EFFECT OF INTERCROPPING SORGHUM AND COWPEA ON THEIR LEPIDOPTERAN STEM AND POD BORER POPULATIONS BUILD-UP WITH PARTICULAR EMPHASIS ON *CHILO PARTELLUS* (SWINHOE) (LEPIDOPTERA: PYRALIDAE) IN SOUTH WESTERN KENYA.

By

ELIAINENY MOSE MINJA

A THESIS SUBMITTED IN FULFILMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (ZOOLOGY) IN THE UNIVERSITY OF DAR ES SALAAM

1990

D E C L A R A T I O N

I ELIAINENY MOSE MINJA DECLARE THAT THE WORK EMBODIED IN THIS THESIS HAS NOT BEEN SUBMITTED FOR A DEGREE OF ANY OTHER UNIVERSITY.

Signed

Eliaineny Mose Minja

1. University internal supervisor- Professor H. Y. Kayumbo
2. ICIPE external supervisors- Dr E. O. Omolo

   Dr J. K. O. Ampofo
3. Chief Academic Officer

D E D I C A T I O N

This thesis is dedicated to my sister and my parents Grace, Ruth and Mose, of blessed memory.

TABLE OF CONTENTS

SECTION A

SECTION B

SECTION C

EXPERIMENTAL RESULTS

SECTION D

SECTION E

ABSTRACT

Polyculture or intercropping is widely practised in Eastern Africa. Normally crops with widely differing growth habits such as legumes and cereals are interplanted. Such crop mixtures may however, lead to increased or decreased pest incidences depending on crop combination, location, season and cropping pattern. The results described in this thesis involved field studies on sorghum stem and cowpea pod borers in relation to cropping patterns and microclimatic factors in 1986-88.

Five cropping patterns were investigated: cowpea and sorghum monocrops, cowpea and sorghum sown simultaneously in the same plot, and cowpea sown before and after sorghum in the same plots. Crops were planted in randomised blocks replicated thrice at ICIPE Mbita Point Field Station (MPFS) and on a farmer's field on Rusinga Island.

Chilo partellus (Swinhoe) (Pyralidae) egg counts were made on twenty sorghum plants. Chilo moths were released on caged field plants to study oviposition. Sorghum plants were artificially infested with eggs to

study larval establishment. Stem borer larval and pupal populations were monitored on destructively sampled sorghum plants. Pod borer egg and larval counts were made weekly. Pupae were sampled every five days. Dead borers and other arthropods on plant samples were noted.

Soil arthropods were sampled weekly using pitfall traps to monitor potential predators. Light intensity was recorded at ground level using a quantum radio meter (LI-1905). Canopy temperature and humidity were recorded.

C. partellus, *Busseola fusca* (Fuller) (Noctuidae), *Eldana saccharina* (Walker) (Pyralidae) and *Sesamia calamistis* (Hmps.) (Noctuidae) were recorded on sorghum throughout the study. Stem borer larval and pupal populations appeared to increase with the age of sorghum. Monocrop sorghum had a significantly higher number of borers and leaf damage than intercrops. There was a significant delay in borer colonization and establishment on sorghum sown after cowpea than the other cropping patterns.

Monocrop cowpea had a significantly higher number of <u>Maruca</u> <u>testulalis</u> (Geyer) (Pyralidae) eggs, larvae, pupae and damaged pods than intercrops. Borer colonization and establishment was delayed in cowpea sown after sorghum.

Diseases and parasites were the predominant mortality factors in larvae and pupae respectively. Soil arthropods were fewer in sorghum monocrop than intercrops. Furthermore, light intensity, temperature and humidity variations within crop canopies were higher in monocrop than intercrops.

Cowpea and sorghum grain yields seemed to have been adversely affected by late planting. However, it appeared that if both crops are to be produced efficiently on a piece of land, then cowpea could be sown before sorghum.

In conclusion therefore, intercropping appeared to have substantial influence in disrupting borer colonisation and establishment as well as favouring predators and parasites.

LIST OF TABLES

TABLE	TITLE	PAGE

LIST OF FIGURES

FIGURE	TITLE	PAGE

ACKNOWLEGDEMENTS

The work embodied in this thesis was sponsored by the German Academic Exchange Service (DAAD) through the International Centre of Insect Physiology and Ecology (ICIPE) where the research was carried out. I am most grateful to DAAD for the financial support and to the Director of ICIPE, Professor Thomas R. Odhiambo not only for availing the funds but also for providing the research facilities and taking keen interest in my training and research programme.

Sincere gratitudes to my employer, the Ministry of Agriculture and Livestock Development, Tanzania, which through the Tanzania Agricultural Research Organization (TARO) granted me study leave.

I would like to express my thanks to the University of Dar es Salaam for my registration and to Professor J. R. Mainoya, the then Dean of the Faculty of Science for encouraging me to apply for the training at ICIPE. Special aknowledgements are extended to Professor H. Y. Kayumbo, my supervisor and the then Head of Department of Zoology and Marine Biology for his keen interest and devotion in supervising the work right from the beginning giving valuable pieces of advice and ideas on the research methodology and preparation of this thesis. Thanks are also due to Dr J. Yarro, Head, Department of Zoology and Marine Biology, University of Dar es Salaam, for his valuable comments on the thesis draft.

I am grateful to my ICIPE supervisors, Dr E. O. Omolo for his interest and patience in attending to the problems pertaining to my work in the field and in the preparation of the thesis; and Dr J. K. O. Ampofo for his valuable pieces of advice and encouraging ideas throughout the period of this work. Sincere thanks to Dr S. Nokoe and staff of Biomathematics Research Unit for analysing my data and allowing me to use their facilities. Thanks are also extended to Drs A. Alghali, M. Basimike and J. Nderitu for their critical comments on the text.

I sincerely wish to thank the ARPPIS Academic Coordinator, Dr M. E. Smalley, for his continued encouragement and timely attention to problems pertaining to my work at ICIPE. Thanks are extended to the ARPPIS secretary, Mrs A. Okumali for her patience in attending to the requirements of my work.

I am greatly indebted to Professor M. J. Way of Imperial College at Silwood Park, for his encouragement and generosity in supplying me with reprints of his work.

I greatly appreciate the devotion shown by my assistant Mr Peter Kijana in helping with all the aspects of the field work. I am grateful to the two farmers on whose land I carried out my experiments, for their interest and assistance in my work. Lastly I would not forget the friendly help that I received from my ARPPIS colleagues and my family relations.

SECTION A

CHAPTER 1

GENERAL INTRODUCTION

Crop production methods in tropical and sub-tropical regions differ markedly from the highly mechanized agriculture in the temperate countries. The introduction of these mechanized technologies to the tropical countries have not successfully been adopted by the traditional subsistence farmers. The recognition of this problem led to the realization of the importance of the studies on the ecology of traditional agroecosystems (Way, 1975; Glass and Thurston, 1978; Harwood, 1979).

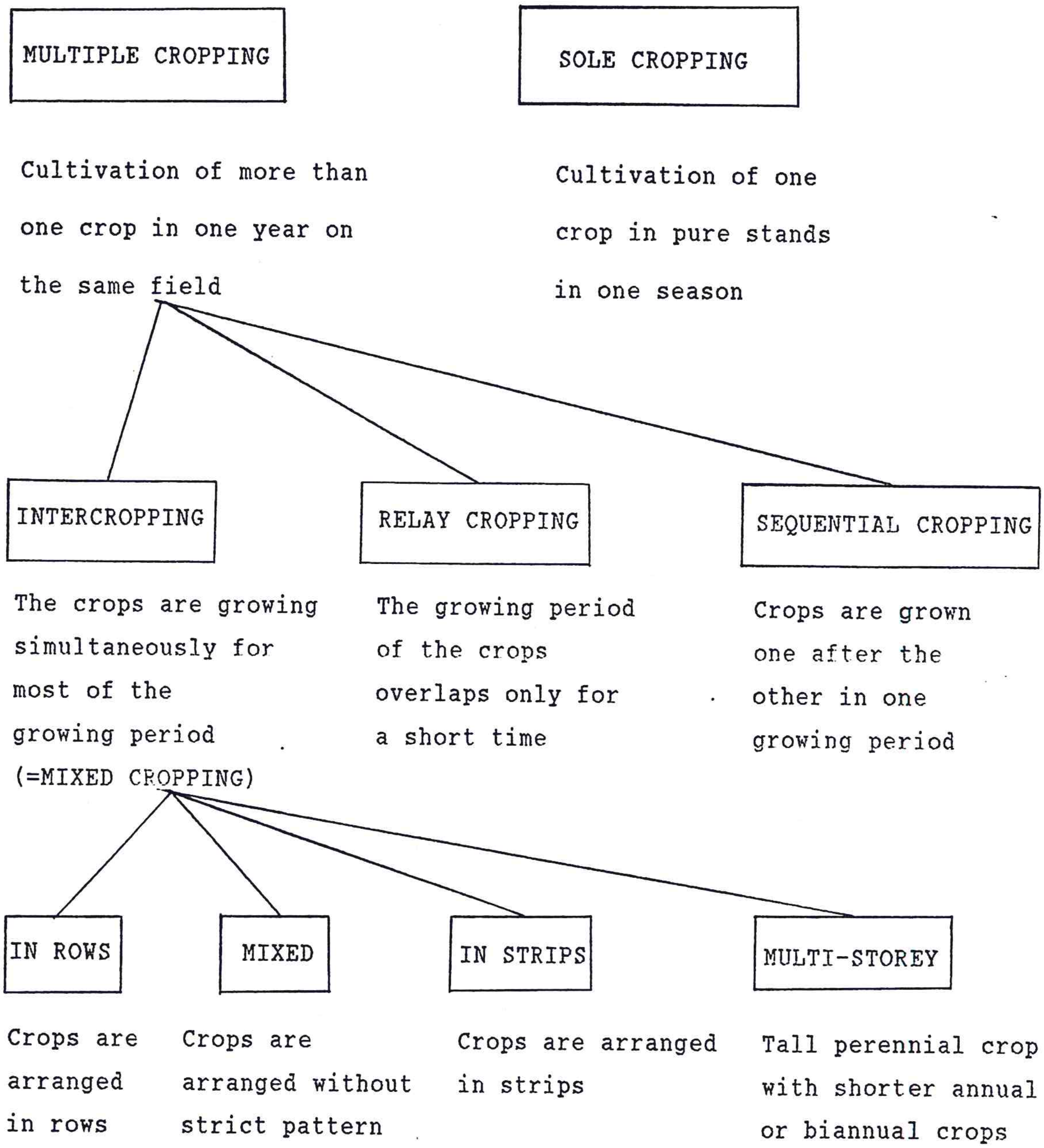
One such traditional system commonly practiced by smallholders in the tropics is polyculture or multiple cropping, and especially crop mixtures, some of which have been used successfully for many centuries as a means to ensure food security over the years at a low household input level (Aiyer, 1949; Willey, 1979).

