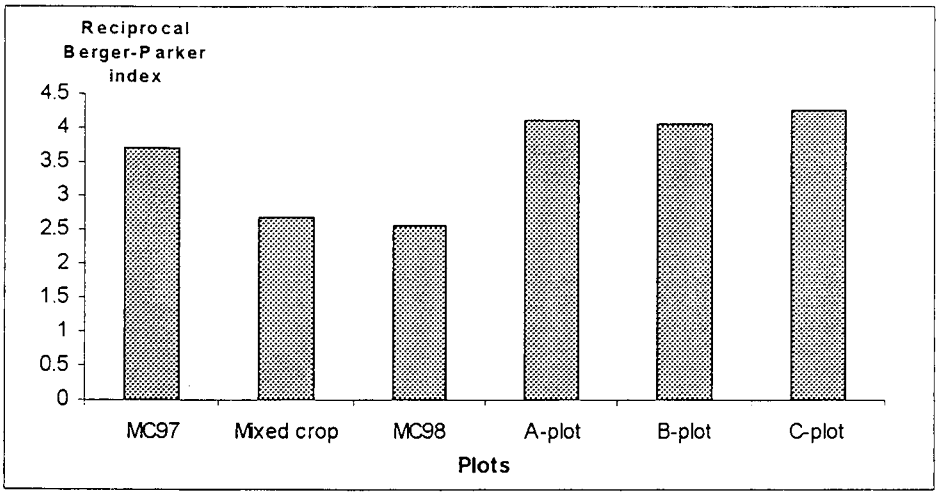

Fig. 5.22. Mean Berger-Perker index (1/d) for the total number of terrestrial insects collected in 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (MC = monoculture)

The monoculture of 1997 also did not have a very high dominance (1/d= 3.709) (Appendix 1.2). The 1998 seasons show higher dominance and lesser diversity than 1997 and 1999. This is probably because more species associated with the maize or pumpkin that offered more shelter and protection (Fig. 5.8).

5.3.4. Similarity

The Bray-Curtis index (C_N) is calculated to test the similarity between the plots. The nearer to 1 the values are, the more similar the different plots are and nearer to zero, the more dissimilar they are (Magurran, 1988). Calculations were done for the first three samples of each plot, *i.e.* monoculture of 1997, mixed crop, monoculture of 1998 and the staggered planting dates plots (A-, B- and C-plot) (Table 1). This was done for comparison reasons to compare data of plants in more or less the same growth stage. The data were then compiled in matrixes (Appendix 2) to eventually form a dendrogram (Fig. 5.23).

Table 1. Bray-Curtis indices for the first three samples of terrestrial insects in 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates: A-, B- and C-plot) (1 as the most similar and 0 the most dissimilar) (MC = monoculture).

	MC 1997	Mixed crop	MC 1998	A-plot	B-plot	C-plot
Monoculture 1997	*	0.055	0.065	0.161	0.091	0.187
Mixed crop	0.055	*	0.669	0.135	0.118	0.065
Monoculture 1998	0.065	0.669	*	0.112	0.103	0.057
A-plot	0.161	0.135	0.112	*	0.575	0.478
B-plot	0.091	0.118	0.103	0.575	*	0.646
C-plot	0.187	0.065	0.057	0.478	0.646	*

It is obvious that there is no similarity between the plots of the different years (Fig. 5.23). In 1998 the monoculture and the mixed crop show a degree of similarity. The plants were planted the same time and were in the same condition and thus could attract the same number of terrestrial insect species.

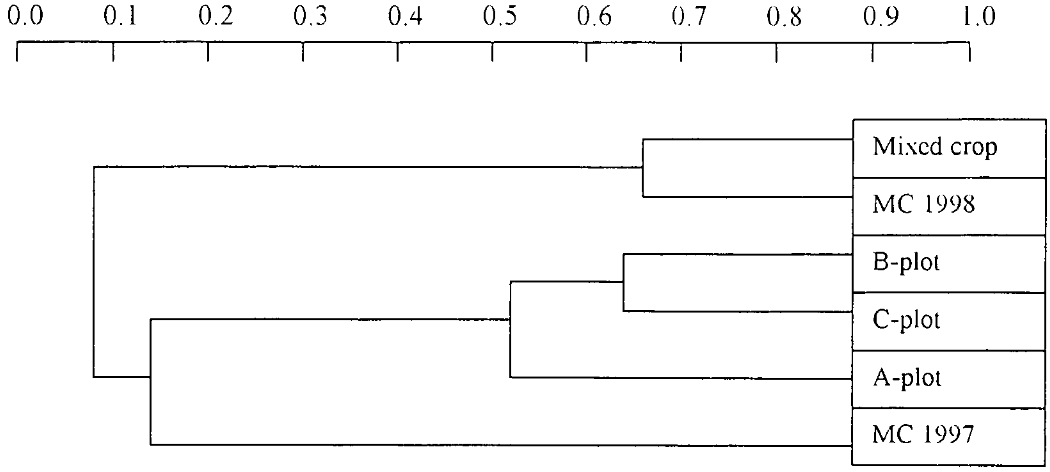

Fig. 5.23. Bray-Curtis index dendrogram to show the most similar plots (MC = monoculture).

In 1999 the B- and C-plots were the most similar (Fig. 5.23). Overall the plots were, however, relatively dissimilar from one other (Table 1). They were planted at different times of the year and the plant and weather conditions at the time of sampling (first three samples) also differed, thus the insects attracted to the plots differed. The monoculture of 1997 was very dissimilar, being a large monoculture it had a very different microclimate and shelter conditions to the plots in the other years.

5.4. CONCLUSION

Land management practices are important to life processes of the terrestrial insect community, especially in annual cropping systems, which are known to be very detrimental to the population growth of such insects. Many terrestrial insects are predators and are thus important in an agricultural landscape. The microclimate and shelter provided by plants have a strong influence on them. In this study, the greatest diversity was found in the big monoculture of amaranth in 1997. In 1998 there was a lower diversity in the amaranth stand due to the attraction of insects to the other plants in the mixed crop setup and also because of the small plots. There was much fallow ground, which could have provided barriers to free movement, and some insect species probably tended to stay in the big maize monoculture, which provided a more homogeneous environment. In the staggered planting date setup of 1999, there was also a higher diversity, possibly because the plots were a bit larger than in 1998. Although terrestrial insects moved around randomly, it would appear that they returned to the stands where the recourse availability, microclimate and shelter were at an optimum.

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Appendix 1

(S: Species; N: Total population number; Dmg: Margalef index; H: Shannon index;
E: Evenness; d: Berger-Parker index)

1.1. Diversity indices of the terrestrial insects in individual samples in six different plots.

	1	2	3	4	5	6	7	8
1997	**09/01**	**21/01**	**04/02**	**18/02**	**04/03**	**01/04**	**15/04**	**13/05**
Monoculture								
S	77	92	110	134	116	97	74	62
Cum. S	77	122	162	196	220	240	250	253
N	541	686	655	1331	920	1520	1255	779
Dmg	12.076	13.934	16.809	18.488	16.851	13.103	10.231	9.162
H	2.836	2.967	3.647	3.861	3.475	2.437	2.321	2.350
E	0.653	0.656	0.776	0.788	0.731	0.533	0.539	0.570
d	0.388	0.411	0.211	0.095	0.193	0.276	0.282	0.300
1/d	2.576	2.433	4.746	10.563	5.169	3.619	3.545	3.329
1998	**19/02**	**06/03**	**18/03**	**01/04**	**15/04**	**29/04**	**15/05**	**15/05**
Mixed crop								
S	16	17	14	8	35	34	22	25
Cum. S	16	22	28	28	56	68	73	82
N	144	52	68	35	222	368	208	379
Dmg	3.018	12.907	3.081	1.969	6.293	5.586	3.934	4.042
H	1.986	2.171	1.899	1.764	2.185	2.097	1.600	1.741
E	0.716	0.766	0.720	0.848	0.765	0.595	0.518	0.541
d	0.431	0.346	0.382	0.314	0.207	0.383	0.553	0.364
1/d	2.323	2.889	2.615	3.182	4.826	2.610	1.809	2.746

Appendix 1 (continued)

Monoculture												
S	13	10	8	10	26	32	25	28				
Cum. S	13	17	19	21	42	59	67	78				
N	176	55	58	69	131	243	287	216				
Dmg	2.321	2.246	1.724	2.126	5.128	5.643	4.241	5.023				
H	1.820	1.588	1.758	1.774	2.720	2.085	1.489	2.175				
E	0.709	0.690	0.846	0.771	0.835	0.602	0.462	0.653				
d	0.443	0.545	0.293	0.304	0.168	0.465	0.652	0.255				
1/d	2.256	1.833	3.412	3.286	5.955	2.150	1.535	3.927				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1999	**17/12**	**31/12**	**13 /01**	**29/01**	**10/02**	**25/02**	**11/03**	**23/03**	**08/04**	**30/04**	**21/05**	**04/06**
A-plot												
S	51	53	66	59	14	84	97	78	78	76	65	44
Cum. S	51	66	81	91	94	119	141	153	159	162	166	170
N	1115	865	907	998	61	1806	1632	1591	1436	827	446	228
Dmg	7.126	0.587	9.545	8.399	3.162	11.068	12.977	10.445	10.592	11.164	10.491	7.920
H	2.542	2.678	3.161	2.516	2.117	2.887	3.171	2.875	2.914	3.317	3.218	3.097
E	0.647	0.675	0.754	0.617	0.802	0.651	0.693	0.660	0.669	0.766	0.771	0.818
d	0.214	0.286	0.246	0.388	0.328	0.196	0.241	0.200	0.312	0.224	0.161	0.118
1/d	4.665	3.502	4.067	2.579	3.050	5.102	4.150	5.003	3.205	4.470	6.194	8.444
B-plot												
S					11	84	81	86	88	94	64	55
Cum. S					11	86	113	134	147	162	167	170
N					80	1864	1220	1293	1702	1178	570	241
Dmg					2.282	11.022	11.257	11.864	11.694	13.151	9.928	9.845
H					1.635	2.675	2.967	3.180	2.717	3.105	2.908	3.339
E					0.682	0.604	0.675	0.714	0.607	0.683	0.699	0.833
d					0.438	0.280	0.189	0.150	0.280	0.303	0.207	0.124
1/d					2.286	3.571	5.281	6.665	3.568	3.300	4.831	8.033

Appendix 1 (continued)

C-plot												
S							81	71	79	75	60	43
Cum. S							81	104	127	140	150	155
N							1841	1566	1963	1167	612	227
Dmg							10.641	9.516	10.287	10.478	9.195	7.742
H							2.758	2.804	2.461	2.974	2.662	3.036
E							0.628	0.658	0.563	0.689	0.650	0.807
d							0.251	0.162	0.300	0.230	0.234	0.233
1/d							3.976	6.165	3.333	4.354	4.280	4.283

1.2. Mean diversity indices of the total number of terrestrial insects sampled in 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates : A-plot, B-plot and C-plot).

(Factors: monoculture 1997, mixed crop, monoculture 1998, B-plot = 8, A-plot =12 and C-plot = 6)

	S	N	Dmg	H	E	d	1/d
1997							
Monoculture	255	7687	13.832	2.987	0.656	0.270	3.709
1998							
Mixed crop	82	1476	5.104	1.930	0.684	0.373	2.684
Monoculture	76	1235	3.556	1.926	0.696	0.391	2.560
1999							
A-plot	174	11912	8.623	2.874	0.710	0.243	4.118
B-plot	171	8151	10.130	2.816	0.687	0.246	4.057
C-plot	153	7376	9.643	2.783	0.666	0.235	4.254

APPENDIX 2

Matrixes of the Bray-Curtis index for 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) on which the Bray-Curtis index dendrogram (Fig. 5.23) is based.

(Monoculture 1997= MC97, Mixed crop= M, Monoculture 1998= MC98, A-plot= A, B-plot= B and C-plot= C)

MATRIX 1

	MC97	M	MC98	A	B	C
MC97		0.055	0.065	0.161	0.091	0.187
M			0.669	0.135	0.118	0.065
MC98				0.112	0.103	0.057
A					0.575	0.478
B						0.646
C						

MATRIX 2

	M/MC98	MC97	A	B	C
M/MC98		0.060	0.124	0.111	0.061
MC97			0.161	0.091	0.187
A				0.575	0.478
B					0.646
C					

MATRIX 3

	B/C	M/MC98	A	MC97
B/C		0.086	0.526	0.139
M/MC98			0.124	0.060
A				0.161
MC97				

MATRIX 4

	B/C/A	M/MC98	MC97
B/C/A		0.105	0.150
M/MC98			0.060
MC97			

MATRIX 5

	B/C/A/MC97	M/MC98
B/C/A/MC97		0.082
M/MC98		

Values of the different clusters in the Bray-Curtis index dendrogram (Fig. 5.23) derived from the matrixes.