The built-in genetic preservation in the small farms, typical of African cropping systems should not be overridden by the widespread adoption of one crop with a narrow germplasm base (Suneson, 1960). Many of these traditional cropping patterns have built-in pest management mechanisms and flexibility that lessen the gross effects of pest damage (Norton, 1976). By planting crops that can be harvested either green or mature, for example, maize and beans (Phaseolus sp.) or cowpea (Vigna sp.), the small-scale farmer can adjust to pest attack. In tropical countries the greens of many tuber and other vegetable crops, for example, sweet potatoes [Ipomea batatas(L.) Poir], cassava (Manihot esculenta Crantz) and squash (Cucurbita sp.) are also edible.

The well known fact that smallholder farmers adhere strongly to multiple cropping despite the proclamation of sole cropping and modern technology packages emphasizes the need for studying these traditional systems in detail to rationalize them (Dissemond and Weltzien, 1986).

There exists a number of different multiple cropping patterns and it is appropriate at this point to define the terminology commonly used.

DEFINITION OF CROPPING PATTERN TERMINOLOGY (After Andrews, 1974; Andrews and Kassam, 1976)



There has been growing interest in research into multiple cropping systems in recent years and many new terms have been adopted by different workers to describe the different types of cropping patterns. To minimize confusion, Gomez and Gomez (1983) gave the following definitions for different patterns:

Cropping pattern--the spatial and temporal arrangement of crops to be raised on a piece of land

Monocropping or monoculture--method of crop production in which only one crop is grown annually on the same piece of land

Multiple cropping or polyculture--method of crop production in which several crops are grown annually on the same piece of land

Sequential cropping--the growing of two or more crops in sequence on the same field within a twelve-month period, with the succeeding crop planted only after the preceding crop has been harvested such that a farmer manages only one crop at any one time in the same field

Relay cropping--the growing of two or more annual crops simultaneously in the same field such that one crop is planted after the other has flowered. If the second crop is planted before the flowering stage of the first crop, then the cropping pattern is intercropping

Intercropping--the growing of two or more crops simultaneously within spatial proximity to result in interspecific competition and complementation. According to Willey (1979) the crops are not necessarily sown at exactly the same time and their harvest times may be quite different but usually they are simultaneous for a significant part of their growing periods. Four intercropping techniques have been described (Andrews and Kassam, 1976; Gomez and Gomez, 1983).

a) **mixed intercropping**--an intercropping with no distinct row arrangement

b) **strip intercropping**--an intercropping with the different crops arranged in strips

c) **multi-storey intercropping**--an intercropping where tall perennial crops are grown with shorter annual or biannual crops

d) **row intercropping**--at least one crop is planted in rows.

Row intercropping of sorghum and cowpea was used in the present study. It is generally claimed that intercropping has many advantages (Steiner 1982). Among such advantages is the mimimization of insect incidence.

The importance of intercropping was first highlighted over forty years ago by Aiyer (1949) who demonstrated that in addition to yield advantages labour was evenly distributed throughout the season. Yield stability is of particular importance to the small farmer (Gomez and Gomez, 1983). The basis for this is that if one crop fails or performs poorly, the other crop or crops would certainly compensate. Such compensation is not possible if the crops are grown separately. The higher yields realized in a given season have been accounted for by the better use of resources and the better control of pests, diseases and weeds (Aiyer, 1949; Willey, 1979).

Research on pests has normally been done on a single crop basis. In multiple cropping, it is necessary to study pests over the entire cropping period, because the pests of one crop might be influenced by the previous crop(s) as well as by companion crops in intercropping patterns (Litsinger and Moody, 1976).

Pest damages, adverse climatic conditions and weeds are probably some of the major constraints to successful crop production. According to Stiling (1985), insect pests generally cause significant losses in the major cereal crops of the world, for example, rice (26.7%), wheat (5.0%), maize (12.4%) and sorghum (9.6%). A considerable part of this loss of yield from cereal crops is experienced as a result of stem borer attacks. In the case of sorghum, it is generally accepted that a range of moth borers constitute the most widespread and serious group of insect pests in the sorghum growing areas of Africa. Important borers include *Chilo* spp. (Pyralidae), *Busseola* sp. (Noctuidae), *Eldana* sp. (Pyralidae), *Sesamia* spp. (Noctuidae), (Walker, 1960; Seshu Reddy, 1983).

Estimates of losses due to borer damage vary greatly from cultivar to cultivar, place to place and from season to season. Such losses are also difficult to assess precisely because of the number of insect species, the various types of damage, the stages of plant development at the time of attack, and often the associated presence of other insects and their natural enemies (Whitney, 1977). When, for example, maize is attacked by newly hatched *Busseola fusca*, it shows a characteristic pattern of holes and "window panes" in the upper leaves resulting from the leaf feeding activities of the young larvae before they enter the stalk via the funnel (Harris, 1962). *Sesamia calamistis* larvae, on the other hand, bore directly into the stalk beneath the leaf sheath where the eggs are laid.

According to Duerden (1953) the ultimate loss in yield is a cumulative effect of a series of separate forms and stages of loss due to the activity of the stem borers. The first infestation occurs about two weeks after planting. The young borer larvae feed on the leaves and stem of the plant and many young plants are killed with subsequent loss of stand. At Kongwa in Central Tanzania Duerden (1953) reported a reduction of 30 per cent of sorghum plant population during the first five weeks after planting. Between then and harvest a further 4 per cent of plants were lost due to the activity of the borers. Following the initial attack the pest bores down into the stem tunnelling both vertically downwards and horizontally across. This boring within the stem restricts the passage of plant nutrients in addition to the obvious material damage to the plant. Consequently a state of general depletion of the plant is brought about which is reflected in lower yielding capacity. As plant maturity and harvest approach a further detrimental effect becomes important. The mechanical strength of the plant is much reduced by the continuous activity of the stem borers and considerable lodging results just before harvest.

One of the major insect pests of cowpea is *Maruca testulalis* Geyer which is found throughout the African continent. It can cause serious losses in cowpea yields. According to Taylor (1968) yield losses ranging from 30-70% could be observed in Nigeria.

Such crop losses and the increasing population pressures coupled with widespread food deficits in tropical African countries, such countries' national programmes together with those of the international donors have been compelled to place a high priority in improving the agricultural productivity and the economic well-being of the small farmer (Matteson et al., 1984). Consequently, understanding traditional agricultural systems and taking them as the basis for further work, including the use of effective traditional pest management methods is the starting point of restructuring the knowledge on the dynamics of pests in the systems. This will help in formulating ways of improving the productivity of such systems.

Research into the technology of intercropping is directed generally at identifying those crop combinations and associated management practices that maximize productivity per unit area of land (Gomez and Gomez, 1983). The index commonly used to evaluate an intercropping technology is the land equivalent ratio (LER), which is defined as:

$$LER = \sum_{i-1}^{n} \left(\frac{X_i}{Y_i} \right)$$

where 'X_i' is the yield of crop 'i' in intercropping and 'Y_i' is the yield of crop 'i' in pure stand.

The LER index essentially compares productivity in intercropping with that in the monocrop, with high values (that is more than one) of LER indicating the advantage of intercropping. It is in this context that other authors (Wahua and Miller, 1978; May and Misangu, 1980) prefer to use the term Relative Yield Total (RYT) to mean the same as LER. Willey (1979), however, discussed various methods of assessing yield advantages of an intercrop and concluded that the LER provided a more practical yardstick.

Gomez and Gomez (1983) gave the following guidelines for the maximization of the benefits from intercropping:

1. **Minimize competition**-by using crops of different maturity periods so that peak demand for limited resources in one crop does not coincide with that of the other. This was achieved in the present work by using a cowpea cultivar that matures earlier than the sorghum.

2. **Minimize pest damage**-by using crop combinations such that the presence of one species results in a reduction of pest incidence in another. Buranday and Raros (1975) have, for example, shown that Plutella xylostella (L.) infestation in cabbage is reduced by the presence of tomato as an intercrop.

3. **Maximize complementary effects**- crop associations with mutual benefits to one another (for example, legumes and cereals) form the best combination.

4. **Maximize effective vegetative ground cover**- ground cover is important in reducing soil erosion (Aina et al., 1977), increasing the number of predators (Dempster and Coaker, 1974) and making efficient use of energy (Trenbath, 1974). The semi-erect cowpea cultivar used in our experiments formed a good early ground cover.

Earlier experiments at the International Centre of Insect Physiology and Ecology (ICIPE), Mbita Point Field Station (MPFS) and surrounding areas have shown that Chilo partellus (= C. zonellus) (Swinhoe) constitute 75 per cent of all cereal stem borers over a period of more than three seasons (Ogwaro, 1983; Dissemond and Weltzien, 1986) and that intercropping sorghum and cowpea reduces infestation and damage caused by the crop borers (Amoako-Atta et al., 1983; Omolo and Seshu Reddy, 1985; Omolo and Ollimo, unpublished). In the course of these studies sorghum and cowpea combination was identified as the best cereal and legume combination in terms of pest control, productivity and yield loss. The experiments were carried out in different ecological zones over several seasons. The worst combination was cereal and cereal (i.e, maize and sorghum) and the other combinations were maize and cowpea; and maize, cowpea and sorghum. These four combinations form a traditional intercropping system commonly used by farmers at subsistence level in Africa. Although intercropping as a cultural control method to stem borers has thus been demonstrated in experimental plots, the mechanisms involved are not quite understood. Even then, Tahvanainen and Root (1972) suggested that some of the factors that may cause lower pest incidence in intercropped systems compared with monocrops are, the presence of more natural enemies, microclimatic gradients, and chemical interactions; which are said to function as an associational resistance.

Since the development of crop-management technologies for subsistence agriculture must fit the ecological features of small farming systems, the present research work was planned to focus on the agroecological aspects of one of the above cereal and legume combinations (i.e., sorghum and cowpea). The studies were carried out on sorghum stem borers with particular emphasis on C. partellus, and on cowpea attention was paid to M. testulalis. The microclimatic factors studied were temperature, humidity and light intensity within crop canopies. The main objectives of the studies were:

1. To investigate stem and pod borers population build-up and development in pure and intercropped systems, and the damage and effects they cause on yield.

2. To study the effect of time of planting the intercrops on the populations of the borers.

3. To monitor the incidence of field natural enemies for the crop borers and maintain field microclimatic data in pure and intercropped systems.

The hypotheses were that:

Crop mixtures create conditions that are less attractive to pests.

Crop mixtures favour natural enemy activity.

Crop mixtures create non-pest physiological effects which may affect crop yield.

CHAPTER 2

LITERATURE REVIEW

2.1 Insect populations in polyculture systems

Plant protection scientists have recently become aware that modern cropping systems may be more fragile and ecologically unstable in terms of pest outbreaks than had been realized before (Altieri and Letourneau, 1982). Part of this instability in agroecosystems can be linked to vegetational simplification resulting from adoption of vast crop monocultures (Tothill, 1958). One approach to pest management frequently advocated by ecologists (for example, Pimentel, 1961; Southwood and Way, 1970; Price and Waldbauer, 1975) is to reduce the destabilizing effects inherent in present agricultural practices and the differences in ecology between pests and beneficial species. Price (1976) emphasized that many suggestions will remain untried because of the potential for reduced production, or at least lower profits. Nevertheless, some possibilities are worth repeating, for eventually all will have to be carefully evaluated on an environmental cost/benefit basis as well as an economical one, the latter being the only one which receives major attention from agriculturalists at the moment.

According to Price (1976), one possiblility for stabilizing a population in the system is to increase colonization rates so that an equilibrium is reached rapidly. This might be achieved by reducing field size, retaining uncultivated refuges in fields, or leaving fields uncultivated between narrow crop rows. Another approach is to reduce extinction rates, particularly of beneficial species, by improving cover early in crop development. Interplanting with carefully selected species might be valuable, particularly if they supplied cover, nectar, pollen, or if they support honey-producing aphids. Predators and parasites would be more effective if crop strains were employed which increased the developmental time of pest species, thus exposing vulnerable stages longer. In natural systems this appears to be one aspect of the defensive strategy adopted by late successional species of plants (Root, 1973, 1975).

The literature on polycultures or multiple cropping systems include many cases of both increased as well as decreased incidences of pests and diseases (Kass, 1978). On some occasions it has been demonstrated that vegetational diversity has positive effects on herbivorous insects and their associated natural enemies (Way, 1953, 1983; IRRI, 1973; Gerard, 1976; Kayumbo, 1975, 1976, 1977; Karel and Mueke, 1978; Abasa, 1983; Amoako-Atta et al., 1983; Amoako-Atta and Omolo, 1983). On the other hand, insect pest population increases have been observed in some intercrops. Such increases have been attributed to the reduction of the overall effort required for the movement of those insects which prefer different hosts for example, for oviposition, feeding or resting. The meloid beetles (Matteson, 1982) and some pod bugs (e.g. *Anoplocnemis curvipes* F.) (Ochieng, 1977; Singh et al., 1978) for instance, oviposit on maize and feed on cowpea. Intercropping cowpea and maize therefore effectively reduced the time and energy required to move from one host to another. Also the increased shading, humidity and reduced temperature induced by some crop mixtures favour high populations of some foliage beetles (Kayumbo, 1976). Some pests are further known to avoid their preferred crop hosts when shaded by taller crops in mixtures (Karel et al., 1982; Service, 1984). It has generally been observed that intercropping results may vary depending on the crop combination, location, season and cropping pattern (Omolo and Seshu Reddy, 1985).

Natural ecosystems are recognized to have greater diversity which in turn leads to a greater chance of stability (van Emden and Williams, 1974), but Way (1971) cautioned against the assumption that diversity in agroecosystems is desirable for minimizing pest damage and concluded that the right kind of diversity is fundamental to pest control. The correct plant diversity for a given microclimatic/biotic situation has to be selected because a specific diversity in the same system can be beneficial in one place but harmful in another. In Tanzania and California for example, intercropping maize and cotton increases _Heliothis virescens_ F. damage, but in Peru (Canete Valley) this system favoured the control of _Heliothis_ (Southwood and Way, 1970).

It is possible that changes in colour, texture and shape of the crop canopy in intercropping systems may vary the optical stimuli available to host-searching insects and decrease their colonization efficiency. There may also be some adverse chemical stimuli which come from the respective companion plants (Altieri _et al_., 1977) that may influence the signals from the host plant to the pest.

It has long been recognized that field beans are less infested by _Aphis fabae_ Scopoli when planted along with oats than when grown as a monocrop. Similar results, however, can be obtained in a field bean monocrop sown sufficiently dense for the crop to meet across rows before the aphid colonists arrive (Way, 1971). In this case the polyculture may only act through filling spaces between plants, preventing them from being highlighted against bare soil.

Cromartie (1975) studied the colonization of Brassicae oleraceae L. by herbivorous insects in plots of 1, 10, and 100 plants cultivated and uncultivated. When the most important pest species co-occurred, Pieris rapae L. was most abundant in the 1-plant plots, Phyllotreta striolata Fabricius in the 10-plant plots and Phyllotreta cruciferae Goeze in the 100-plant plots, when grown weed free. On uncultivated land only P. rapae was able to establish itself. The other species were infrequent and not abundant. Dempster (1969) noted that P. rapae laid much fewer eggs on brussel sprouts when densely surrounded by a white flowering weed, Matricaria sp. and suggested that the predominantly white background of those plots may have inhibited egg laying. Raros (1975) while experimenting with artificial intercrops, reported a certain preference of the Asian corn borer, Ostrinia furnacalis Guenee moths for maize plots with a brown burlap between the rows over those with green or green-brown burlap. However, differences in response between a living intercrop (maize and peanuts) and sole maize were still considerably bigger.

Odour-conditioned anemotaxis has often been proven to explain long-range insect locomotion leading towards distance sources of chemical stimuli such as host plants or sex pheremones (Kennedy, 1977). Adults of Phyllotreta cruciferae Goeze, a flea beetle which is an important pest of cole crops (Brassicea oleracea L.), were more abundant in collards (B. oleracea var. acephala) grown in monoculture than those adjacent to natural vegetation. Plots intercropped with tomato and tobacco were less colonized and displayed less feeding damage than collards grown as a monocrop. Predators and parasites at no time affected the beetles significantly in both cropping patterns. Laboratory experiments indicated that chemical stimuli given off by non-host plants such as tomato, Lycopersicon esculentum Mill. and ragweed, Ambrosia artemisiifolia Cav., interfered with the host-finding and feeding behaviour of P. cruciferae (Tahvanainen and Root, 1972).

Douwes (1968) reported more frequent landings of the geometrid moth, Cidaria albulata L. on its host plant (Rhinanthus sp.) in dense stands than on scattered ones. When at a distance from large patches of Rhinanthus, the female made longer, faster flights, but flight path became much shorter with more changes in direction near or above those patches. This behavioural pattern apparently in response to higher concentrations of its host's odours, caused it to remain in or near large aggregations of *Rhinanthus*. However, attractive olfactory mechanisms are often disturbed by the presence of non-host plants. In sparse dispersions of host the chemical attractants seem to be 'lost' in the environment (Tahvanainen and Root, 1972). Furthermore, some plant species even possess strongly repellent odours.

However, Tahvanainen and Root (1972) postulated that this effect may be rather widespread, especially in natural ecosystems where a wide spectrum of chemical stimuli emanates from plants. Many of those stimuli are likely to be repellent or inhibiting to phytophagous insects. Aiyer (1949) suggested that polyculture would reduce the incidence of pests and diseases when associated species serve as repellent for a disease or pest of another species. He cited aromatic plants such as onion and garlic as examples. Buranday and Raros (1975) tested the effect of tomato and cabbage intercrop on the abundance and oviposition of the diamondback moth, *Plutella xylostella* (L.) and found that more adults entered the sole cabbage plot and laid significantly more eggs than in the intercropped cabbage. The moths were probably repelled by one or more volatile compounds emitted by the tomato plants. The favourable effects of tomato could still be maintained at a planting pattern of two cabbage rows between every two rows of tomatoes.

Diversified plant stands are often found to have a richer insect fauna than monocultures because more insect species and their attendant arthropod predators find ecological niches there. In this regard the latter often have a stronger controlling impact on the build-up of a potential pest (Pimentel, 1961; Pimentel and Goodman, 1978; van Emden and Williams, 1974; Altieri _et_ _al_., 1978). Among the most carefully documented cases of reduced pest incidence are those due to predators originating from or being attracted to the polycultures (Dempster and Coaker, 1974; IRRI, 1974; O'Donell and Coaker, 1975; Smith, 1976; Theunissen and Den Ouden, 1980; Altieri and Todd, 1981).

Dempster and Coaker (1974) reported the reduction of three pest species associated with cabbage when the crop was undersown with clover. In the case of _Pieris rapae_, where the number of eggs laid was not significantly altered through the presence of clover, the reduction was due to an increased number of predators. It has been observed (IRRI, 1974) that spider predation apparently contributed to the decreased corn borer (_O. furnacalis_) infestation in intercropped plots.

Way (1975) called barriers or hazards to insect dispersal an "Outstanding and fundamental component of insect pest control". Mechanical barriers interfere with pest behaviour and decrease colonization efficiency which, in turn, results in lower population densities on the crop (Tahvanainen and Root, 1972). Maize stalks in a squash and maize intercrop has been reported to interfere with the flight movements of squash leaf beetles, *Diabrotica balteata* LeConte (Risch, 1981).

The dispersal of both adult and larval stages of arthropod pests may be impeded where host and non-host are grown together (Perrin, 1977). Success may also partly depend on the particular intercropping patterns. Taylor (1977) for example, observed less flower damage due to *Maruca testulalis* Geyer when cowpea was intra-row rather than inter-row planted with maize.

The presence of different plant species in a field may keep away insect pests searching for their particular food plants. Risch (1981) showed that in a maize, bean and squash intercrop the non-host plants interfered with the behaviour of the squash leaf-feeding *Diabrotica* beetles. The differences in abundance between monoculture and polyculture did not result from activities of parasites or predators, but rather from differences in the overall patterns of beetle movement. In polycultures with maize, beetles avoided feeding on host plants shaded by maize. The maize stalks also interfered with adult beetle flight movements. It was observed that beetles landing on non-host plants flew off again after a short time, often out of the field. However, when landing on host plants their dispersal behaviour was arrested and they would start feeding. This behaviour resulted in increased rates of migration from polyculture plots and this subsequently lead to lower beetle populations. Similar results were obtained with striped cucumber beetle, Acalymma vittata (Fab.) by Bach (1980) and the pea leaf weevil, Sitona lineatus (L.) by Baliddawa (1984).

Various microclimatic effects have been proposed to explain the causes of differences in insect population trends between mixed and sole crop systems. The degree of shading and the nature of cultural practices often differ between intercropping and sole crop systems and might affect considerably the microclimate for insects and diseases (Dempster and Coaker, 1974; Trenbath, 1974; Altieri et al., 1981).

A closed canopy with its more humid microclimate is favourable for the growth of fungal diseases (Trenbath,

1974) but also it enhances entomophagous fungi considerably. Ground cover, by increasing humidity and shade near the soil is reported to favour general predators such as spiders, carabids and staphylinids (Dempster, 1969; Dempster and Coaker, 1974; Altieri et al., 1981). Perrin (1977) and Mumford and Baliddawa (1983) suggested that differences in the canopy structure alter the microclimate in mixed crops from that of the sole crops. Perrin and Phillips (1978) and Baliddawa (1985) suggested that shading may be unfavourable for insect colonization and could lead to increased emigration and mortality, as well as reduced fecundity in mixed crop systems. Kyamanywa and Ampofo (1988) reported that reduced light intensity in a cowpea and maize mixture contributed to a relative scarcity of the legume flower thrips, Megalurothrips sjostedti Trybom in the mixture.

Mayse (1978) reported significantly greater abundance of predators, namely predacious bugs like Orius insideiosus Say and Nabis sp., and syrphid larvae, in high-density than in low-density soybean stands. He attributed this partially to a more favourable microclimate due to higher humidity. Price (1976) reported that colonization of a soybean field by predators increased rapidly only after canopy closure.