M/MC98	0.669
B/C	0.646
B/C/A	0.526
B/C/A/MC97	0.150
B/C/A/MC97/M/MC98	0.082

CHAPTER 6

FEEDING GUILDS AND DOMINANCE STRUCTURES OF TERRESTRIAL INSECTS IN THREE DIFFERENT CULTIVATION PRACTICES

6.1. INTRODUCTION

The insect guild composition of the terrestrial insect community differs in many aspects from that of the arboreal insect community. Terrestrial guilds are similar and also composed of predators, parasitoids, phytophages and scavengers or detritivores. Many of the predators and scavengers are truly groundliving, whilst the parasitoids and most of the phytophages found on the ground are temporary tourists. Most of the phytophages depend on the plants and cannot remain on the ground for too long, but must return to their food source. Phytophages found on the ground were either dislodged through wind-action or could have dropped from the plant to escape from an arboreal predator (Losey & Denno, 1998).

The majority of terrestrial predators do not, or seldom climb onto plants (Honěk, 1988). They thus mainly depend on insects falling from plants as prey. The type of cultural practice or plant stand affects terrestrial insects, not only concerning shelter and microclimate, but also prey availability. The life-time fitness of such species depends on the quality and quantity of resources encountered in the different habitat types (Bommarco, 1998).

Terrestrial insects are greatly influenced by soil practices. Landscape structure could influence their success in finding and aggregating in areas of high pest density (Bommarco, 1998). Predator activity can be influenced by factors such as soil microtopography (*e.g.* smooth, rough or deeply fissured soil surfaces) and vegetation structure and density (Thomas, Parkinson & Marshall, 1998). Deep ploughing, for example, drastically changes the soil structure and is probably one of the most disturbing practices as far as ground-dwelling predators are concerned (Baguette & Hance, 1997). Species have different ecological requirements depending on their size, larval cycle and food requirements and thus react differently to soil disturbance (Baguette & Hance, 1997). However, important predators such as species from the family Carabidae, often occur abundantly in field crops, in spite of soil disturbance by tillage operations and frequent changes in vegetation, associated with rotational production systems (Ellsbury, Powell, Forcella, Woodson, Clay & Riedell, 1998).

Overall annual cropping systems are thus detrimental for terrestrial insect population growth, due to the high levels of disturbance (Landis, Wratten & Gurr, 2000). A more stable habitat and increased level of shelter provided by conservation tillage practices are more likely to foster beneficial species (Horne & Edward, 1998). Habitat management is therefore essential for these important biological control agents. This is a form of conservation biological control, aimed at favouring natural enemies and enhancing biological control in agricultural systems. Conservation biological control involves manipulation of the environment to enhance the survival, fecundity, longevity and behaviour of natural enemies thereby increasing their effectiveness (Landis *et al.*, 2000). A suitable ecological infrastructure must be established within the landscape to provide resources such as food (alternative prey or hosts) and shelter from adverse conditions. Border areas are a good example of such refugia. Furthermore, the practical use of beneficial insects requires knowledge about monitoring methods in agricultural fields and the influence of environmental factors on their distribution (Dammer & Heyer, 1997). Cultural practices can thus have an enormous influence on the terrestrial insect community, an aspect which was investigated in this study.

The following questions were asked in this part of the study:

1. How do the terrestrial feeding guilds in three different agricultural practices, *i.e.* monoculture, mixed cropping and staggered planting dates, compare?
2. Which are the dominant insect groups and what are the tendencies observed in them?
3. Is there any correlation between the tendencies in the dominant phytophage, predator and parasitoid groups?

6.2. MATERIAL AND METHODS

Insects were collected using a pitfall-trapping program. Pitfall-trapping is a widely used method for investigating the activity and occurrence of terrestrial insects (Honek, 1997). Sampling was done in the monoculture of 1997 (Fig. 2.1), the mixed crop and monoculture of 1998 (Fig. 2.2) and the staggered planting date setup in 1999 (30 November = A-plot; 30 December = B-plot and 30 January = C-plot) (Fig. 2.3). Aluminum tins were randomly placed in the soil with the rim at the level of the ground surface. They were screened from rain, irrigation water and the sun with white rooflike protectors. No bait was used and the tins were half-filled with ethylene glycol ($CH_2OH.CH_2OH$). The pitfalls were emptied every second week and the insects were preserved in 70% ethanol. The different insect feeding guilds and the relationship between them were determined for the total samples taken from the monoculture of 1997 and the mixed crop and monoculture of 1998 (Appendix 1). Calculations were done for the first three samples in each plot of the staggered planting dates setup in the 1999 season (Appendix 1). The dominant families were determined by expressing the number of individuals of an insect species as a percentage of the total number of individuals in the sample (Wassner, 1994). Following the results in Appendix 2, dominant species were taken at a value of more than 4% for the predators, parasitoids and phytophages. The tendencies in these species were then followed. The 1997 trial was done separately by Potgieter (1997), consequently the reference collection differs from the 1998/1999 collection. For comparative purposes the corresponding species had to be determined (Appendix 3), *e.g.* Coreidae sp5 in 1997 equals Coreidae sp1 in the 1998/1999 reference collection.

6.3. RESULTS AND DISCUSSION

Crops grown in large monoculture systems often suffer from severe pest problems. Monoculture reduces a complex natural plant system to a single species community. Multispecies cropping systems increase plant diversity and thus also decrease pest problems (Stamps & Linit, 1998). Phytophages are more likely to locate and remain on single species of plant host occurring in large dense stands, compared those that occur in association with other plant species. This can be seen with the composition of terrestrial insect guilds in the large monoculture of 1997 (Fig. 6.1). Because the phytophages in the pitfalls are mainly derived from the plants, the phytophages are very abundant in the pitfalls of the monoculture (Appendix 1). The predators are also abundant because of optimum shelter and prey availability. Presence of prey and suitable microclimate decrease predator dispersal and cause some species to stay within mixed stands (Honek, 1997). Because of the dense stand, the soil temperature was probably also lower than open soil without ground cover. Terrestrial insect activity patterns depend on the soil temperature (Dammer & Heyer, 1997). Insect activity has an upper and lower limit in terms of temperature. Above or below a certain temperature the activity of an insect will decrease. Overall, however, activity increases with increasing temperature till the upper limit is reached after which activity will decrease. These factors, namely the lower temperature and large prey availability in the monoculture could have reduced the activity of some species and the chance of encountering a pitfall trap decreased. Due to this less predators were caught in the 1997 pitfalls, when compared to the 1998 and 1999 season (Appendix 1).

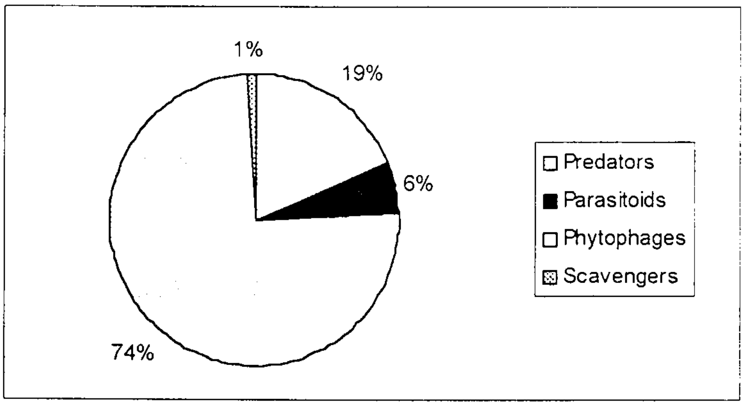

Fig. 6.1. Terrestrial insect guilds in an *Amaranthus hybridus* cultivation determined over eight samples in the monoculture, 1997.

The phytophage abundance was much lower in the monoculture of 1998 (Fig. 6.2). The monoculture was much smaller than that of 1997. Due to more open spaces where sunlight could reach the soil surface and the consequent higher temperature, the activity of predators was also greater. In the 1998 season the monoculture also had a higher abundance of predators than the mixed crop setup (Fig. 6.3). The monoculture had a slightly higher abundance of arboreal phytophages (prey) and offered more shelter than the mixed crop setup and was thus probably more favourable for predators (Fig. 4.1 and 4.2).

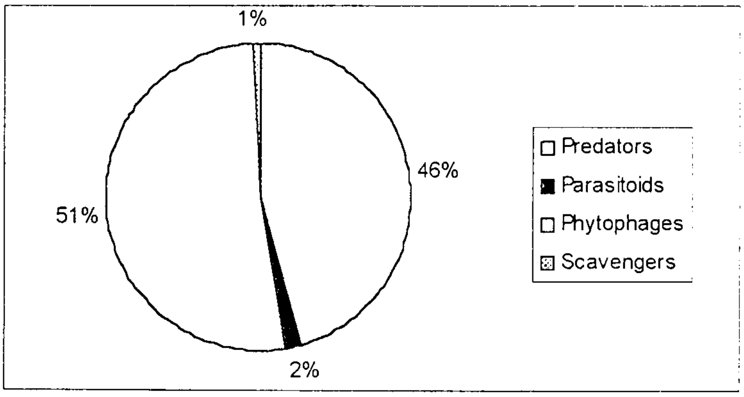

Fig. 6.2. Terrestrial insect guilds in an *Amaranthus hybridus* cultivation determined over eight samples in the monoculture, 1998.

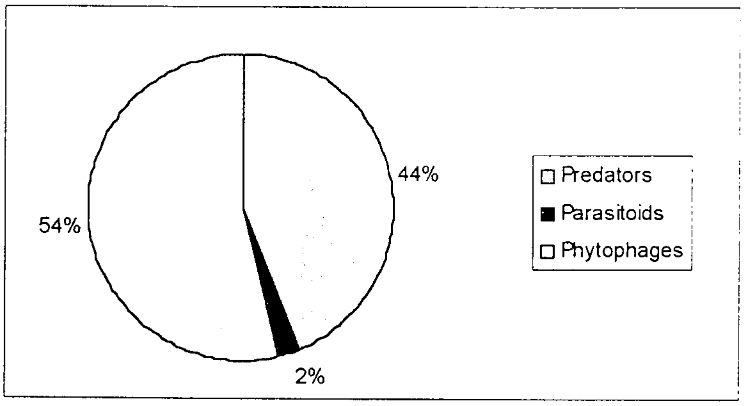

Fig. 6.3. Terrestrial insect guilds in an *Amaranthus hybridus* cultivation determined over eight samples in the mixed crop setup, 1998.

In 1999 the plots had a much higher abundance of predators than in 1997 and 1998 (Fig. 6.4) (Appendix 1). The plants of the 1999 season experienced root fungal rot and were in a bad condition, especially the B-plot. The 'plants stress hypothesis' predicts that herbivore abundance is higher on hosts under stressful conditions. This happens due to decreased chemical defenses in stressed host tissue (Cornelissen, Madeira, Allain, Lara, Araujo & Fernandes, 1997). Prey for predators was thus abundant, but because the plants were stressed, much space was available for sunlight to reach the soil surface and the soil temperatures were thus high. The activity of the predators was thus also high and the chance of landing up in a pitfall increased accordingly.

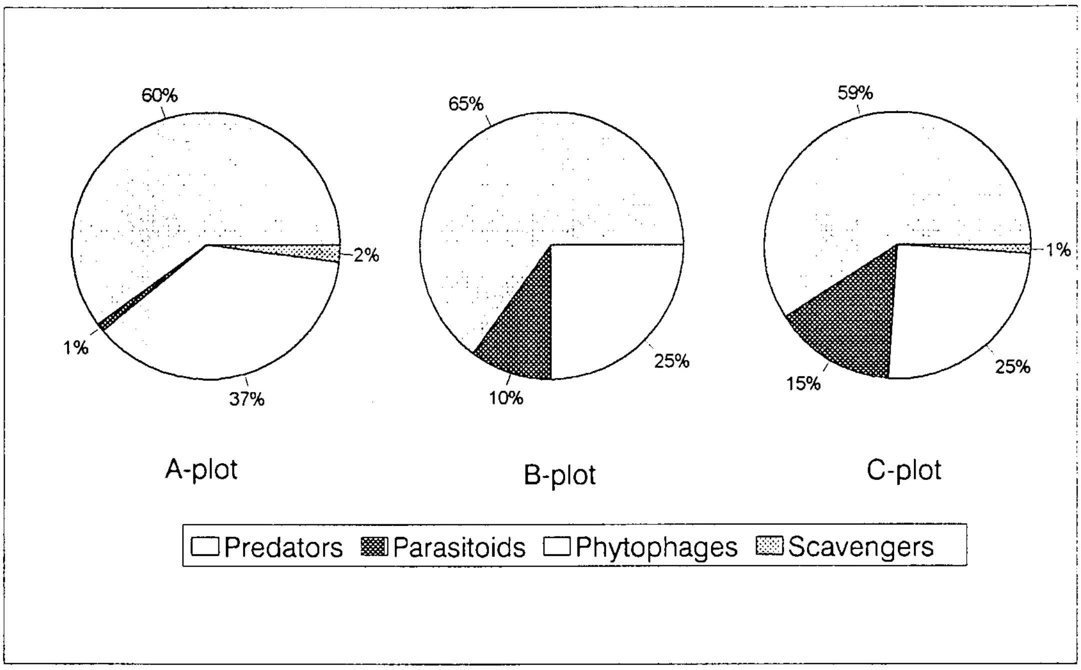

Fig. 6.4. Terrestrial insect guilds of an *Amaranthus hybridus* cultivation determined over the first three samples in each plot of the staggered planting date setup, 1999.

The B-plot (Fig. 6.4) had the highest incidence of predators. Stress conditions in this plot were highest, consequently the prey availability and temperatures were highest and there was greater activity. The high abundance of parasitoids in the B-plot and the C-plot is noteworthy. The A-plot does not have nearly as high an abundance. Parasitoids clearly became more abundant later in the growing season. This is likely due the parasitoid populations having to establish first and then increasing in population numbers. The A-plot was planted in the beginning of the season when the parasitoids had not yet established. This is the case in the first three samples, but when looking at the total samples of the A-plot (Fig. 6.5), it can be seen that the parasitoids did in fact increase in this plot later on.

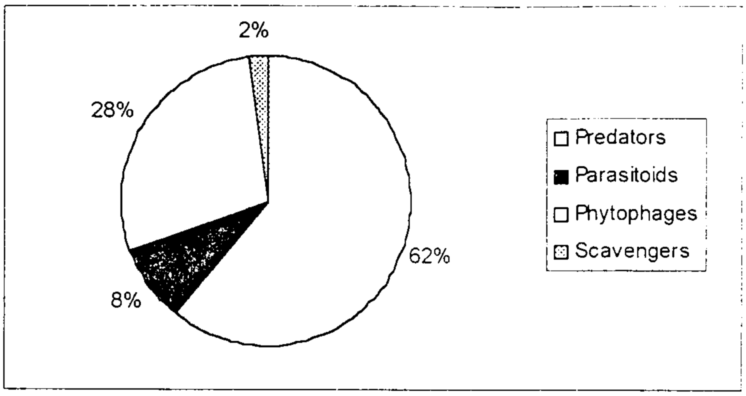

Fig. 6.5. Terrestrial insect guilds in an *Amaranthus hybridus* cultivation determined over twelve samples in the A-plot of the staggered planting dates culture, 1999.

The dominant terrestrial species present in agricultural habitats may vary, depending on the diversity and management intensity of a particular agricultural system (Ellsbury, *et al.*, 1998). Some species favour open ground and some species prefer dense shaded plant stands (Armstrong & McKinlay, 1997). This is one of the factors explaining the strong fluctuations in the incidence of families from one year to another in this study (Appendix 2). Other factors may include climate, prey availability and competition. Species that were very abundant in 1997, were very scarce or absent in the other years, *e.g.* Coccinellidae, Araneae sp1, Pentatomidae and Lygaeidae sp4. In 1998 and 1999 Labiduridae, Cicindellidae, Elateridae and Formicidae were very abundant and scarce or absent in 1997 (Appendix 2). Generally species from these families form important trophic guilds in cultivated crops and thus studies, to determine the effects of agroecosystem management on their abundance and community structure, are important (Clark, Gage & Spence, 1997). A species was taken as dominant if it surpassed 4% of the total number of insects sampled (Appendix 2).

The dominant predator families were Labiduridae (Dermaptera) and Cicindellidae (Coleoptera) (Appendix 2). Diapriidae (Hymenoptera: Chalcidoidea) were the most abundant parasitoids. The greatest abundance of phytophagous insects occurred in the Melyridae (Coleoptera), Miridae (Hemiptera) and Aphididae (Homoptera).

The Labiduridae earwigs were very abundant in 1999, much less so in 1998 and absent in 1997 (Fig. 6.6), suggesting that this species prefer open stands. The plot in

1997 was a densely shaded plant stand, while the other plots were more sparsely planted. In 1999 the peak abundance occurred near the end of the growing season (sample 9) and decreased quickly as the warm season drew to a close.

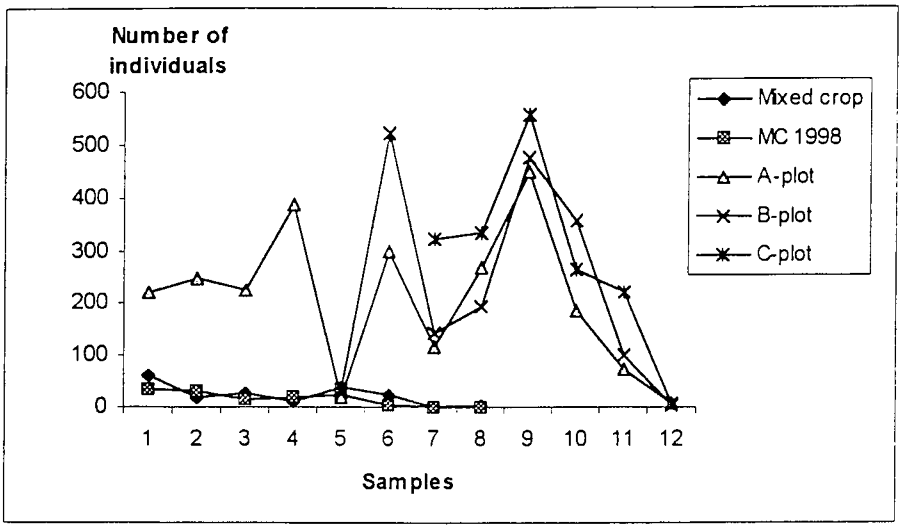

Fig. 6.6. Labiduridae collected in pitfall traps in 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (MC = monoculture).

The Cicindellidae mainly consisted of *Lophyra* spl. (Fig. 6.7). The Cicindellidae were almost absent in 1997, scarce in 1998 and very abundant in 1999. Thus, Cicindellidae also appear to prefer sparse stands. In the B-plot abundance peaked at sample 6 and in the A- and C-plot at sample 7 with the highest incidence in the C-plot (Fig. 6.7). The populations also decreased quickly towards the end of the growing season when prey availability became less.

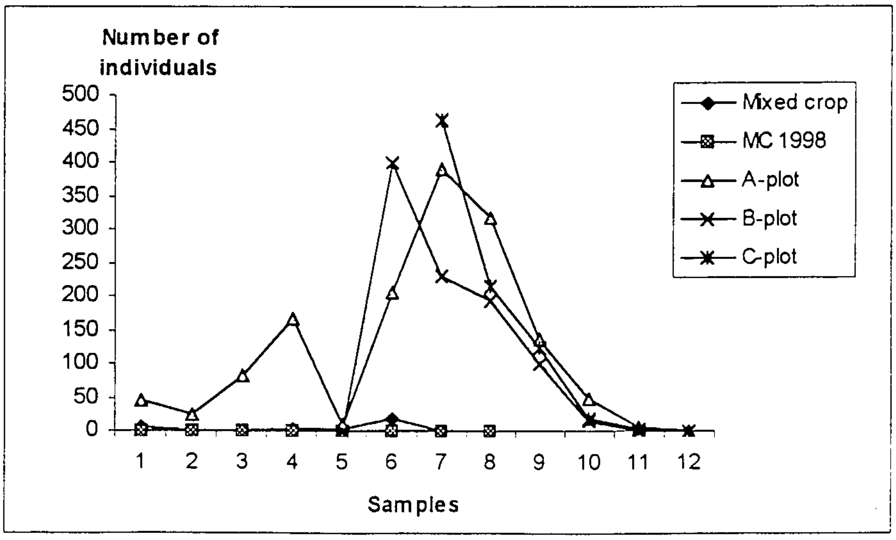

Fig. 6.7. *Lophyra* sp.1 (Cicindellidae) collected in pitfall traps in 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (MC = monoculture).

The most abundant parasitoid was Diapriidae sp1 (Chalcidoidea). This species was poorly represented in 1998 (Appendix 2). Abundance was slightly higher in 1997 (Fig. 6.8), however greatest abundance occurred in 1999. Peak abundance was observed at sample 6 in the A-plot and at sample 7 in the B- and C-plot, that in the C-plot being slightly higher. There was thus a shift in this species (perhaps following a host) from the A-plot to the new B- and C-plot at sample 7. The increase in parasitoid numbers coincided with an increase in Aphididae numbers, probably suggesting that these aphids are a host of the Diapriidae species (Fig. 6.8). For example, in the B-plot a high number of Aphididae were recorded at sample 6 with a resulting increase in Diapriidae numbers at sample 7.

The occurrence of the aphid, *Rhopalosiphum padi*, here as part of the terrestrial fauna must be regarded as temporary. This species had a high abundance in the monoculture of 1997 peaking at samples 3 and 5 (Fig. 6.8). In the 1999 season many were caught in the pitfalls. The B-plot had the highest abundance, coinciding with the highest abundance of Coccinellidae collected at sample 6 (Fig. 4.7). This is indicative of dropping behaviour by the aphids to escape from their predators (Losey & Denno, 1998). In 1998 another species of aphid was sampled and *R. padi* was only represented by a few individuals. The second species was not very abundant in 1997 and 1999, but also showed distinct population fluctuations.

Astylus atromaculatus is a pollen feeder and thus occurred primarily towards the beginning of the growing season (Fig. 6.9). The occurrence of this species as part of the terrestrial fauna must also be regarded as temporary. The monoculture of 1997 showed a very high abundance of these beetles. It was a large monoculture, which shed a heavy pollen load and a large feeding niche was thus available. In 1998 this species preferred the pumpkin, which had comparatively more pollen in a larger plant stand (Fig. 6.10). This corresponds with the 'resource concentration hypothesis' that phytophagous insects prefer larger resource patches above small patches (Matter, 1997). The C-plot showed the highest abundance in 1999. This is interesting since only a few plants in this plot reached the pollen shedding stage and it would seem that *A. atromaculatus* may have used this plot as a refugium at the end of the season.

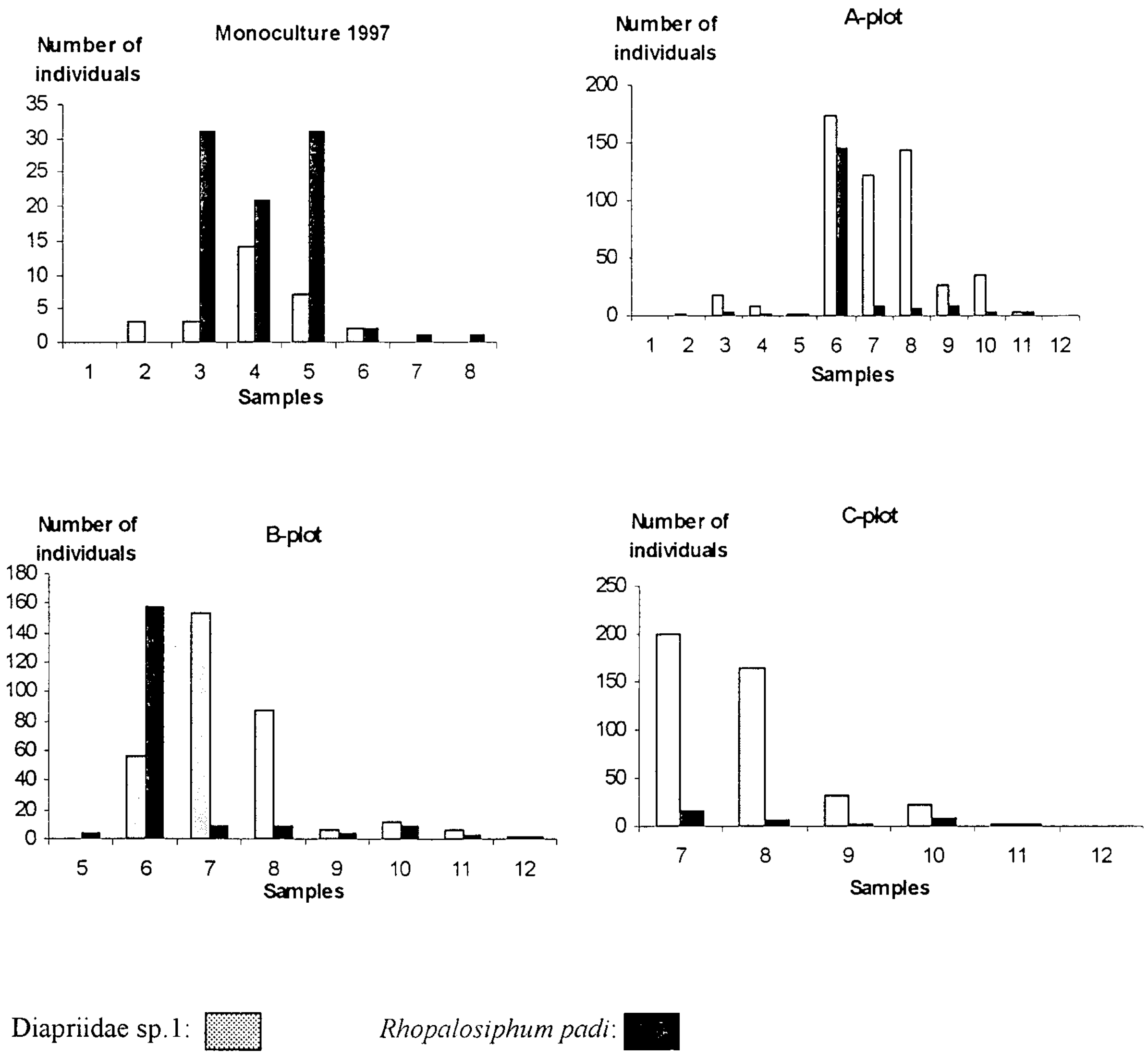

Fig. 6.8. Diapriidae sp.1 (Chalcidoidea) and *Rhopalosiphum padi* (Aphididae) collected in pitfall traps in the monoculture, 1997 and in each plot of the staggered planting dates culture, 1999.