2.2 Importance of grain sorghum in East Africa

Sorghum (Sorghum bicolor [L.] Moench) is the most important cereal crop for millions of people in the semi-arid areas of the East African region (Gebrekidan, 1982). Of the 47 million hectares of sorghum grown in the world, Eastern Africa cultivates 13% (Omolo and Seshu Reddy, 1985). Yields of grain sorghum on peasant farms in this region are very low, ranging from 500 to 1300 kg/ha, compared with 3605 kg/ha in the United States of America (Gebrekidan, 1982; FAO, 1983). A major factor considered next to adverse climatic conditions that is responsible for limiting sorghum grain yield in the region is the damage caused by insect pests.

2.3 Sorghum stem borer species of importance in East Africa

The most important field pests include many species of stem borers which belong mainly to the Pyralidae and Noctuidae families (Lepidoptera), the sorghum shootfly, midge and headbugs (Le Pelley, 1959; Young and Teetes, 1977; Bohlen, 1978). There are twenty three species of stem borers infesting sorghum, causing damage to leaves, leaf whorls and also boring into the stem causing deadhearts and chaffy heads (Seshu Reddy, 1983). The most important stem borers in the region include *Busseola fusca* Fuller, *Chilo partellus* Swinhoe, *Eldana saccharina* Walker and *Sesamia calamistis* Hampson (Omolo and Seshu Reddy, 1985).

The Pyralidae are relatively small, inconspicuous moths usually with drab coloured wings (Harris, 1985). Pests of sorghum included in this family are *C. partellus* and *E. saccharina*. Noctuidae are generally larger and more robust but are also relatively inconspicuous moths (Harris, 1985). The African species of *Busseola* and *Sesamia*, which comprise most of the stem boring species of Noctuidae on sorghum, were revised by Tams and Bowden (1953). *C. partellus*, *B. fusca* and *S. calamistis* are the only species generally considered to be of major importance on sorghum at present, although this situation could easily alter in future if changes in distribution, climate and agronomic practices, or varietal susceptibility favoured any of the minor pest species (Harris, 1985). The biology of *C. partellus*, *B. fusca* and *S. calamistis* were studied in Uganda by Ingram (1958) while that of *E. saccharina* in relation to the other three was also done in Uganda by Girling (1978).

2.4 Biology of important sorghum stem borers in East Africa

2.4.1 B. fusca and S. calamistis

Both species are native to East Africa and they occur most frequently in maize and sorghum of medium age (from about 5 weeks after plant emergence). The pattern of attack by B. fusca and S. calamistis was observed to be similar in both maize and sorghum, with S. calamistis having a delayed population peak than that of B. fusca (Girling, 1978). Neither species appeared to be affected very much by climatic conditions, as long as these were within the optimum range as they were found at Kawanda, Uganda (Girling, 1978).

B. fusca--has been recognized as a major pest of maize and sorghum in all African countries south of the Sahara (Jepson, 1954; Swaine, 1957). The main features of the field biology in relation to the plant itself have been described by a number of authors (Jack, 1917; Anderson, 1926; Swaine, 1957; Ingram, 1958; Girling, 1978).

According to Ingram (1958) the pre-oviposition period is two days (48 hours) and oviposition lasts for about three days. The total life span of the adult female is five days (approximately 96 hours). The eggs are laid in groups of about 70 at a time (range between 68 and 88). The maximum number laid by a caged female was 568 eggs. A group consists of some 3-4 rows of eggs, each row being about 1.5 cm long with all the eggs closely adhering to one another. They are nearly always laid at the bottom of the stem, between the sheaths of the drying lower leaves and the stem itself. The egg is round and flattened at top and bottom, with finely fluted sides. It is white when laid, but gradually turns brown as it develops.

The egg hatches in 6-9 days at an average temperature of 26.4°C (Swaine, 1957). The young larva makes its way up the funnel of the plant, mining the leaf sheath and tunnelling inside the midrib for several days. As it matures, the larva migrates down the stem through the funnel and then tunnels into it. The remainder of the larval period is completed within the stem where pupation also takes place. Total larval period is between 45-50 days at an average temperature of 26.4°C. Pre-pupal period is about 24 hours while the pupal period is about 14 days (Swaine, 1957).

S. calamistis--is widely distributed in East Africa but rarely occurs in very dry areas. It has not been recorded to cause heavy attacks to maize and sorghum. There is much variation in size, smaller specimens being commoner in finger millet (Eleusine coracana [L.] Gaertn.) and some of the grasses, and larger ones in maize and sorghum.

The eggs are very much similar to those of *B. fusca*, both in size and general appearance, and are likewise laid between the leaf sheaths and the stem, but the egg batches are very much smaller and rarely consist of more than 20 eggs.

The egg hatches in 7-9 days under laboratory conditions (Ingram, 1958) and the young larva usually bores straight into the stem, although the funnel is occasionally mined. In young plants the larva burrows up and down to produce a typical "deadheart". The larva has a habit of migrating from plant to plant or to the tillers. The larval stage takes 27-36 days, pre-pupa 24 hours, pupa 10-12 days. Total life-cycle is about 45-58 days (Ingram, 1958).

2.4.2 *E. saccharina*

It is a native to East Africa, but the form that attacks crop plants there probably spread into East

Africa from West Africa during the last 25 years (Girling, 1978). It attacks mature and old plants, and this is what makes it the potentially most important species. It attacks mature sugar-cane, leading to a direct sucrose loss and also it does more damage to the softer varieties which may be grown for quicker development and high returns. It has been spreading quite quickly to sorghum and maize particularly in those areas where the three crops are cultivated closely together.

In cane fields egg batches were found in dry trash (Dick, 1945; Waiyaki, 1968). In the laboratory egg batch size varied from 2-200 eggs (Girling, 1978) although Dick (1945) found larger batches in the field, where there is a wider choice of suitable oviposition sites. Egg development varies with temperature, ranging from 5 days at 25^{o}C to 8 days at 18.9^{o}C (Girling, 1978). The larval stage lasts for 15-35 days, pre-pupal 2-3 days, pupa 8-13 days.

2.4.3 C. partellus

The genus Chilo is taxonomically difficult but has been thoroughly revised recently by Bleszynski (1970). C. partellus is a native of India. It first appeared in

East Africa about 50 years ago (Tams, 1932; Mohyuddin and Greathead, 1970). It has spread widely in East and Southern Africa and is regarded as one of the major grain sorghum pests in South Africa (Van Hamburg, 1980). It is found in young maize and sorghum but prefer mature sorghum. The pest also appears to prefer dry areas (Girling, 1978).

The pre-oviposition period is 24 hours and nearly all the eggs are laid in the first two days after emergence. The eggs are laid in imbricated rows in groups of 50 to 100 (Ingram, 1958). Chadha and Roome (1980) recorded egg batch sizes ranging from 10 to 200 eggs. The maximum number of eggs laid by a caged female was 417 in six groups (Ingram, 1958). The eggs are translucent when laid, but turn white on the first day and then become grey when they are about to hatch. The egg is flat, scale-like and ovoid. Groups of eggs are laid anywhere on the food-plant, though most frequently on the lower surface of mature leaves near the midrib (Ingram, 1958).

The incubation period in the laboratory was eight days and in most cases hatching takes place before daybreak (Ingram, 1958). The young larva is positively phototropic and negatively geotropic and migrates to the top of the plant (maize or sorghum). Newly hatched larvae must find their way to the whorl where they feed, a distance of up to 2 or 3 metres (Bernays et al., 1985). The climb is a hazardous one and many larvae fail to reach their destination (Bernays et al., 1983).

Although the primary movement of newly hatched larvae from oviposition site to the whorl is upward, there are downward components, notably at the whorl itself. Also the insect climbing up the culm on the leaf sheath may move out onto the undersurface of the leaf. If it reaches a distal point on the leaf, it commonly drops on its silk thread and is carried away by air movement (Roome, 1980). Light is also reported to play an important part in the zig-zagging which results in the avoidance of leaf bases during the climb (Bernays et al., 1985). Other larvae failed to avoid the leaf bases and moved up to the abaxial surfaces of the leaves. Regaining the culm necessitated a reversal of the upward orientation which occurred when the larva reached a leaf edge, following which it moved down usually on the adaxial surface to the leaf axil. From there it resumed its climb up the culm. Bernays et al. (1983) reported that no other signals are required to produce upward movements apart from light since hatching in this species occurs only in the day. Positive phototactic responses in other species of newly hatched caterpillars have been described (Madge, 1964; Mangum and Ridgeway, 1968; Green and Morrill, 1970; Wiener and Norris, 1982).

According to Bernays et al. (1985) the positive response to light is labile and lost under some circumstances, for example, upon entry into the whorl. This enhances the likelihood of the insects remaining in the leaf whorl and entering more deeply as leaves develop. The change may have importance for C. partellus in other ways. If larvae for any reason find their way in crevices, such as leaf axils, loose sheaths and rolled leaf bases, then they may lose their phototactic responses and remain in the crevice which is almost invariably unsuitable for establishment. Field observations have shown this to happen (Bernays et al., 1983).

Ingram (1958) also reported that if the larva does not move from the top of the plant on which it hatched, it mines it in exactly the same way as does the larva of B. fusca. Subsequently it bores down inside the funnel of the plant or it may leave this and migrate down the stem, before entering it, just above an internode, and proceed tunnelling upwards. In older plants of sorghum or maize, the whole larval life may be spent in the developing head or tassel, respectively.

Ingram (1958) further observed that in frequent cases only one egg-batch would be found on a plant and only that plant would be mined, but later all the tillers of that plant would be bored by nearly mature larvae. Chapman et al. (1983) reported that most larvae did not become established in the whorl of the plant on which they hatched, but some of those that did not do so became established in other plants in the vicinity. Only occasionally did as many as 50% of the larvae hatching become established in host-plants and in several cases only about 20% were found six days after hatching. Therefore, while relatively large numbers of larvae may initially be found in the whorl of the plant on which they hatch, a considerable number disperse to neighbouring plants so that on a small plant, an egg batch of 40 eggs might be expected to result in the infestation of about seven plants. Van Hamburg (1980) observed that 100% of the sorghum plants in a field became infested although eggs were laid on only 18%. Most of these additional plants contained only one larva. The original plant on which the insects hatched initially housed a large number, but this declined over the first week so that relatively few plants held more than five larvae after six days. This indicates the results of migration of larvae from high to low densities in neighbouring plants, a process through which high mortalities occur, and an average population of 2-4 larvae per plant maintains.

Laboratory observations by Ingram (1958) showed that the larval stage lasts between 28 and 33 days, pre-pupa is about 24 hours and adults emerge 8-10 days later, giving a total life-cycle of about seven weeks (egg, 8 days; larva, 28-33 days; pre-pupa, 1 day; pupa, 8-10 days). Field observations (Ingram, 1958; Neupane _et al._, 1985) indicated that under natural conditions the larval stages take only 15-20 days, thus giving a slightly shorter total life-cycle (32-39 days).

Reports on sorghum grain losses due to _C. partellus_ infestation alone are very few. Starks (1969) observed in Uganda that this borer caused 56% grain loss to sorghum when plants were infested 20 days after emergence. Seshu Reddy (1985) reported 75-88% grain loss when plants were infested 10 days after emergence and that severe foliar damage, dead hearts and stem tunnelling were associated with the infestation and subsequent yield losses when plants were infested between 10 and 30 days after emergence. Alghali (1987) observed that sorghum yield components were slightly reduced when infestation occurred 2-4 weeks after seed germination.

2.5 Importance of cowpea in East Africa

Cowpea, Vigna unguiculata (L.) Walp (V. sinensis L.) is an ancient African crop which is now grown throughout the tropical and subtropical regions of the world as a grain, vegetable, fodder and cover crop. It is chiefly an important mixed crop in the cereal farming areas of Africa and India where the grain, young leaves and tender pods are used as human food while the haulms are a livestock feed. In the advanced agricultural areas cowpea is grown mainly as fodder and cover crop (Steele and Mehra, 1980). Whereas in Brazil, India and West Africa cowpea is mainly grown for the dry grain, in East Africa it is grown for the green soft leaf and tender pods as vegetables and also for the dry grain.

The average yields in East Africa range from 340-450 kg/ha, but with good husbandry it is possible to get average yields of 670-900 kg/ha without insecticide use (Acland, 1971). Generally, insect pests are often responsible for up to a 100% yield losses in cowpea, although mixed cropping reduces pest populations of some insect species (Singh and van Emden, 1979; Singh and Jackai, 1985).

2.6 Major insect pests of cowpea in East Africa

Many insect species attack cowpea in the field but those considered as major ones include the Aphids (Aphis craccivora Koch and Aphis fabae Scopoli), Legume flower thrips (Megalurothrips sjostedti Trybom), Legume pod borer (Maruca testulalis Geyer) and Pod bugs.

2.6.1 Aphids

Aphid species primarily infest seedlings, although they attack all tender plant parts including the pods. They cause direct damage to the plant by removal of its sap. Small populations may have little impact on the plant, but large populations can cause distortion of leaves, stunting of plant growth and poor nodulation of the root system. Yield is reduced, and in extreme cases the plant dies (Singh and van Emden, 1979). Indirect and often more serious damage from the aphids is the transmission of aphid-borne viruses (Bock and Conti, 1974).

A. craccivora is the main aphid species infesting cowpeas in Africa and Asia. A. fabae has also been reported as a minor pest in East Africa (Bohlen, 1978; Singh and van Emden, 1979). The biology of A. craccivora has been studied extensively at the International Institute of Tropical Agriculture (IITA), where it was found to vary greatly with the host plant, soil fertility, soil moisture and temperature (Singh and Allen, 1980). Adult longevity ranges from 5 to 15 days and have a fecundity of over 100 nymphs/female. A generation can be completed within 10-20 days, and there are four nymphal instars (Singh and Allen, 1980). The biology of *A. fabae*, though not extensively studied in Africa, appears to be similar to that of *A. craccivora* (Singh and Jackai, 1985).

2.6.2 Thrips

The legume flower thrips, *M. sjostedti*, are a major pest of cowpeas and often cause up to 60 per cent damage to the crop (Singh *et al*., 1978). The nymphs and adults feed on flower buds and flowers and can cause complete loss of flower production. The biology of this pest is not completely known, although the entire life cycle is reported to take about 18 days (Singh and Jackai, 1985). Eggs are laid in the flower buds, and nymphs and adults develop on flower buds and the flowers.

2.6.3 Pod bugs

Several species of pod bugs (mostly Coreids and Pentatomids) infest cowpeas at the podding stage and cause considerable damage. Normally their populations are high because the adults constantly migrate from wild host plants to the cultivated fields. They breed throughout the year if food is available and the climate favourable. Nymphs and adults suck the sap from developing pods and can cause serious yield losses through premature drying of pods and abnormal pod formation.

Coreidae-this family has three species which cause economic losses of cowpea in East Africa: Clavigralla tomentosicollis Stal. (synonym: Acanthomia tomentosicollis Stal.) found in East and West Africa, C. elongata Signoret in East Africa, and Anoplocnemis curvipes Fab. which is found in East, Central and West Africa.

C. tomentosicollis-is medium-sized, hairy and grey. Nymphs form large colonies on cowpea pods and peduncles and are not easily disturbed. Adults are not strong fliers and have a longevity of 100-150 days. Eggs are laid in batches of 10-70, and on average, about 200 eggs are laid per female. Each instar lasts about 2 days, but the last instar is about 6 days. The total nymphal period is about 14 days (Singh *et al.*, 1978).

C. elongata-is smaller than *C. tomentosicollis*. It is grey and has a cylindrical body. Adult longevity is from 40 to 80 days. Eggs are laid singly, with about 250 eggs per female. The eggs hatch in about 6 days. There are five nymphal instars, and the total nymphal period is about 20 days (Singh *et al.*, 1978).

A. curvipes-has a large host range, including leguminous trees and several other wild plants. The adults are black, fairly large and strong fliers. Adult longevity ranges from 24 to 84 days, but unmated males and females may survive up to 150 days. Eggs are laid in batches, normally in chains, and are dark grey. Leguminous trees and wild plants are preferred to cowpea for oviposition. Egg batch size varies from 10 to 40 and a single female lays 6-12 batches. The eggs hatch in about 7-11 days. There are five nymphal instars and the early instars resemble ants. The total nymphal period is about 30-60 days, depending on the host plant and the climatic conditions (Singh and Jackai, 1985).

Pentatomidae-this family constitutes some of the minor pests of cowpea which include: Nezara viridula L., that is also found on a wide range of other host plants; and Aspavia armigera Fab., which is frequently found on cowpea.

2.7 Biology of the cowpea pod borer (Maruca testulalis Geyer)(Lepidoptera: Pyralidae)

M. testulalis is found throughout the African continent and can cause serious losses in cowpea yields (Singh and van Emden, 1979). Taylor (1968) reported yield losses ranging from 30-70% on different cowpea varieties in Nigeria and that one larva can destroy 3-4 flowers and cause up to 30 per cent pod damage. Up to 100 per cent damage has been reported on susceptible varieties (Usua, 1975).

The biology of this species has been studied in detail by Taylor (1967, 1978), Jackai (1981) and Odebiyi (1981). Females may lay up to 200 eggs on flower buds, flowers, and leaves. The eggs are translucent blending the colour of the background substratum (Jackai, 1981). The egg appear dorsoventrally flattened while glued singly on to the plant surface. Eggs hatch in 2-3 days and there are five larval instars.

Larval development takes about 8-14 days (Jackai, 1981). A 2-day pre-pupal period follows the larval period. The pupal stage takes 6-9 days and the pupae are initially green or pale yellow but later darken to greyish-brown. Pupation occurs on the soil in a double-walled pupal cell, and adults emerge after about 5-10 days and have a life span of 5-15 days (Taylor, 1967).

The early larvae, in the absence of flower buds, flowers and green pods, feed on young tender shoots and peduncles. Later, when the flowers are formed, they prefer to feed on floral parts and the green pods. They hide during the day in the flowers or pods and are active during the night, wandering around the host plant and invading uninfested flowers and pods. The larvae usually web together the leaves, flowers and pods (Taylor, 1967).

2.8 Conclusions

Different agroecosystem diversity levels have thus been demonstrated to minimize some insect pest populations and damage in both tropical and temperate regions. A fairly significant effort has been made in the documentation of the benefits of intercropping various crop-crop and crop-weed combinations, the resultant favourable microclimatic effects, and the determination of the ecological basis for this phenomenon.

Some of the crop-crop combinations reported to have led to lower insect pest populations include the stem- and pod-borer complex in sorghum, cowpea and maize combinations (Amoako-Atta et al., 1983; Omolo and Seshu Reddy, 1985), the Asian corn borer in maize and peanut intercrop (Raros, 1975; Hasse, 1981), coconut bug in coconut, shrubs and citrus mixture (Way, 1953, 1983), the diamondback moth in cabbage and tomato intercrop (Buranday and Raros, 1975), pests of beans in maize and bean mixtures (Altieri et al., 1978), pests of squash in squash, maize and bean mixtures (Risch, 1980) and the cowpea pod-borer in a cowpea and sorghum intercrop (Taylor, 1977).

Crop-weed combinations demonstrated to have favourable control effects on pest populations include *P. rapae* on Brussels sprouts and collards (Pimentel, 1961b; Dempster, 1969), *P. cruciferae* on collards (Tahvanainen and Root, 1972), *Brevicoryne brassicae* L. on Brussels sprouts (Dempster, 1969; Smith, 1976) and pests of beans (Altieri et al., 1977, 1981).

The ecological basis of insect pest population phenomena have experimentally been demonstrated on the striped cucumber beetle, A. vittata (Bach, 1980, 1981), beetle pests of beans and squash (Risch, 1981) and the pea leaf weevil, Sitona lineatus L. (Baliddawa, 1984).

Proposals and suggestions to explain the effects of various microclimatic factors on insect population trends in monoculture and polyculture systems have been given (Dempster, 1969; Dempster and Coaker, 1974; Perrin, 1977; Altieri et al., 1981; Mumford and Baliddawa, 1983; Baliddawa, 1985). The only critical field experiment reported from our local cropping conditions is that on the effect of cowpea and maize mixture on light interception at the cowpea canopy and its influence on cowpea flower thrips population (Kyamanywa and Ampofo, 1988).

In most of the previous work done on the intercropping of cereals and legumes at the ICIPE Field Station and surrounding areas however, the crops were sown simultaneously (Amoako-Atta et al., 1983; Omolo and Seshu Reddy, 1985) and some of the pest population assessments were not regularly carried out during the crop's growth period (Dissemond and Weltzien, 1986). In those cases where regular pest monitoring was carried out, the interval between successive sampling dates was rather too wide (Amoako-Atta *et al*., 1983). In addition, some of the mechanisms responsible for the regulation of the pest populations in those systems are not fully understood. Critical field experiments on the effect of time of planting the intercrops are very few (Altieri *et al*., 1978). Field microclimatic records for intercropped experiments are scanty (Altieri *et al*., 1978; Kyamanywa and Ampofo, 1988). The present work was therefore planned to investigate the effect of time of planting the cowpea and sorghum intercrops on the stem and pod borer populations on regular weekly assessments through the cropping seasons. Furthermore, some microclimatic records were maintained for the different planting patterns to evaluate their possible effects on the insect pest populations.