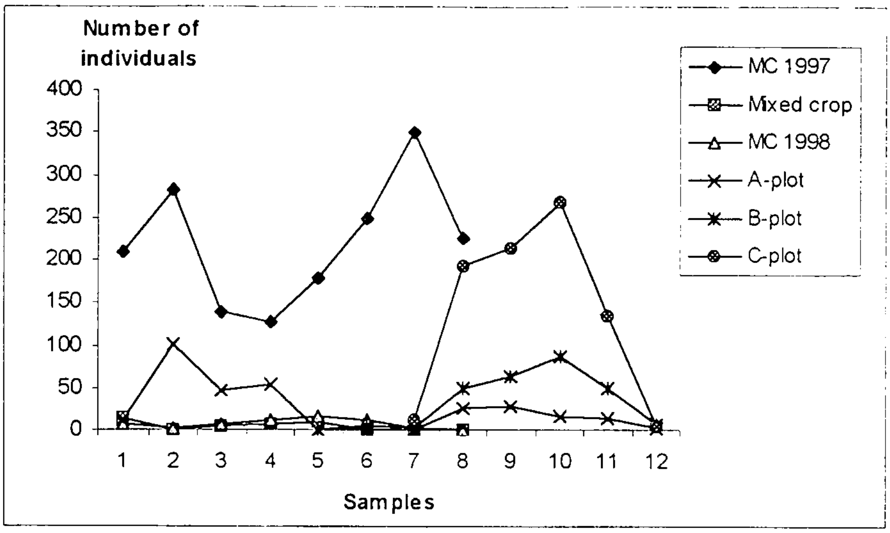

Fig. 6.9. *Astylus atromaculatus* (Melyridae) collected in pitfall traps in 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (MC= monoculture).

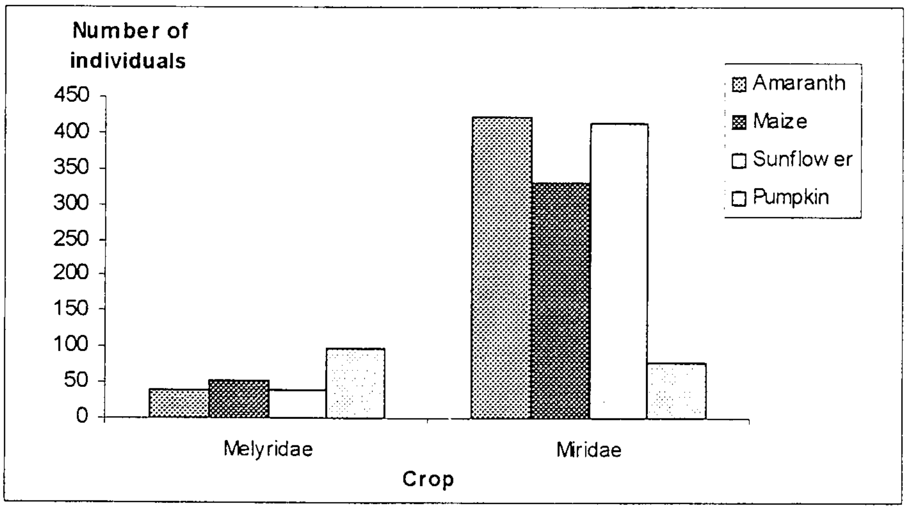

Fig. 6.10. Comparison of Melyridae (*Astylus atromaculatus*) and Miridae (*Lygus* sp.1) in amaranth, maize, sunflower and pumpkin in the mixed crop setup, 1998.

Lygus sp.1 (Miridae), also a temporary 'terrestrial' tourist, is a seed-sucker and thus occurred later in the growing season coinciding with seed forming and thus the availability of a seed-sucking niche. This species was particularly abundant in the 1997 season (Fig. 6.11), peaking at sample 6. Abundance was also very high in 1998, peaking at sample 6 for the mixed crop and at sample 7 for the monoculture. These peaks were also near the end of the growing season. *Lygus* sp1 were also abundant on the sunflower and the maize, which presented a large seed-sucking niche (Fig. 6.10). The Miridae abundance was lower in 1999, probably because fewer seeds were produced. Plants were stressed and largely failed to reach maturity.

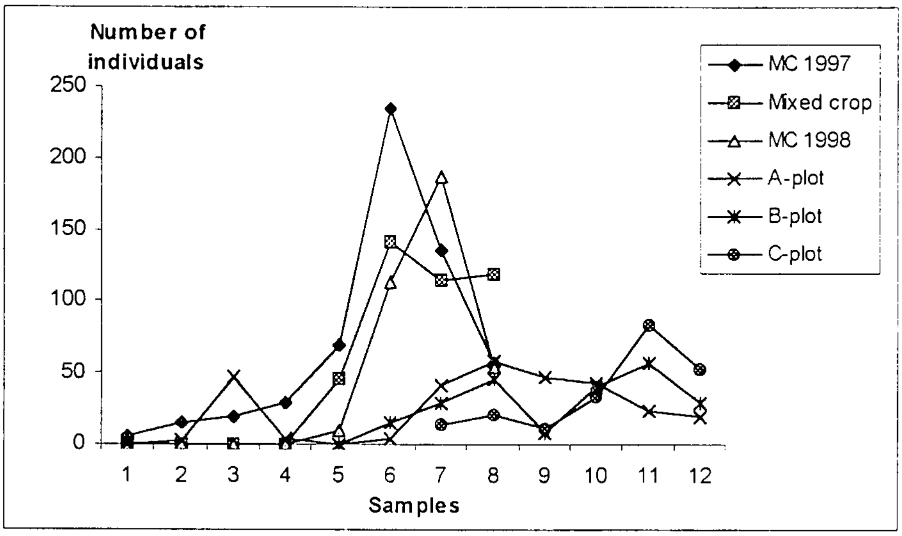

Fig. 6.11. *Lygus* sp.1 (Miridae) collected in pitfall traps in 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (MC = monoculture).

6.4. CONCLUSION

Terrestrial insects differ in their preference of dense and sparse plant stands, since different plant stands provide different microclimates and shelter possibilities. This results in population fluctuations within different species from one year to another. Phytophage availability, as prey for groundliving predators, also varies from one type of plant stand to another. The terrestrial phytophage community closely reflects that represented in Chapter 4 - those sampled in the pitfalls were mainly associated with the plants and would thus be influenced by the type of cultivation practice. For example, more phytophages were recorded in the monoculture compared to the mixed crop setup, since the monoculture was a much larger source of nutrition. The monoculture of 1997 was a very dense plant stand, and thus attracted predator species that prefer this type of microclimate. The overall activity in this stand was much less than in the other years, in spite of abundant prey availability. In the 1998 and 1999 seasons the activity of the predators was high. The stands were not as densely planted and there was thus less plantcover. The result was that more sunlight reached the soil surface increasing soil temperatures and so probably promoting terrestrial activity. Many beneficial insects are groundliving, for conservation reasons it is therefore important to establish refugia for them during periods when no cultivation is taking place. These refugia or resources must be integrated into the landscape in such a way that they are favourable for the beneficials and practical for producers to implement. The ease and relatively low cost of monitoring ground-foraging predators should also make it possible to incorporate them in IPM programs.

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Appendix 1

Terrestrial insect feeding guilds in three different cultivation practices in three different years, 1997 (monoculture), 1998 (mixed crop and monoculture) and 1999 (staggered planting dates) (1997 and 1998 over eight samples and 1999 the first three samples of each plot).

	Predators		Parasitoids		Phytophages		Scavengers	
	Total	%	Total	%	**Total**	%	**Total**	%
1997								
Monoculture	1432	18.63	429	5.58	5749	74.79	77	1.00
1998								
Mixed crop	647	43.84	29	1.97	794	53.79	6	0.41
Monoculture	564	45.67	19	1.54	641	51.90	11	0.89
1999								
A-plot	1727	59.82	24	0.83	1069	37.03	67	2.32
B-plot	2043	64.60	307	9.71	800	25.29	13	0.41
C-plot	3160	58.85	816	15.20	1349	25.12	45	0.84

Appendix 2

Dominant terrestrial insect species in different cultivation practices of *Amaranthus hybridus* with the species expressed as a percentage of the total in 1997 (MC), 1998 (MC and Mixed crop) and 1999 (Staggered planting dates). Names and numbers in bold indicate the most dominant species (MC = monoculture).

Family	Species	MC	1997	Mixed	crop	MC	1998	A-	plot	B-	plot	C-	plot
		Total	%	Total	%	Total	%	Total	%	Total	%	Total	%
Predators													
Labiduridae nymph		*		13	0.88	*		422	**14.62**	396	**12.52**	714	**13.30**
Labiduridae sp1		*		185	**12.53**	128	**10.36**	689	**23.87**	701	**22.16**	1211	**22.55**
Cicindellidae	*Lophyra* sp1	4	0.05	31	2.10	1	0.08	150	**5.20**	630	**19.92**	802	**14.93**
Coccinellidae	*Scymnus* sp1	151	1.96	*		*		*		*		1	0.02
Coccinellidae sp3		340	4.42	*		*		*		*		*	
Anthicidae	*Anthicus* sp1	6	0.08	14	0.95	15	1.21	54	1.87	34	1.07	113	2.10
Formicidae sp1		*		*		101	8.18	*		*		*	
Formicidae sp2		*		12	0.81	*		128	4.43	8	0.25	2	0.04
Formicidae sp4		*		17	1.15	18	1.46	34	1.18	37	1.17	19	0.35
Formicidae sp8		1	0.01	228	**15.45**	145	**11.74**	*		29	0.92	*	
Parasitoids													
Diapriidae sp1		29	0.38	1	0.07	*		19	0.66	210	**6.64**	398	**7.41**
Scelionidae sp1		*		13	0.88	9	0.73	*		35	1.11	71	1.32
Scelionidae sp2		4	0.05	4	0.27	3	0.24	*		49	1.55	288	**5.36**
Phytophages													
Miridae	*Lygus* sp1	566	**7.36**	421	**28.52**	364	**29.47**	50	1.73	44	1.39	46	0.86
Lygaeidae sp4 (97)		1325	17.24	*		*		*		*		*	
Rhophalidae sp1		*		146	**9.89**	59	4.78	*		4	0.13	3	0.06
Aphididae	*Rhopalosiphum padi*	87	1.13	4	0.27	12	0.97	3	0.10	171	**5.41**	25	0.47
Thripidae sp1		11	0.14	3	0.20	10	0.81	3	0.10	73	2.31	77	1.43
Melyridae larvae		*		*		3	0.24	290	**10.50**	*		*	
Melyridae	*Astylus atromaculatus*	1760	**22.90**	38	2.57	61	4.94	158	**5.47**	8	0.25	419	**7.80**
Tenebrionidae	*Zophosis boei*	1	0.01	31	2.10	36	2.91	86	2.98	13	0.41	51	0.95
Diptera sp2		136	1.77	7	0.47	7	0.57	39	1.35	7	0.22	18	0.34

Appendix 2 (continued)													
Family	Species	MC	1997	Mixed	crop	MC	1998	A-	plot	B-	plot	C-	plot
		Total	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
Diptera sp5		154	2.00	2	0.14	1	0.08	54	1.87	21	0.66	77	1.43
Diptera sp6		14	0.18	8	0.54	10	0.81	33	1.14	28	0.89	110	2.05
Acari		2	0.03	18	1.22	9	0.73	9	0.31	113	3.57	92	1.71

Appendix 3

Correlated species in the different reference collections of 1999/1998 and 1997.

1999 & 1998		1997	
Family	Species	Family	Species
Predators			
Coreidae sp1		Coreidae sp5	
Carabidae	Harpalinae sp2	Carabidae sp3	
Carabidae	Treachiinae sp1	Carabidae sp2	
Carabidae sp5		Carabidae sp4	
Staphylinidae sp1		Staphylinidae sp4	
Anthicidae	*Anthicus* sp2	Anthicidae	*Anthicus* sp3
Sphecidae sp6		Sphecidae sp3	
Sphecidae sp14		Specidae sp1	
Sphecidae sp16		Sphecidae sp2	
Formicidae sp1		Formicidae sp3	
Formicidae sp3		Formicidae sp2	
Formicidae sp8		Formicidae sp4	
Formicidae sp11		Formicidae sp1	
Araneae sp2		Araneae sp7	
Araneae sp4		Araneae sp26	
Araneae sp5		Araneae sp10	
Araneae sp7		Araneae sp4	
Araneae sp14		Araneae sp18	
Araneae sp17		Araneae sp11	
Araneae sp22		Araneae sp6	
Parasitoids			
Braconidae sp1		Braconidae sp6	
Braconidae sp2		Braconidae sp2	
Braconidae sp3		Braconidae sp8	
Braconidae sp7		Braconidae spp.11 & 13	
Ichneumonidae sp4		Ichneumonidae sp1	
Ichneumonidae sp5		Ichneumonidae sp2	
Ichneumonidae sp8		Ichneumonidae sp4	
Chalcidoidea sp6		Chalcidoidea sp21	
Chalcidoidea sp7		Chalcidoidea sp21	
Chalcidoidea sp8		Chalcidoidea sp15	
Chalcidoidea sp10		Chalcidoidea sp19	
Chalcidoidea sp11		Chalcidoidea sp20	
Chalcidoidea sp12		Chalcidoidea sp10	
Chalcidoidea sp16		Chalcidoidea sp27	
Chalcidoidea sp17		Chalcidoidea sp22	
Chalcidoidea sp18		Chalcidoidea sp17	
Chalcidoidea sp19		Chalcidoidea sp3	
Chalcidoidea sp21		Chalcidoidea sp1	
Diapriidae sp1		Chalcidoidea spp.5 & 24	

Appendix 3 (continued)

Scelionidae sp1		Chalcidoidea spp.29 & 31		
Phytophages				
Tingidae sp1		Tingidae sp3		
Miridae sp1		Lygaeidae sp3		
Miridae sp2		Miridae sp7		
Lygaeidae sp2		Lygaeidae sp17		
Lygaeidae sp3		Lygaeidae sp7		
Cicadellidae sp2		Cicadellidae sp5		
Aphididae sp2		Aphididae sp3		
Tenebrionidae	*Eurychora* sp1	Tenebrionidae sp5		
Tenebrionidae	*Somaticus* sp1	Tenebrionidae sp4		
Apionidae sp1		Apionidae sp3		
Diptera sp2		Diptera sp4		
Diptera sp4		Diptera sp1		
Diptera sp5		Diptera sp6		
Diptera sp6		Diptera spp.16 & 8		
Diptera sp8		Diptera sp24		
Diptera sp12		Diptera sp19		
Diptera sp13		Diptera sp24		
Diptera sp17		Diptera sp3		
Diptera sp18		Diptera sp17		
Diptera sp20		Diptera sp26		
Diptera sp21		Diptera sp11		
Diptera sp22		Diptera sp18		
Diptera sp23		Diptera sp10		
Diptera sp24		Diptera sp9		
Diptera sp25		Diptera sp7		
Diptera sp26		Diptera sp23		
Diptera sp28		Diptera sp25		
Diptera sp29		Diptera sp14		
Chironomidae sp1		Diptera sp5		
Culicidae sp1		Diptera sp27		
Lepidoptera larvae2		Lepidoptera larvae1		
Lepidoptera larvae3		Lepidoptera larvae 6		

CHAPTER 7

DIVERSITY, FEEDING GUILDS AND DOMINANCE STRUCTURES OF INSECTS IN BORDER AREAS

7.1 INTRODUCTION

Border areas are an integral part of any annual cropping system. It is from here that insects disperse to a cultivated crop in spring and back again in autumn. These border areas provide a refugium both for phytophagous and beneficial insects during harsh environmental conditions. Vegetation manipulation in agroecosystems and their surroundings, such as border areas, is an IPM practice that can be used to enhance beneficial arthropod numbers in crops (Rieux, Simon & Defrance, 1999).

Beneficials, particularly adult parasitoids, need pollen and/or nectar for nutrition (Bowie, Gurr, Hussain, Baggen & Frampton, 1999). Cultivated crops do not always provide these commodities and it can thus be advantageous to maintain plants with nectar and pollen in border areas for this purpose. Flowering plant habitats can also be established to provide these resources in a more stable fashion over the entire season and for years to come (Landis, Wratten & Gurr, 2000).

Many agricultural systems are recognized as particularly difficult environments for natural enemies, especially in annual monocultural cropping systems, where the rate of establishment of natural enemies and their success in controlling the target pest are lower than in long-term stable cropping systems. Annual cropping systems are detrimental to insect population build-up due to high levels of disturbance. Habitat management, a form of conservation biological control, aims to create a suitable ecological infrastructure within the agricultural landscape to provide resources such as food for adult natural enemies, alternative prey or hosts and shelter from adverse conditions (Landis, *et al.*, 2000). Creating island refugias increases the abundance of insects, especially that of predators by providing alternative food sources and a stable microclimate (Honek, 1997). The principle aim of this approach, however, is not to increase the biodiversity, but rather to strengthen the existing beneficial arthropod community (Rieux, *et al.*, 1999). In annual cropping systems, maximizing the overwintering survival of natural enemies may be critical in ensuring adequate biological control in the following growing season. The vast majority of predators overwinter in field margins (Landis, *et al.*, 2000).

If the border area is well-managed, that is, if the prey and microclimate are suitable, there will be decreased predator dispersal to other areas. Certain species will be prompted to stay and even encouraged to breed (Honek, 1997) and when cultivation of the crop starts, dispersal to the new and better resources will occur.

Other important aspects are the distance between the border area and the cultivated crop, as well as the size of the border area. Some species are disadvantaged in small or isolated habitats, but not all species are equally affected. In previous studies (Zabel & Tscharntke, 1998), it was found that the number of predator species was not affected by habitat area, but only by habitat isolation. The percentage of predator species decreased with habitat isolation because of poor dispersal capabilities and consequently, failure to colonize isolated habitats. Phytophages, on the other hand, are not affected by habitat isolation as much, but more so by habitat area (Zabel & Tscharntke, 1998). Most phytophagous species are flying insects and according to the 'resource concentration hypothesis', flying insects prefer larger patches of vegetation to smaller ones (Matter, 1997). Also, the greater the patch, the more visual and chemical stimuli for the flying insects to react to.

The border area in this study consisted mainly of a wide variety of grasses. The morphology and physiology of grasses promotes tolerance to pressure caused by drought, cold and herbivory (Tscharntke & Greiler, 1995), which are more or less characteristic of Free State winters. The palatability of grasses is greatly reduced by their high silicate content. However, the primary function of silicate, as well as lignin, may be non-defensive (Tscharntke & Greiler, 1995). The grasses are not very long and dense in winter, but this does not necessarily affect the important terrestrial predators, as long as enough prey is still available (Tscharntke & Greiler, 1995).

Border areas are thus an important part of a cropping system mainly for enhancing the occurrence of beneficial insects. The structure of the insect community in the border area and the possible influence of the border on the insects in a cultivated land of *Amaranthus hybridus*, was determined. The questions asked were:

1. What is the diversity of the arboreal and terrestrial insects in the border area?
2. What are the major feeding guilds and how do they compare in the arboreal and terrestrial insect community?
3. What are the dominant families in the arboreal and terrestrial insect communities and what are their tendencies?

7.2. MATERIAL AND METHODS

Sampling was done in the border area adjacent to the cultivated *A. hybridus* plots in 1999 (primarily next to the A-plot, which was planted on 30 November). Habitat connectivity appears to be important for increasing predator populations in the agricultural landscape for possible biological control of actual or potential pests (Zabel & Tscharntke, 1998). The border area must thus not be too far from the cultivated crop so that biological control via the natural enemies in it can be enhanced. The border area was approximately 5 meters away from the cultivated crop, and approximately 50 x 10 meters in size. Samples were collected every second week. Sweeping and beating methods were used to sample arboreal insects, and aspirators were used to collect small insects from the sweep nets and beating sheets. Eight samples of arboreal insects were taken coinciding with the samples taken for the A-plot. Care was taken to sample the same plant biomass in the border area as in the other plots. Terrestrial insects were sampled with pitfall traps. Twelve collections were done, allowing comparison with the A-plot, in which twelve samples were taken on corresponding dates (Appendix 1, Chapter 2). All insects were killed with ethyl acetate and then preserved in 70% ethanol after which they were identified to at least family level. The data were processed and different indices were calculated and compared with that of the adjacent A-plot (Appendix 1.1). The different insect feeding guilds and the relationship between them were determined (Appendix 1.2). To determine the dominant species, each species was expressed as a percentage of the total number of individuals collected (Wassner, 1994). The dominant species were then taken at more than 5% for both the arboreal and terrestrial insect communities

and the tendencies in them were followed. The cumulative species index was used to test for the correct sample size and showed that the graphs did not reach an asymptote for either the arboreal or terrestrial insect community (Fig. 7.1).

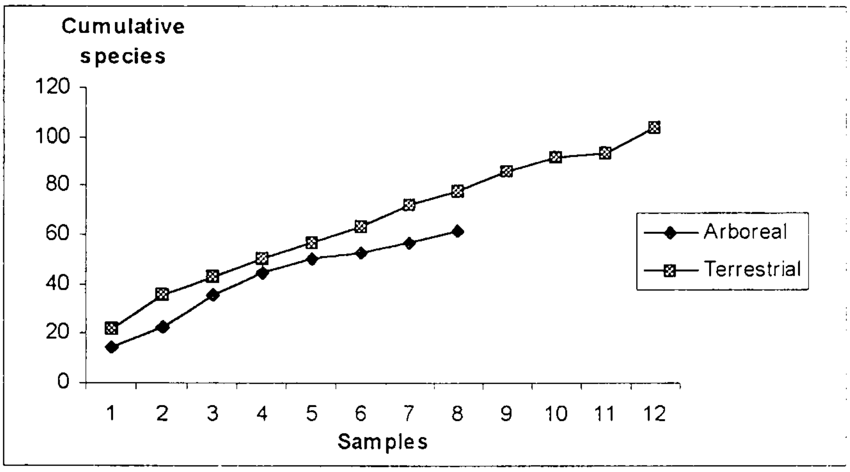

Fig. 7.1. Arboreal and terrestrial cumulative species in the border area.

7.3. RESULTS AND DISCUSSION

7.3.1. Diversity indices

7.3.1.1. Species richness

The Margalef index (D_{mg}) represents the relative abundance of species. The total abundance of the arboreal insect community in the border area (D_{mg}= 9.110) was higher than the abundance in the adjacent A-plot (D_{mg}= 6.556) (Fig. 7.2) (Appendix 1.1). This can be attributed to a higher diversity of plants species and consequently more available niches. The abundance of arboreal species decreased towards the end of the season (Fig. 7.3) as temperatures dropped and plants either died or became dormant.

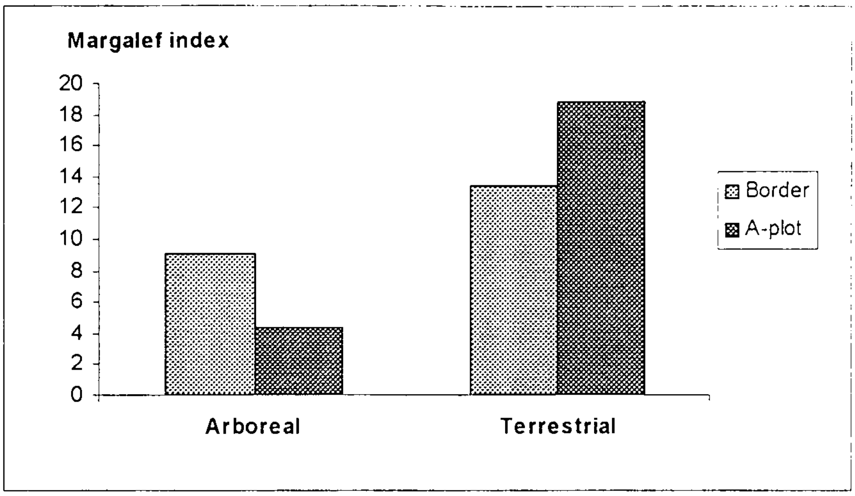

Fig. 7.2. Margalef index (D_{mg}) for the total arboreal and terrestrial insects in the border area and the A-plot.

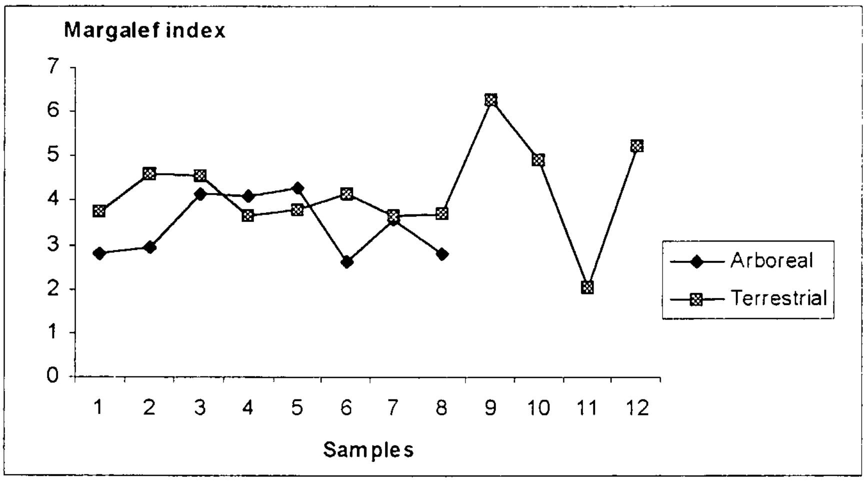

Fig. 7.3. Margalef index (D_{mg}) of the arboreal and terrestrial insects in the border area for individual samples taken.

The abundance of species in the terrestrial insect community (D_{mg}= 13.448) was higher than that of the arboreal insects (D_{mg}= 9.110) (Fig. 7.2). Albeit that the grass was not very long, which could have affected the arboreal insects, the terrestrial insects should not be affected at all (Zabel & Tscharntke, 1998). The abundance of terrestrial insects in the border area (D_{mg}= 13.448) was lower than that of the A-plot (D_{mg}= 18.327) (Fig. 7.2) (Appendix 1.1). A better microclimate existed in the A-plot during the growing season, but the inverse is true in the winter, when the border area had more shelter. The terrestrial insect abundance in the border area increased towards the end of the season as the cultivated crop started dying (Fig. 7.3) and the insects migrated to the more sheltered border area.