S E C T I O N B

CHAPTER 3

GENERAL MATERIALS AND METHODS

3.1 Experimental location

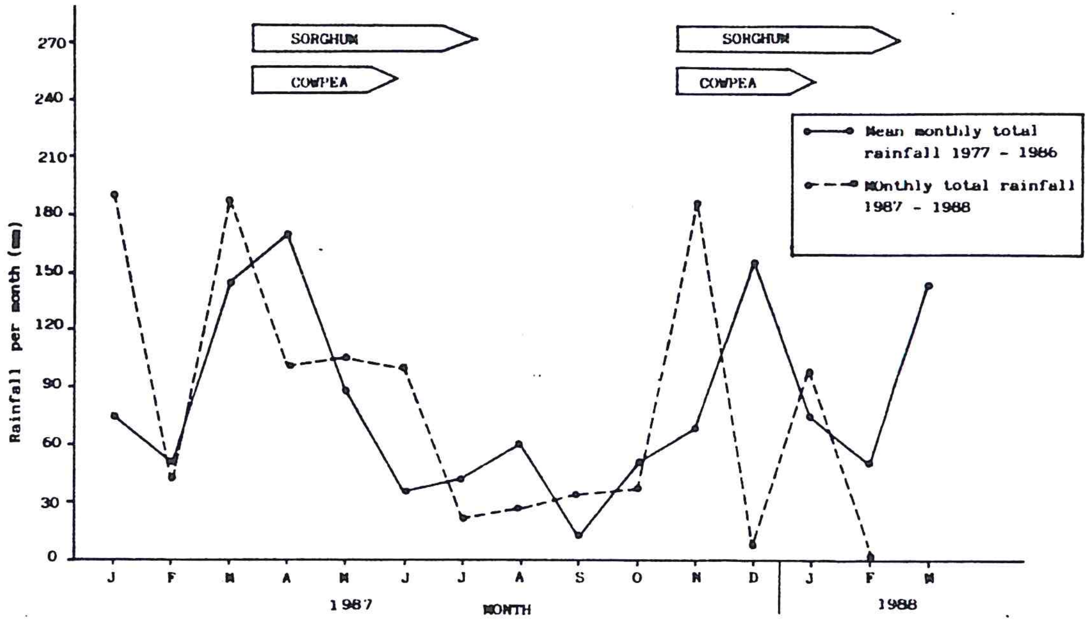
The experiments were carried out during the major and minor growing seasons of 1986 to 1988 at the International Centre of Insect Physiology and Ecology, Mbita Point Field Station (ICIPE-MPFS), and on farmer's field in Rusinga Island, both of which border the shores of Lake Victoria in South Western Kenya. The station is located between 0^{o} 25'- 0^{o} 28' south of the equator and 34^{o} 11'-34^{o} 17' east at an altitude of 1170m and an annual rainfall of 880mm. The rainfall patterns during the study period and planting schedules are shown in Fig. 1. The wind direction at ICIPE-MPFS was NE during the morning and SW in the late afternoon with almost still air at midday. The two experimental field sizes used were: 0.28 hectare field near the main ICIPE-MPFS (to be referred to as MPFS field in all accounts in this report) and another 0.28 hectare on a farmer's field on the western side of Rusinga Island, about 10 km west of ICIPE-MPFS. The area in Rusinga is at an altitude of

1125m above sea level with an annual rainfall of about 940mm.

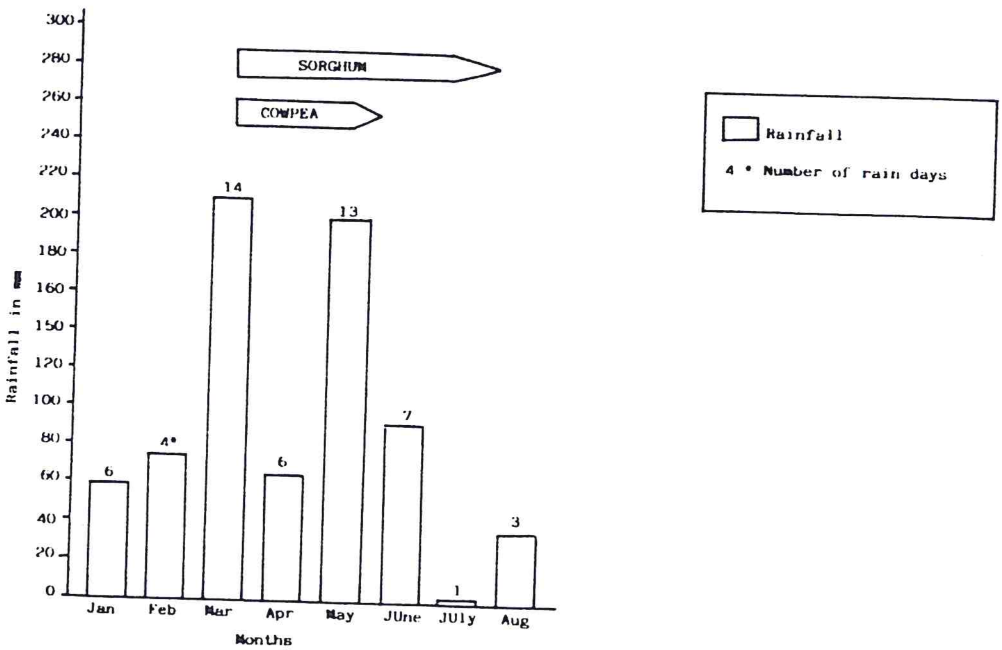
3.2 Experimental crops

The target crops of sorghum and cowpea for this study were chosen on the basis that they are part of the crop combinations which form a traditional intercrop system used by most subsistence farmers in Africa. The erratic rainfall pattern of our location (Fig. 1) influenced further the decision in the choice of planting materials best suited to the local environment. Sorghum variety Serena, was the main experimental crop. It is a popular sorghum cultivar recommended in lowland sorghum growing areas of East Africa below 1530m elevation. It has a compact conical head bearing light brownish grains with floury endosperm and a maturity period of 110-120 days. Cowpea variety was Ex-Luanda, which is a local semi-erect cultivar that has been grown around the Lake Victoria region for some decades (Amoako-Atta et al., 1983) and has adapted itself to the dual function of leaf and seed production. It has a medium yielding capacity of 300 to 500 kg/ha without protection from insect pests and a relatively short maturation period of about 70 to 85 days. Normally it is intercropped with sorghum, maize and other crops.

FIGURE 1



SORGHUM
COWPEA
SORGHUM
COWPEA
Mean monthly total rainfall 1977 - 1986
MOnthly total rainfall 1987 - 1988
Rainfall per month (mm)
270
240
210
180
150
120
90
60
30
0
J F M A M J J A S O N D J F M
1987
MONTH
1988



SORGHUM
COWPEA
Rainfall
4 * Number of rain days
Rainfall in mm
300
280
260
240
220
200
180
160
150
120
100
80
60
40
20
0
6
4*
14
6
13
7
1
3
Jan Feb Mar Apr May JUne JUly Aug
Months

3.3 Experimental field procedures

There have been difficulties in conducting most of the work on intercropping because of lack of uniform methodologies of research, specifically on experimental design for heterogenous plant compositions (Anon, 1978). Farm sizes in the traditional systems of the tropical African farmer range from $10m^2$ to 3ha per farm holding. Despite the small farm sizes crop diversity may be as high as six species randomly mixed together in a single plot.

3.3.1 Field preparation and layout

The experimental fields at both sites were first ploughed and harrowed using a tractor. This was followed by seedbed preparation using the hand hoe. In the process all crop residues were removed to ensure an adequately fine and firm seedbed for the small sorghum and cowpea seeds.

An area measuring 76m x 34m was marked out and divided into three blocks of 76m x 10m separated by 2m pathways. Each block was further divided into five medium sized plots of 14m x 10m with 1.5m alley space between adjacent plots.

3.3.2 Treatments used and experimental design

An experimental design which include various crop combinations as treatments was adopted from Amoako-Atta et al. (1983). Five treatment combinations:

i) Sorghum monocrop
ii) Cowpea monocrop
iii) Sorghum and cowpea intercrop planted simultaneously
iv) Sorghum planted two weeks before cowpea on the same plot
v) Cowpea planted two weeks before sorghum on the same plot,

were adopted throughout in the field experimentation.

The five treatments were randomly assigned to the five plots in a block. Allotment of treatments to the plots differed from season to season, by the use of random numbers. This was considered desirable as an in-built crop rotation within the test area to eliminate soil trend or effect on the cropping pattern.

3.3.3 Planting and crop management

Plant spacing within the monocrops was 90cm x 15cm for sorghum and 75cm x 30cm for cowpea generating a plant population of about 74,074 sorghum plants per hectare and 44,444 cowpea plants per hectare respectively, after thinning. Sorghum spacing in the intercrops was similar to that in the monocrop but cowpea was spaced at 90cm x 40cm, which gave an added small population of about 27,778 cowpea plants per hectare. This was done in order to maintain a carrying capacity that would not overburden the land per unit area when using the additive model (Fisher, 1977; Omolo and Ollimo, unpublished; Rees, 1986).

Triple super phosphate (TSP, containing 43% P_2O_5) fertilizer was applied at a blanket rate of 100 kg P_2O_5/ha by drilling it into the planting rows before sowing. Sowing was done by hand at the rate of about five sorghum and three cowpea seeds per hole and the seedlings were later thinned to one per hill at twenty days after emergence (DAE). On the initial planting date of each season, seed sowing was done for cowpea and sorghum monocrops, cowpea and sorghum simultaneously, cowpea only where sorghum was to follow later, and sorghum only where cowpea was to follow afterwards. Fourteen days after that date, cowpea and sorghum were sown in alternate rows in their respective treatment plots. The plots were irrigated on the same day after planting unless there was enough moisture in the soil.

Most of the short rain season crop was grown under irrigation because the rains were highly unreliable, but the long rain season crop was only irrigated (at MPFS) when rains were inadequate, otherwise the long rains were more evenly distributed compared with the short rains.

In order to make an effective study of the pest population complex and their natural enemies, it was decided not to apply any pesticides on the crops, which is a normal practice by the farmers in the areas surrounding Mbita Point Field Station. The plots were kept nearly weed-free by hand pulling and or hoeing in order to avoid the variable effects of weed growth on the total plant diversity in each plot.

3.3.4 Experimental plot sampling units

An experimental plot layout which can generate enough sampling units for data collection in a heterogenous plant composition was adopted from Amoako-Atta et al. (1983). This was achieved by pegging the 14m x 10m plots at 2m intervals on each side immediately after thinning the plants. Manila line cords were permanently installed adjoining each sister peg at opposite ends on each respective plot to demarcate 2m x 2m sampling cells, resulting in 35 cells per plot

(Fig. 2). The border cells in each plot were considered as guard cells and were not included in weekly samplings because of edge-effects. All inner cells were given random numbers and were subsequently used for regular sampling, egg counting, oviposition and larval dispersal studies, thermometer screen installation and grain yield assessment.