7.3.1.2. Rank abundance

There are four types of rank abundance plots, *i.e.* the geometric series, the log series, the lognormal distribution and the broken stick model. The rank abundance plots of the arboreal (Fig. 7.4) and the terrestrial (Fig. 7.5) insect community equal the lognormal model, which implies that the community is more or less composed of 65% rare species, 25% species with intermediate abundance and 10% very abundant species. There was thus not high dominance in the communities.

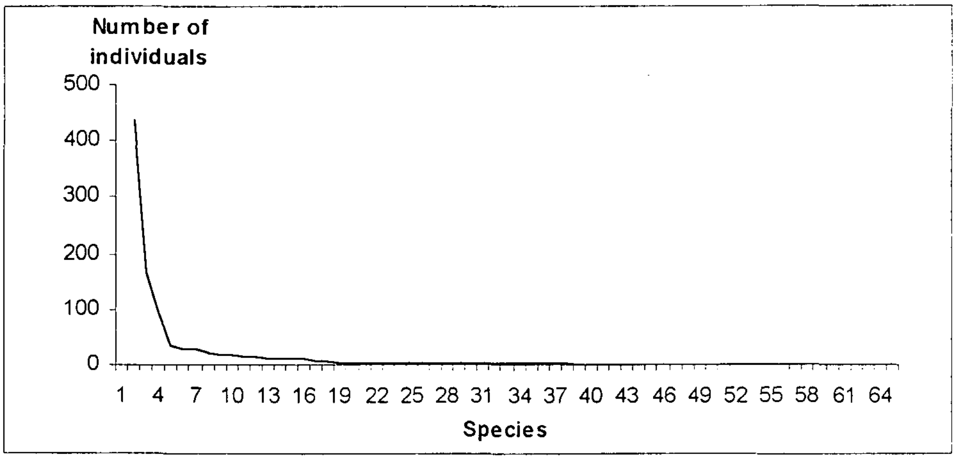

Fig. 7.4. Rank abundance plot of the arboreal insects in the border area.

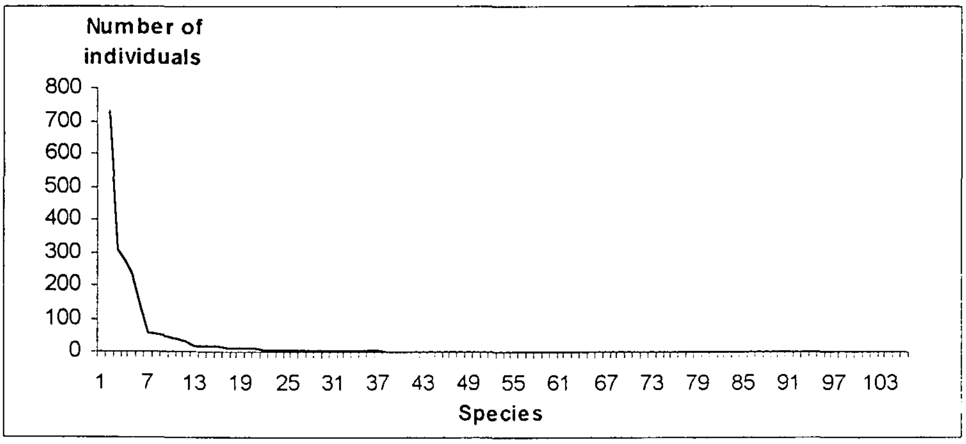

Fig. 7.5. Rank abundance plot of the terrestrial insects in the border area.

7.3.1.3. Proportional abundance of species

7.3.1.3.1. Diversity

The Shannon index is an indicator of the diversity in a community. The arboreal insect community in the border area (H= 2.294) had a slightly higher diversity than the adjacent A-plot (H= 2.269) (Fig. 7.6) (Appendix 1.1). As mentioned earlier, the border area had a much higher plant diversity and could thus support a more diverse insect community. The terrestrial insects in the border (H= 2.609) had a lower diversity than the A-plot (H= 3.457) (Fig 7.6) (Appendix 1.1). In this case the microclimate during the growing season was better in the cultivated crop than in the border. Predators are not much affected by the plant species, but rather by the prey and microclimate in the stand and thus preferred the cultivated crop where there was abundant prey and a more acceptable microclimate. After the growing season the insects dispersed back to the border area.

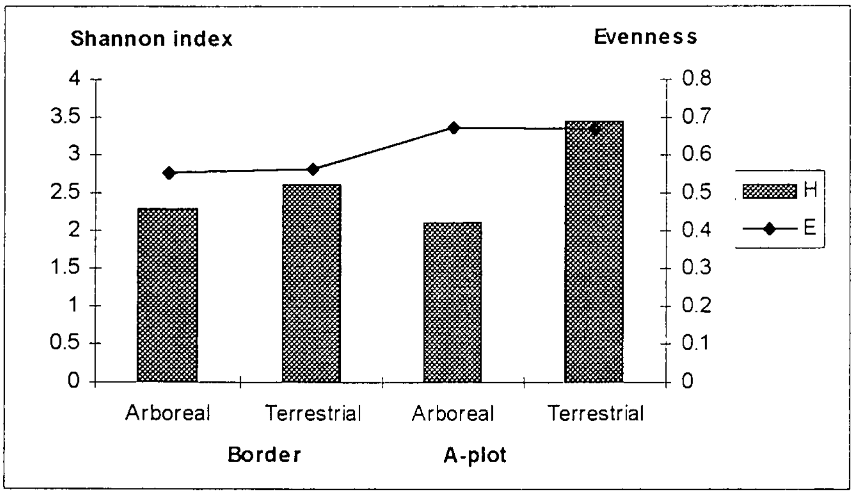

Fig. 7.6. Shannon index (H) and evenness (E) for the arboreal and terrestrial insects in the border area and the A-plot.

The evenness of the arboreal and terrestrial insect communities in the A-plot (E= 0.603 and 0.670 respectively), however, was higher than that of the border (E= 0.552 and 0.561 respectively) (Fig. 7.6) (Appendix 1.1). The species in the border were thus not always evenly distributed. As the species moved between the cultivated crop and the border area, only a few species that were specific to the grass environment remained behind, thus implying large diversity fluctuations that could have attributed to the unevenness.

7.3.1.3.2. Dominance

The Berger-Parker index is an indicator of the dominance in a community. The diversity increases and the dominance in the insect community decreases when the inverse value of the index (1/d) increases. The species with the highest number of individuals is used, and thus the lower the number of that species, the more evenly the total number of individuals is distributed between the species, resulting in lower dominance and higher diversity. The arboreal insect community in the border area (1/d= 2.770) was slightly more diverse and thus exhibited slightly less dominance than the adjacent A-plot (1/d= 2.312) (Fig. 7.7) (Appendix 1.1). This was because the border had a higher diversity of plants. The terrestrial insects in the border (1/d= 3.132) had lower diversity and higher dominance than the terrestrial insects in the A-plot (1/d=4.785) (Fig. 7.7). The terrestrial insects preferred the habitat with the best prey and microclimate, *i.e.* the cultivated crop, and only a few species probably stayed in the border area permanently. In the cultivated stand these insects could increase in numbers due to the favourable environmental conditions.

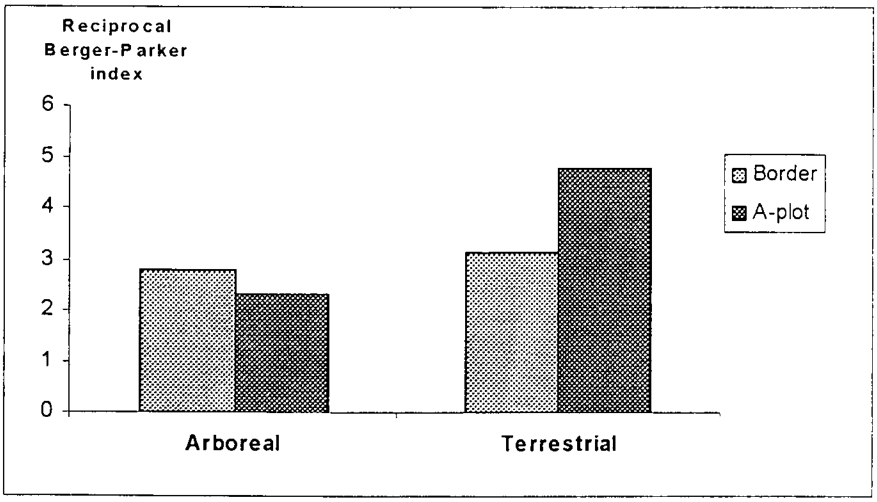

Fig. 7.7. Reciprocal Berger-Parker index (1/d) for the arboreal and terrestrial insects in the border area and the A-plot.

7.3.2. Feeding guilds and dominance structures

The arboreal insect community mainly consisted of phytophagous species (Fig. 7.8) while the terrestrial community, in comparison, had a much greater occurrence of predators and scavengers or detritivores (Fig. 7.9) (Appendix 1.2). This is in agreement with other studies where it is reported that grass ground-cover shelters many entomophagous species (Rieux, *et al.*, 1999). It is thus important that the border area is preserved, especially during the winter, when no other cultivation practices occur. The detritivores in the border area mainly consisted of Tenebrionidae (Table 1), which are secondary phytophages. There was a lot of grass debris on which these species could feed.

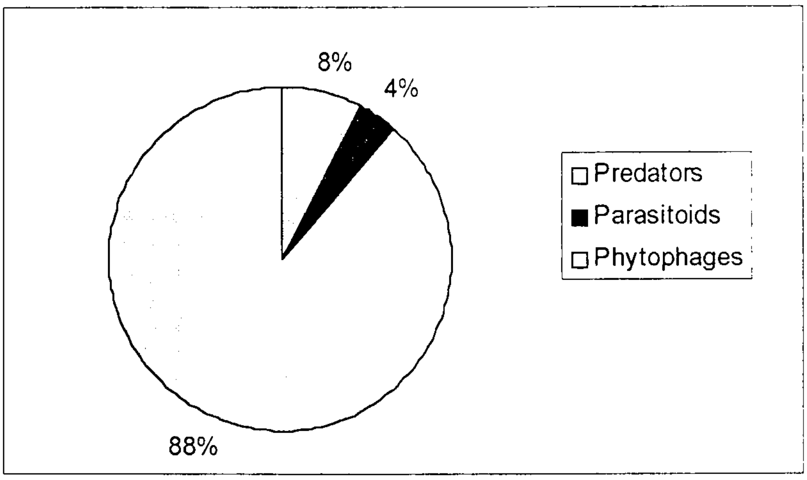

Fig. 7.8. Feeding guilds of arboreal insects in the border area.

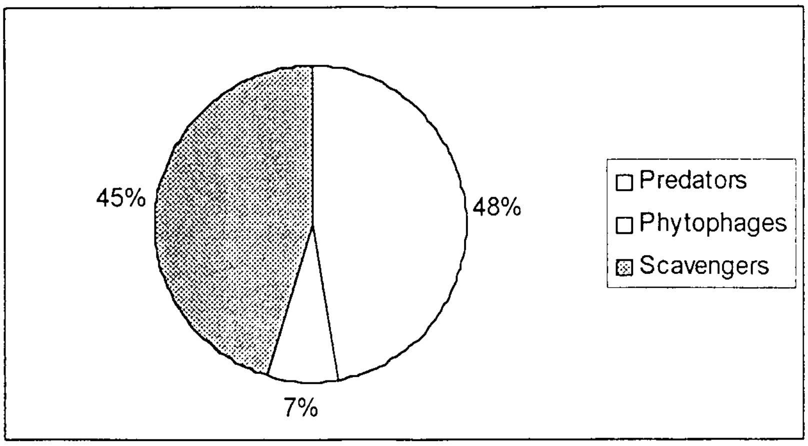

Fig. 7.9. Feeding guilds of terrestrial insects in the border area.

The dominant species in the border area mainly consisted of phytophages, as is the case in the A-plot. The dominant predator and detritivorous species were mostly terrestrial. A species was taken as dominant if it surpassed 5% of the total sampled (Table 1). It is also notable that some species that occurred in the A-plot did not occur in the border area at all, such as the predator Cicindellidae (Table 1). Cicindellidae prefer open, sparse stands such as the A-plot.

Table 1. Dominant species of the arboreal and terrestrial insect communities in the border area and A-plot with the species expressed as a percentage of the total. Names and numbers in bold indicate the most dominant species.

Family	Species		Border area				A-	plot	
		Arbo	real	Terres	trial	Arbo	real	Terres	trial
		Total	%	Total	%	Total	%	Total	%
Predators									
Labiduridae sp1		*		272	**11.92**	*		2492	**20.92**
Cicindellidae	*Lophyra* sp1	*		*		*		1436	**12.06**
Formicidae sp2		14	1.39	235	**10.30**	*		188	1.58
Formicidae sp4		3	0.30	310	**13.58**	*		487	4.09
Diplopoda		*		42	1.84	*		*	
Phytophages									
Termitidae sp1		*		47	2.06	*		*	
Miridae	*Lygus* sp1	436	**43.25**	4	0.18	149	**24.59**	292	2.45
Rhophalidae sp1		94	9.33	21	0.92	10	1.65	70	0.59
Diptera sp4		27	2.68	1	0.04	*		82	0.69
Diptera sp12		167	**16.57**	1	0.04	*		20	0.17
Diptera sp25		30	2.98	*		*		103	0.86
Detritivores									
Tenebrionidae	*Zophosis boei*	*		729	**31.95**	*		207	1.74
Tenebrionidae	*Zophosis* sp3	*		148	6.49	*		81	0.68
Tenebrionidae	*Somaticus* sp1	*		55	2.41	*		34	0.29

In the arboreal insect community Miridae (*Lygus* sp1) and Diptera sp12 were the most abundant species. The Miridae (Fig. 7.10) and Diptera sp12 (Fig. 7.11) had several major peaks during the season, but there was a general decrease towards the end of the growing season as they went into an overwintering phase or died. The terrestrial detritivore species, *i.e. Zophosis boei* (Tenebrionidae), also decreased towards the end of the season (Fig. 7.12). The terrestrial predators, on the other hand, *i.e.* Labiduridae sp1 (Fig. 7.13), Formicidae sp2 and Formicidae sp4 (Fig. 7.14), increased towards the end of the season. These species are opportunistic predators and freely moved to any habitat with available prey. As the cultivated crop neared the end of its growing season and prey availability, optimum microclimate and shelter decreased, these predators migrated to the border area where optimum conditions still prevailed.

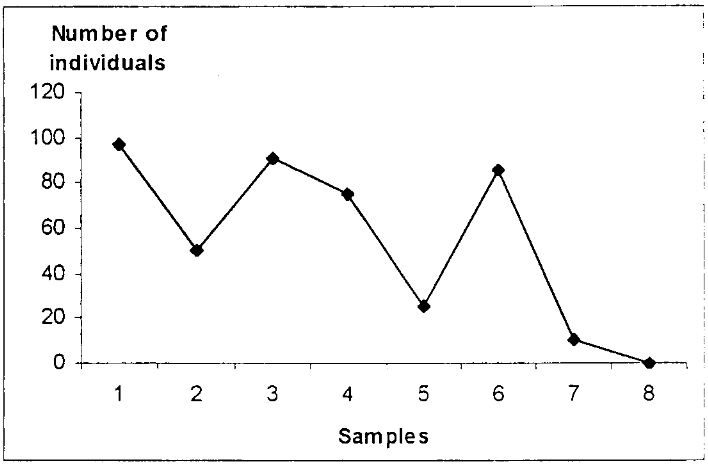

Fig. 7.10. Miridae (*Lygus* sp1) collected from the plants in the border area.

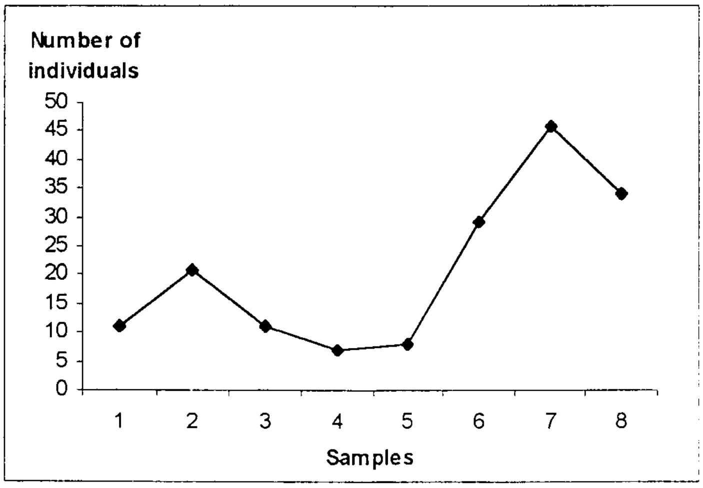

Fig. 7.11. Diptera sp12 collected from the plants in the border area.

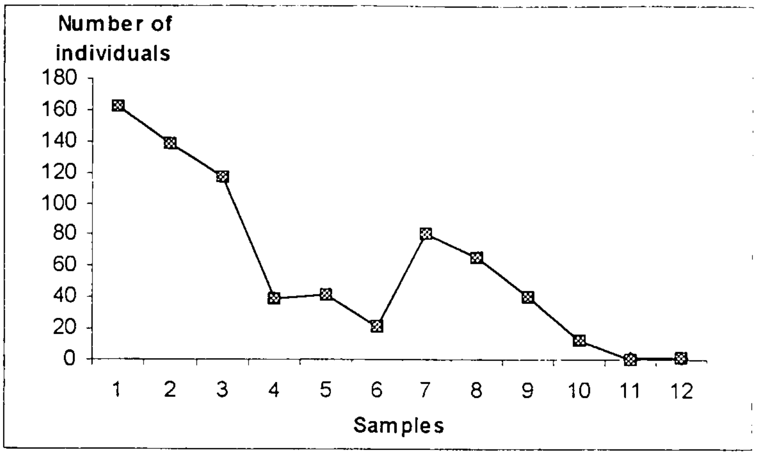

Fig. 7.12. *Zophosis boei* (Tenebrionidae) collected in pitfalls in the border area.

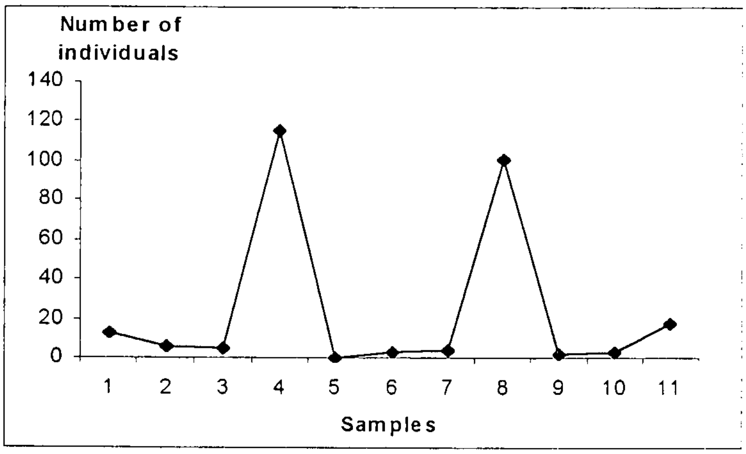

Fig. 7.13. Labiduridae sp1 collected in pitfalls in the border area.

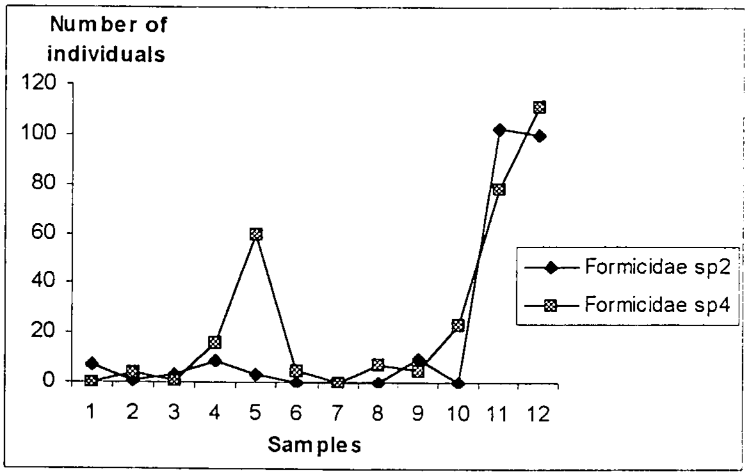

Fig. 7.14. Formicidae sp2 and Formicidae sp4 collected in pitfalls in the border area.

In general the phytophages thus decreased and the predators increased at the end of the season in the border area. The border area is thus important for the conservation of predators during the winter.

7.4. CONCLUSION

The arboreal insect community of the border area was more diverse than that of the cultivated crop, because the border had a higher diversity of plants with numerous niches. Terrestrial insects in the border area had a lower diversity than in the adjacent cultivated crop, because there was abundant prey and a better microclimate in the crop. As the growing season of the crop came to an end, the terrestrial insects and especially the predators, migrated to the border area, where there was still prey and a viable microclimate. The phytophagous insects decreased towards the end of the season as they went into overwintering phases or died. The border area supported many predators, especially during the cold months. Biological control strategies in annual crops must thus include provision of permanent habitats like border areas, to act as reservoirs for natural enemies.

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Appendix 1

1.1. Diversity indices for the arboreal and terrestrial insects in the border area in total.

(S: Species; N: Total population number; Dmg: Margalef index; H: Shannon index; E: Evenness; d: Berger-Parker index)

		S	N	Dmg	H	E	d	1/d
Border area	Arboreal	64	1008	9.110	2.294	0.552	0.433	2.770
	Terrestrial	105	2283	13.448	2.609	0.561	0.319	3.132
A-plot	Arboreal	43	606	6.556	2.269	0.603	0.361	2.312
	Terrestrial	174	11912	18.327	3.457	0.670	0.209	4.785

1.2. Arboreal and terrestrial insect feeding guilds of insects sampled in the border area.

	Arboreal		Terrestrial	
	Total	%	Total	%
Predators	77	7.64	1077	47.20
Parasitoids	37	3.67	6	0.26
Phytophages	893	88.59	166	7.27
Scavengers	1	0.10	1033	45.27

CHAPTER 8

GENERAL CONCLUSION AND RECOMMENDATIONS

8.1. GENERAL CONCLUSION

Farming is becoming more and more expensive. Pesticides are very costly and also detrimental to human and environmental health. Some sort of pest control, however, is necessary to keep pest populations under economic injury levels. Farmers are looking for low cost alternative methods, which will provide a long-term solution for pest problems. Alternative methods, such as biological control and cultural practices, are referred to as integrated pest management (IPM) when they are used in combination. Input costs can be lowered further, by using and enhancing beneficials that are already present. This is known as conservation biological control and involves the manipulation of the environment of natural enemies so as to enhance their survival and/or physical and behavioral performance, resulting in enhanced effectiveness (Barbosa, 1998a). This approach can be applied to exotic (*i.e.* introduced) as well as indigenous (native) natural enemies. Classical biological control (importation of exotic enemies against either exotic or native pests) (Ehler, 1998) is not always successful and leaves room for improvement. General approaches to natural enemy conservation include reducing direct mortality, providing supplementary resources, controlling secondary enemies and manipulating host plant attributes (Landis & Menalled, 1998).

Cultivation practices can have a direct impact on natural enemy survival, and can change microclimates to favour the development, survival and behaviour of natural enemies (Barbosa, 1998a). Monocultures, mixed cropping and staggered planting dates, are cultivation practices that influence the interactions between the different components in a feeding web. The appropriate use of cultural practices can enhance physical and/or biological diversity of the habitat and thus enhance natural enemy performance.

Pest problems in Western hemisphere agriculture are largely a result of the expansion of crop monoculture at the expense of biodiversity and natural vegetation (Gurr, Van

Emden & Wratten, 1998). Monoculture reduces a complex natural ecosystem to a single plant species environment. Big monocultures present more visual and chemical stimuli for flying insects, prompting them to land more readily on plants than in a more diverse setup. This promotes rapid population growth of a single or a few phytophagous insect species that more likely than not develop into pests (Stamps & Linit, 1998). This correlates with the results of this study, *i.e.* large populations of arboreal phytophagous species in monocultures. Consequently farmers must use large amounts of pesticides to keep these insects under economic injury levels resulting in high production costs.

A mixed cropping setup diversifies the environment. This contributes to a greater diversity of niches and consequently a more diverse phytophage community, which in turn supports a more diverse natural enemy community. Diversification also provides alternative food sources for adult beneficials, alternative hosts for parasitoids, or a favourable microclimate, which promote the maintenance of natural enemies (Barbosa, 1998a). The diversity in the mixed crop setup was higher for the phytophages and natural enemies in this study. Mixed cropping promotes the biodiversity of phytophages and not only the increase of a few phytophage species. This practice also meets the agronomic, socio-economic and nutritional needs of the small-scale farmer better (Abate, Van Huis & Ampofo, 2000).

Adjusting planting and harvesting time to escape pest damage is one of the important strategies of keeping pest damage below economic levels. By planting early sure pest population peaks can be avoided. Comparing the different plots in the staggered planting date setup in this study, the earliest planted crop proved to be the most advantageous. These plots can also be seen as monocultures, but planted at successive dates. Early planted crops also benefit from a full season's rainfall and soil nitrate fluxes. One plot can be planted early for maximum yield and possibly after a month another can be planted, just to attract the pest populations, which should then be at peak population build-up. In this study, the second planted crop attracted the most phytophagous species, which supports this proposal.

Phytophages are influenced by plant density, patch size and vegetation diversity (Bottrell, Barbosa & Gould, 1998). The 'resource concentration hypotheses' proposes that movement of insects into large and out of small patches would produce a pattern of increasing diversity with patch size (Matter, 1997). True to this the monoculture, the biggest plot in this study, thus had the highest overall phytophage abundance, followed by the 1999 staggered planting date plots and the mixed cropping plots.