3.4 Maintenance of field microclimatic records

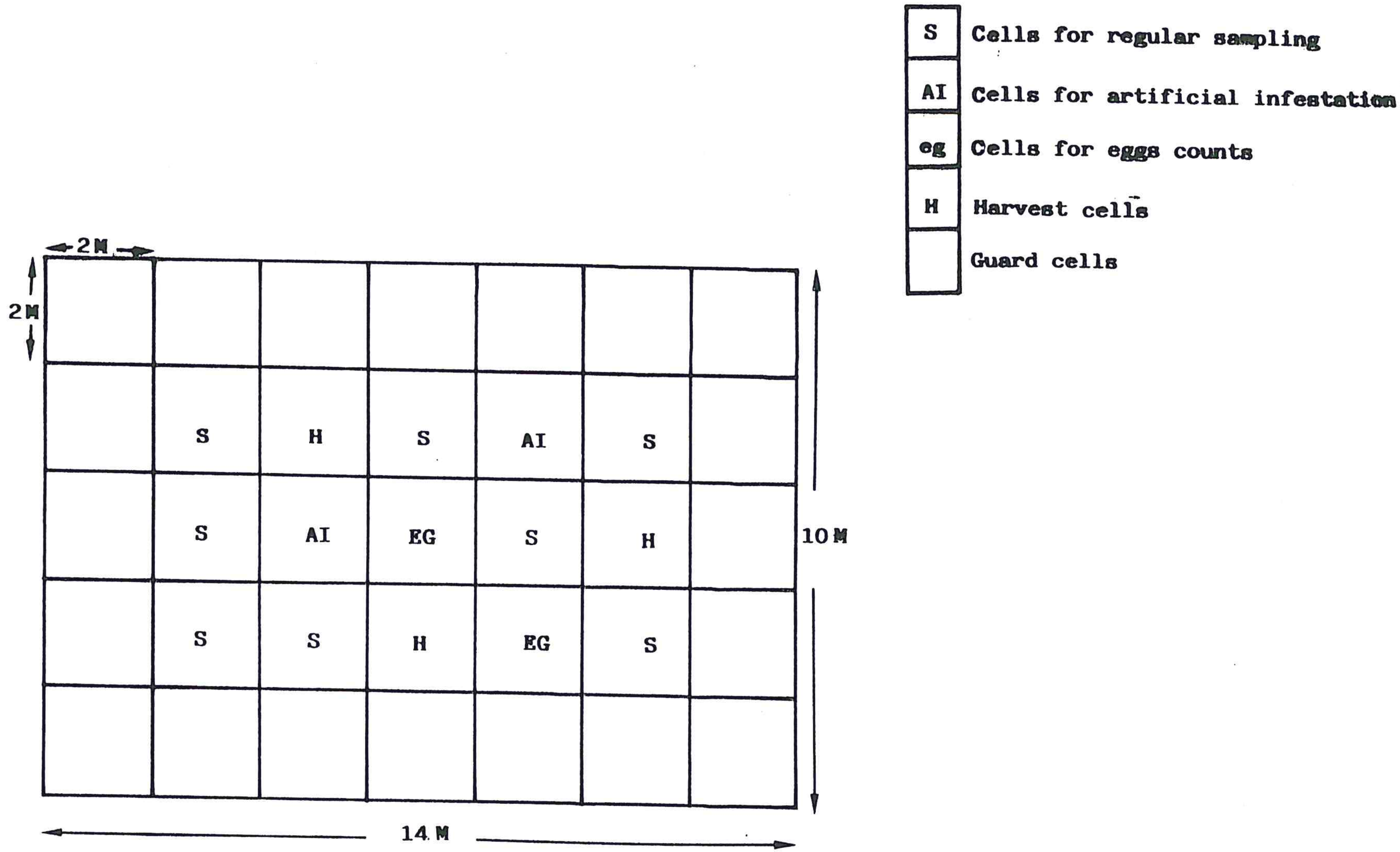
Temperature, relative humidity and light intensity were monitored in the four planting patterns from the fourth week after plant emergence till harvest. The instruments from which these readings were taken were placed in one plot cell per treatment. There were therefore five thermometer screens and on the occasion of taking light intensity readings the sensor was placed in the same cell in which the screens had been installed.

3.4.1 Temperature and relative humidity

Two dry-and wet-bulb thermometers were permanently maintained in a wooden screen in one plot per treatment from four weeks after plant emergence till harvest. The screen was securely anchored to the ground in the centre of one of the inner plot cells. The thermometers were

FIGURE 2

Plot dimensions and stratification into experimental units



2 M
2 M
S
H
S
AI
S
S
AI
EG
S
H
S
S
H
EG
S
10 M
14 M
S
Cells for regular sampling
AI
Cells for artificial infestation
eg
Cells for eggs counts
H
Harvest cells
Guard cells

placed in the screen at 30cm and 120 cm from the soil surface and daily readings were taken at 0900 hours. The relative humidity figures were obtained from the appropriate tables.

3.4.2 Light interception within the crop canopy

The incident light at ground level was measured twice a week at 0900 hours using a quantum radio meter (LI-1905) which had a meter long sensor. The sensor was placed on the ground across two rows of sorghum with cowpea in between in the intercrop plots, and across two cowpea rows in the cowpea monocrop.

3.5 Pest and plant damage assessment

In plant species diversity as found in subsistence agroecosystems, each crop within the system has its own array of pests which may behave differently in the presence of other plants. The levels of natural stem and pod borer population occurrence on the plants in their spatial and temporal patterns were assayed by regular plant sampling and direct counts of the different stages of the borers in the monocrop and intercrop patterns. In the case of the stem borers whole sorghum plant stems were sampled and the number of different borer species stages of development recorded. C. partellus egg counts and artificially infested black head stage eggs used to study larval establishment, were carried out on uncaged field plants; while oviposition studies were conducted on field plants enclosed in mobile steel frame cages covered by a fine netting material. Such cages were removed from the plants after the experimental period.

On cowpea, M. testulalis eggs were counted on randomly selected plants in the plot cells. Samples of flower buds, flowers and green pods (depending on the growth stage of the plants) were drawn from randomly selected plants in the plot cells and used for M. testulalis larval population studies. Pupae population was monitored by trapping them on the soil underneath the cowpea plants where pupation normally occurs.

Destructive samplings were carried out weekly for each treatment throughout the growing season starting two weeks after plant emergence (WAE). A uniform distribution of the pests was assumed based on the fact that the experimental field was between cultivated fields with similar crops (particularly cereals) all seasons. Furthermore, each experimental plot had its own guard row cells to eliminate edge-effects and at the same time it was assumed that the pests had equal chances of colonizing all the plots and disperse uniformly in the inner plot cells. With such assumptions put forward, one cell earmarked in each plot at the beginning of the season using random numbers was used on every sampling date. A new cell was always used in subsequent sampling dates. The cells allocated for harvesting were left undisturbed except for such activities like weeding.

3.5.1 Stem borer population and damage assessment on sorghum

Five sorghum plants per cell were selected at random and uprooted. This uprooting was only done before stem elongation (5 WAE), thereafter the main stem in a sampling hill was cut at soil surface level and used for different pest and damage assessments. Insect population assessment was carried out by recording all the stem borer species found on each sorghum plant taking note of their stages of development. Other arthropods associated with the stem borers, some of which included parasites and predators were also recorded at the time of sampling and stem dissections in the field. Sampled larvae and pupae were collected and reared in the laboratory for the recovery of internal parasites and also to obtain adult moths for cross identification when necessary.

Plant damage assessment was carried out by recording borer damaged leaves and tunnelled stem portions. Leaf damage was assessed on a 1-9 scale adopted from Guthrie et al. (1960):

class 1: no visible damage

class 2: a small amount of short-hole type lesions on a few plant parts

class 3: short-hole injury common on several plant parts

class 4: several plants and areas with short-holes and elongated lesions

class 5: several plant parts with elongated lesions (smaller than 2.5cm)

class 6: several plant parts with elongated lesions (larger than 2.5cm)

class 7: long lesions common on about one half of the plant parts

class 8: long lesions common on about two thirds of the plant parts

class 9: most of the plant parts with long lesions-the plant is (almost) destroyed.

Every sampled plant was assessed individually and the mean score for the plot was determined from these parameters. According to Guthrie et al. (1960) most of the feeding in the whorl is done by first and second instar larvae, whereas the injury on the sheath, midrib, and around the colars is caused by the third and fourth instar larvae.

Stem tunnelling was obtained by stripping off all leaves from individual sorghum plants and taking the total length of the stem including the sorghum head portion. The stem was split open and the portion(s) which had been tunnelled by the borers was measured. The percentage of stem length tunnelled was calculated from the two measurements.

3.5.2 Cowpea pod borer population and pod damage assessments

M. testulalis studies on cowpea were carried out at a shorter time interval compared with those on sorghum stem borers because of the short duration of some of *M. testulalis* developmental stages (i.e. the egg stage) and the cowpea phenological stages on which this insect feeds. The stem borers can feed on sorghum stems until they are relatively old.

Six cowpea plants per plot, three in each of two plot cells in the monocrop, and four plants, two in each of two cells in intercrop plots were randomly selected and used for *M. testulalis* egg counts every three days starting 20 days after plant emergence. Larval sampling was carried out by randomly picking twelve flower buds, flowers or pods (depending on the growth stage of the crop) from one cell per plot every four days starting twenty five days after plant emergence. All M. testulalis larvae found in these samples together with their different stages of development were recorded. A new cell was used on each sampling date. Pupae were sampled using square corrugated carton paper pieces of 40cm x 40cm each placed in the middle of two plot cells directly under cowpea canopy and held in place by sprinkling a few grains of soil on the upper surface. The corrugated surface faced the soil and the depressions were the preferred sites for hiding and spinning of cacoons by the pre-pupa. Pupae were collected every five days starting 35 DAE.

Cowpea pod damage assessment was done at 65 DAE (when most of the first pods to develop were at the ripening stage) by randomly selecting twenty four pods from each of the monocrop plots and sixteen pods from intercrop plots. The pods with M. testulalis damage signs (entry and exit holes) in each plot were counted and the percentage damage determined. The assessment was repeated 75 DAE on the pods formed in subsequent flowerings and also after harvesting (at 70 DAE) those pods on which the first assessment had been done. All *M. testulalis* population studies continued up to 90 DAE when almost half of the plants had started shedding off most of their leaves and very few plants had pods.

3.6 Laboratory rearing of field collected insects

Field collected borer larvae and pupae were maintained individually in well labelled rearing dishes in the laboratory and daily observations were kept on their development. The stem borer larvae were supplied with fresh 8cm sorghum stem cuttings every other day. A 1.5cm central tunnel was made in the cutting using the head end of a pair of forceps to help the larvae settle quickly and feed, and also because most stem borer larvae (particularly *B. fusca*) were found to be unable to excavate a feeding hole after they had passed the third and fourth instar stages. Daily records included larval pupation, parasite emergence or disease incidence; pupal parasite emergence or diseased individuals; and adult emergence from pupae. Cross identifications of adult moths by comparing them with a standard collection were also carried out whenever necessary.

Cowpea pod borer larvae and pupae sampled from the field were also maintained individually in labelled rearing dishes and supplied with fresh flower buds, flowers or green pods (depending on availability) everyday. Records similar to those kept on the stem borer larvae and pupae were maintained for the pod borer.

All experimental observations on the plants including sorghum stem dissections were performed in the field between 0700 and 1200 hours throughout the cropping seasons. Laboratory observations were carried out in the morning (between 0700 and 1000 hours) and late in the evening (2100 to 2200) in order to cover adult emergence and oviposition periods. Experimental data were subjected to analysis of variance unless otherwise stated and significant means were separated using Duncan's Multiple Range Test (DMRT) (Duncan, 1955) at 5% level of significance.