Terrestrial insects are an important part of the insect community because many predators are terrestrial and thus contribute greatly to the predator complex. Conserving these species is thus essential. Terrestrial insects are greatly influenced by the microclimate and shelter provided by plants and would thus prefer stands in which these factors are at an optimum. Some species prefer dense plant stands, while others prefer more sparse stands. The monoculture of 1997 was a very dense stand with less terrestrial predator activity. Stands in 1998 and 1999 were not as dense, the soil temperature was higher (more sunlight reaching the ground) resulting in higher predator activity with a consequent higher prey encounter rate. Patch size is also important. Terrestrial predators are poor dispersers and tend to stay in, or return to, the plot with optimum microclimate, shelter and prey availability. Plots in the 1998 season were small and the insects presumably preferred the large adjacent monoculture of maize. To conserve the terrestrial predators, plots must thus not be too small and optimum conditions must be maintained where possible.

Another aspect which affects arboreal insects is plant quality. When plants affect the other components of a feeding web, it is known as a 'bottom-up' system. In multi-trophic level communities, bottom-up effects manifest when organisms at each trophic level are limited by resources from the level below (Letourneau & Dyer, 1998). Bottom-up effects, such as nutritionally poor or toxic plants, affect the phytophages on them (Stewart, 1996). The 'top-down' theory, on the other hand, suggests that abundance at each level is set directly or indirectly by the consumers at the top of the chain (Polis & Strong, 1996). The plants in 1999 were in a weak condition due to fungal root rot. It can thus be assumed that the phytophages on these plants were subject to bottom-up effects. In 1998 there was also a high diversity of natural enemies, but whether this could be adjudged as exerting a 'top-down' effect on the system, was not determined. In the 1997 monoculture natural enemies were not as abundant, but the plants were in a good condition, which was positive for phytophage population growth. The dominant families all occupied different niches (*i.e.*, leaf-feeders, pollen-feeders and seed-suckers), therefore no lateral effects (such as competition) were expected. In 1997 there was thus probably a noteworthy bottom-up effect.

Central to conservation biological control is the maintenance or enhancement of beneficials that will reduce herbivores effectively and consequently enhance crop productivity (Letourneau, 1998). In this study, only a few phytophage species are dominant, for example, in the A-plot the dominant phytophagous species made up approximately 70% of the total phytophagous community. Only a few natural enemies are thus necessary for these dominant species, they will possibly also attack the sub-dominant phytophages. The conservation of a few natural enemies, rather than the conservation of all or most natural enemies in an agroecosystem, would make the development and acceptance of conservation biological control tactics by farmers easier and more cost-effective. Fewer tactics will be required for the cost-effective control of pests, than if all natural enemies required conservation (Barbosa, 1998b).

Another aspect that is important to consider in conservation biological control is intraguild predation. Intraguild predation occurs when predators that share a common prey also feed on each other. This may disrupt biological control strategies (Cisneros & Rosenheim, 1998). When a predator's usual prey is rare or unavailable the predator may broaden its diet to include new organisms such as other predator species in the same guild (Lucas, Coderre & Brodeur, 1998). When prey populations increase again there will not be enough natural enemies to control phytophage numbers. This can be addressed by increasing plant diversity and thereby also the phytophage diversity on which predators can feed. Releasing relatively harmless phytophagous prey as alternative for predators is another possible solution (Janssen, Pallini, Venzon & Sabelis, 1998).

Some predators 'help' each other. This is known as synergistic interaction. This interaction occurs when one species of predator influences prey behaviour and thus affects prey susceptibility to other predator species (Losey & Denno, 1998). The combined predation rates of both predators can subsequently be nearly double the sum of the individual predation rates. Such an effect occurs between Coccinellidae and Carabidae with Aphididae as common prey. Aphids escape from Coccinellidae by dropping from the plant, which renders the aphids susceptible to predation by the terrestrial Carabidae. Terrestrial predators are an important asset, although they do not necessarily occur on the plants and their conservation is thus essential.

Parasitoids are also important natural enemies. The physical and chemical characteristics of the food plants of herbivorous hosts, as well as the distribution of these plants in space and time, influence parasitoid survival, parasitoid-host interactions and thus the potential effectiveness of parasitoids as biological control agents. Some plants emit blends of volatile compounds from damaged tissues caused by herbivory. Parasitoids can use these signals to distinguish between plants with potential hosts and plants without potential hosts to improve their foraging efficiency (De Moraes, Lewis, Pare, Alborn & Tumlinson, 1998). The objective of conservation biological control is to ensure the occurrence of as many parasitoid resources and hosts possibly coinciding in space and time. Food for adult parasitoids, favourable microclimates, alternative hosts and perhaps even protection from their own natural enemies must be provided by plants (Barbosa & Benrey, 1998). One way to accomplish this is by diversifying plant species and the structural complexity of vegetation such as in a mixed cropping setup. The greater the variety in a habitat, the greater the likelihood that parasitoid requisites will be met. The impact of plant and habitat diversity on hyperparasitism or predation must also be taken into account in the development of conservation biological control. Parasitoids have their own suite of predators and parasitoids attacking them. This can disrupt the effective control of phytophage host populations (Rosenheim, 1998).

Superparasitism occurs in nature. This is when a host that is already parasitized, is parasitized again by another parasitoid species. In such cases the availability of hosts plays an important role and a switch to superparasitism is adopted when unparasitized hosts are scarce (Royer, Fournet, Brunel & Boivin, 1999). The effect of 'pure' parasitism can thus be smaller than estimated. The same methods might be applied as when intra-guild predation occurs. Superparasitism can be addressed by increasing plant diversity and thus also host diversity. Again, releasing relatively harmless phytophagous hosts as alternative for parasitoids may be a possible solution (Janssen, *et al.*, 1998).

Many cropping systems are annual, and thus only temporally available for phytophages and their natural enemies. Outside this period they must find other resources essential for their survival. These resources include food, alternative hosts and suitable sites for overwintering (Ferro & McNiel, 1998). To conserve natural enemies it is important to incorporate permanent habitats like border areas to act as reservoirs for natural enemies. Here they can overwinter, build up population numbers and later disperse again. Natural habitats in the vicinity of the cultivated crop can be quite important in providing alternative food and refugia for natural enemies. These habitats may provide alternative prey or hosts, pollen or nectar, as well as microhabitats that are not available in weed-free cultivations (Letourneau, 1998). Refugia provide indirect benefits to predators by enhancing the likelihood that they will find prey, particularly during times of scarcity (Barbosa, 1998a). Natural enemies are also greatly affected by disturbance in the cultivated field. The level of disturbance must be reduced (such as reduced tillage procedures) to enhance the survival and effectiveness of beneficials.

8.2. RECOMMENDATIONS

Cultural practices are important to enhance the abundance of natural enemies. Crop stands must not be too small and the more diverse a crop setup, the better. A diverse cropping system is also advantageous for the small-scale farmer. It is also advantageous to plant early to escape insect damage and maximize yield. If plants are planted too late, they never reach maturity and the desired crop yield is not reached. Stands with optimum resource availability, microclimate and shelter must be provided to enhance the fecundity and efficiency of terrestrial enemies. Stands must also not be too dense as this restricts the activity of predators. Refugia must be provided for the beneficials where there is less disturbance, alternative prey and hosts occur, and nectar and/or pollen are available for adult parasitoids. These must also act as overwintering sites for beneficials. Refugia can be border areas or weed strips planted in the land, but they must not influence crop yield. These refugia must be practical, allowing producers to implement them with ease.

These recommendations are based on the conservation biological control concept, which aims at using and enhancing the beneficials, which are already present. This method involves the manipulation of the environment of natural enemies, so as to enhance their survival and performance, resulting in enhanced effectiveness. These recommendations are easy to apply by the farmer and therefore of importance to obtain maximum yield in the long term with lower production costs.

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SUMMARY

Biodiversity is a non-detachable part of the concept of sustainable agriculture. The reliance on only a few crop species in the agricultural landscape poses special problems and risks due to biotic hazards. To enhance diversity, agriculture must diversify crop production and exploit under-utilized and new crops. *Amaranthus hybridus* is such a crop and has great potential due to its hardiness and high nutritional value. Acceptable crop yield depends on the influence of insects. Some sort of pest management thus forms an integral part of agriculture. Due to detrimental effects on the environment and the high cost of pesticides, farmers are looking for alternative low cost methods, which will provide a long-term solution for pest problems. Cultivation practices are one such method, which aim to enhance natural enemy performance. This study was conducted near the Tempe airport, 20 km northwest of Bloemfontein (SE 2926Aa) in the Free State. A monoculture trial was run in 1997 and 1998, a mixed crop setup in 1998 and a staggered planting date culture in 1999. Monoculture, the most widely used method of farming in the Free State, reduces a complex natural ecosystem to a single plant species environment, resulting in more visual and chemical stimuli for flying phytophagous species, prompting them to land more readily than in a more diverse plant environment. Thus, large populations of phytophages occur in the monoculture, some of which, due to favourable microclimate could develop to pest status. Mixed cropping is a more diverse plant system, thus presenting a greater diversity of niches and consequently a higher diversity of arboreal phytophages and natural enemies. Adjusting planting and harvesting time, such as staggered planting dates, can be used to escape pest damage and keep it below economic levels. By planting early sure pests population peaks can be avoided. The terrestrial insect community is also of major importance, since many predators are groundliving. Terrestrial insects are influenced by the microclimate and shelter provided by plants and preferred stands in which these factors are at an optimum. In this study it was found that predators are most effective in large, sparse stands. To conserve natural enemies it is important to incorporate permanent habitats like border areas where they can overwinter, build up population numbers and from which they can disperse to newly planted crops. This study promotes conservation biological control, which aims at using and enhancing beneficials, which are already present, by using different cultivation practices. Farmers often lack the biological and ecological information necessary to develop better pest management. This study was aimed at providing that information to obtain maximum yield in the long term with lower production costs.

Key Words: *Amaranthus hybridus*, monoculture, mixed cropping, staggered planting dates, arboreal insects, terrestrial insects, refugia, border areas, diversity, feeding guilds.

OPSOMMING

Biodiversiteit is 'n onafskeibare konsep in volhoubare landbou. Daar is sekere gevare en risikos aan verbonde deur net 'n paar gewasse te plant. Landbou moet eerder 'n verskeidenheid gewasse of nuwe gewasse produseer ten einde biodiversiteit te bevorder. *Amaranthus hybridus* (morogo) is 'n nuwe gewas wat groot potensiaal het a.g.v. sy hoë voedingswaarde en gehardheid. Insekte beïnvloed aanvaarbare gewas opbrengs en daarom is een of ander vorm van plaagbestuur 'n integrale deel van landbou. Insekdoders het soms 'n nadelige uitwerking op die omgewing en is ook baie duur, daarom soek boere alternatiwe metodes met laer kostes wat langtermyn oplossings vir plaag probleme sal bied. Verbouingspraktyke is een van die alternatiewe metodes en stel ten doel om die effektiwiteit van natuurlike vyande te verbeter. Die huidige studie is gedoen naby die Tempe Lughawe, 20 km noordwes van Bloemfontein (SE 2926Aa) in die Vrystaat. Verskillende verbouingspraktyke is gebruik, nl. 'n monokultuur in 1997 en 1998, 'n wisselbou opset in 1998 en opeenvolgende plant datums in 1999. Monokulture is die algemeenste landbou metode in die Vrystaat. Dit reduseer egter 'n komplekse natuurlike ekosisteem na 'n enkel plant spesie omgewing wat meer visuele en chemiese stimuli vir vlieënde fitofage bied en hulle dus meer aanspoor om te land as in 'n diverse sisteem. Groot getalle fitofage insekte het dus in die monokultuur voorgekom en a.g.v. gunstige omstandighede kan van hulle plaag status bereik. Wisselbou is 'n meer diverse plantsisteem met groter diversiteit van nisse en dus ook 'n hoër diversiteit van fitofage en natuurlik vyande. Die aanpassing van plant- en oestye, bv. opeenvolgende plant datums, kan gebruik word om plaagskade te beperk en onder ekonomiese vlakke te hou. Deur vroeg te plant word plaagskade dus verhoed omdat plaag spesies nog nie op daardie stadium piek getalle bereik het nie. Die terrestriële insek gemeenskap is ook belangrik, omdat baie predatore grondlwened is. Hierdie insekte word beïnvloed deur mikroklimaat en skuiling wat deur die plante verskaf word en verkies dus stande waar hierdie faktore optimaal is. In die studie is gevind dat terrestriële predatore groot, yl geplante stande bo digte klein stande verkies. 'n Ander aspek wat belangrik is vir bewaring is om permanente habitatte, bv. randgebeide, vir voordelige insekte daar te stel. Hierdie areas moet geskik wees vir oorwintering, populasie groei en moet 'n platform skep vanwaar hierdie insekte kan versprei sodra gewasse geplant word.

Hierdie studie is gebasseer op bewarings biologiese beheer, wat reeds teenwoordige, nuttige insekte gebruik en bevorder deur verskillende verbouingspraktyke. Boere het dikwels nie die nodige biologiese en ekologiese inligting wat beter plaag beheer sal verseker nie. Hierdie studie stel ten doel om daardie inligting te verskaf ten einde maksimum opbrengs met laer produksie koste op die langtermyn te lewer.