S E C T I O N C

E X P E R I M E N T A L R E S U L T S

CHAPTER 4

TITLE: *C. PARTELLUS* OVIPOSITION ON SORGHUM INTERCROPPED WITH COWPEA UNDER OPEN AND CAGED FIELD CONDITIONS

4.1 INTRODUCTION

The discovery of a suitable host plant by many herbivorous insects is an essential phase in their life cycle. Complex visual, olfactory, and gustatory stimuli methods are employed by these insects in search of food. The disruption of the searching behaviour through crop diversification can therefore be a useful tool in pest control (Cromartie, 1981). For most annual crops, the numbers of exogenous insects invading at the beginning of the growing season, either from adjacent uncultivated areas or from great distances, is a vital factor determining final pest abundance in a given situation (Southwood and Way, 1970).

Tall crops such as traditional cultivars of sorghum and millet may act as physical barriers or traps to pests invading from outside the cultivated area. Alternatively, it has been found that strongly aromatic plants such as onion, garlic, lemon grass, tomato and tobacco can provide olfactory camouflage for more vulnerable crops (Tahvanainen and Root, 1972; Buranday and Raros, 1975).

The oviposition behaviour of C. partellus has carefully been studied by Ingram (1958), Roome et al., (1977) and Chadha and Roome (1980). Ingram (1958) reported that groups of eggs were laid anywhere on the food-plant, though most frequently on the lower surface of mature leaves near the midrib. Roome et al., (1977) reported from field observations that the majority of egg batches were laid on the lower leaves of the plant. Most often such egg batches were found in the depression beside the midrib of leaves or in creases in dead leaves (Chadha and Roome, 1980). The two authors further reported that in the absence of smooth plant material, glass, polythene, metal and plastic, all appeared to be accepted for oviposition.

Most of the work reported on C. partellus oviposition in the field was mainly conducted on cereal crop monocultures. The present experiment was designed to monitor C. partellus oviposition in the different sorghum cropping patterns.

4.2 MATERIALS AND METHODS

Studies on the effect of various intercrops on C. partellus oviposition were carried out in the field. The intercrops were: sorghum monocrop, sorghum and cowpea sown simultaneously, sorghum sown before and after cowpea; were carried out in the field starting three weeks after plant emergence. Studies were made in both open and caged field plants. With regard to the former, oviposition was monitored starting three weeks after crop emergence. In this case twenty sorghum plants, ten in each of two inner plot cells in every plot were randomly selected, carefully examined and the number of egg batches together with number of eggs per batch counted and recorded every four days at the field station and once a week on the farmer's field between 0700 and 0900 hours.

The position of the egg batch on the plants was also recorded. In addition to sorghum, cowpea plants as well as other weeds in the experimental plots were searched for C. partellus eggs in 1987/88 short rainy season at the field station.

Portable metal frame cages 1.5m x 1.5m x 1.0m were placed in one inner plot cell in two replicates per treatment and covered with a fine white cloth mesh. This cage covered two sorghum and three cowpea rows in the monocrops, and two sorghum and one cowpea row in the intercrops. All plants were inspected for naturally laid *C. partellus* eggs before cage introduction and such eggs were destroyed if found. From the fourth week after plant emergence two gravid one day old mated moths from a laboratory culture were introduced into each cage in the evening between 1600 and 1800 hours. On the following morning (0700-0800 hours) the plants in the cage were carefully searched for egg batches. The number of egg batches and their size were recorded separately for sorghum and cowpea. All eggs were later destroyed and the moths were killed. Moth introductions were made twice a week for a period of four weeks. This period coincides with the peaks of field moths' oviposition and that of the plants' vegetative growth. The whole experimental area was maintained weed free throughout the study period. The cages were removed from the field at the end of this experiment as the plants were overgrowing their height.

4.3 RESULTS

Throughout these studies *C. partellus* eggs were found on the sorghum plants during each cropping season. Eighty percent of the total number of eggs observed in these experiments over the two years were found near the midrib on the upper surface of mature leaves, 16% were on the lower surface also near the midrib of mature leaves and the remaining 4% were on the upper exposed surfaces of mature leaf sheaths. Eggs on the leaf sheaths were observed after 75 days from plant emergence. Eggs were found on the lower surface of mature leaves more frequently when the plants were less than 45 days old.

Overall, the egg batches observed over the two year period were on green or surfaces with shades of green (leaf sheaths) on the sorghum plants but also they were on several occasions observed on the upper surfaces of mature cowpea leaves in the intercrops and on leaves of both grass and broad leaved common weeds; in particular *Setaria verticillata* (L.) Beauv. locally called Anaga (Graminaea), *Corchorus olitorius* L. (Tiliaceae) locally called Apoth, and *Flaveria australasica* Hook. (Compositae). These weeds had been collected at Mbita by A. and A. Dissemond and identified by C. H. S. Kabuye, East African Herbarium Nairobi and H. Hindorf, Institut fur Pflanzenkrankheiten der Universitat Bonn. No C. partellus eggs were observed in cowpea monocrop.

The total number of C. partellus egg batches observed on sorghum plants at the farmer's field on Rusinga in 1987 was very small (25) compared with the number at the field station in the three seasons (104 in 1986/87, 112 in 1987 and 114 in 1987/88). Similarly the total egg count for Rusinga was also small (543 compared with 2814 in 1986/87, 3250 in 1987 and 3133 in 1987/88). The largest egg batch recorded in the two year period was 160 eggs and the smallest was 8 eggs.

4.3.1 C. partellus egg population on open field sorghum plants in four cropping patterns

The distribution of C. partellus eggs on sorghum in the four cropping patterns for 1986-88 period is shown in Fig. 3.1. Eggs were observed on the crop from ten days after sorghum plant emergence (10DAE) through harvest except in sorghum sown after cowpea where there was a delay until 42DAE. Generally there were three egg peaks during crop's growing period, the main peak occurred between 10 and 40DAE, then a second one between 50 and 75DAE followed by a minor peak towards harvest (Fig.

3.1). However, the main egg population peak in sorghum sown after cowpea shifted to between 45 and 85DAE while in sorghum sown simultaneously with cowpea there was only one prominent peak (26DAE).

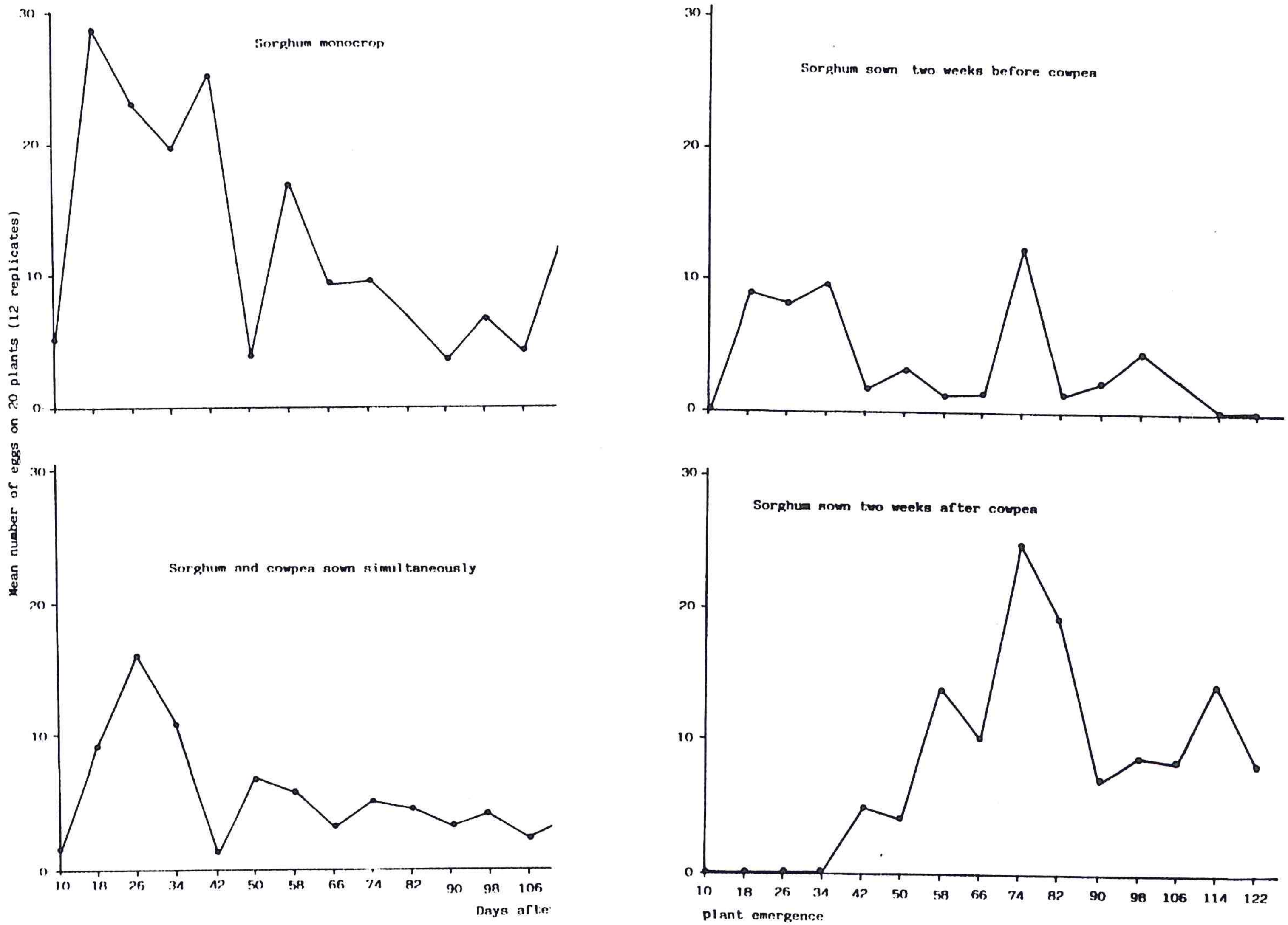
The mean number of C. partellus egg batches and their sizes in the four sorghum cropping patterns are shown in Tables 4.1 and 4.2 respectively. Significantly (P=0.05) more egg batches and eggs were observed on both monocrop sorghum and that sown after cowpea than on the other two intercrops which were in turn statistically similar.

Seasonal trend of C. partellus eggs in 1986-88 planting seasons at Mbita and on Rusinga Island is shown in Fig. 3.2. The three seasons at Mbita show two egg population peaks, the first peak between 10 and 45DAE and the second between 55 and 90DAE. On Rusinga Island however, there was only one peak towards harvest. The seasonal mean number of egg batches and eggs are shown in Tables 4.1 and 4.2 respectively. There were significantly (P=0.05) more egg batches and eggs in the three seasons at Mbita than on Rusinga Island.

The variations between the number of egg batches and eggs in the four cropping patterns in each season are

FIGURE 3.1

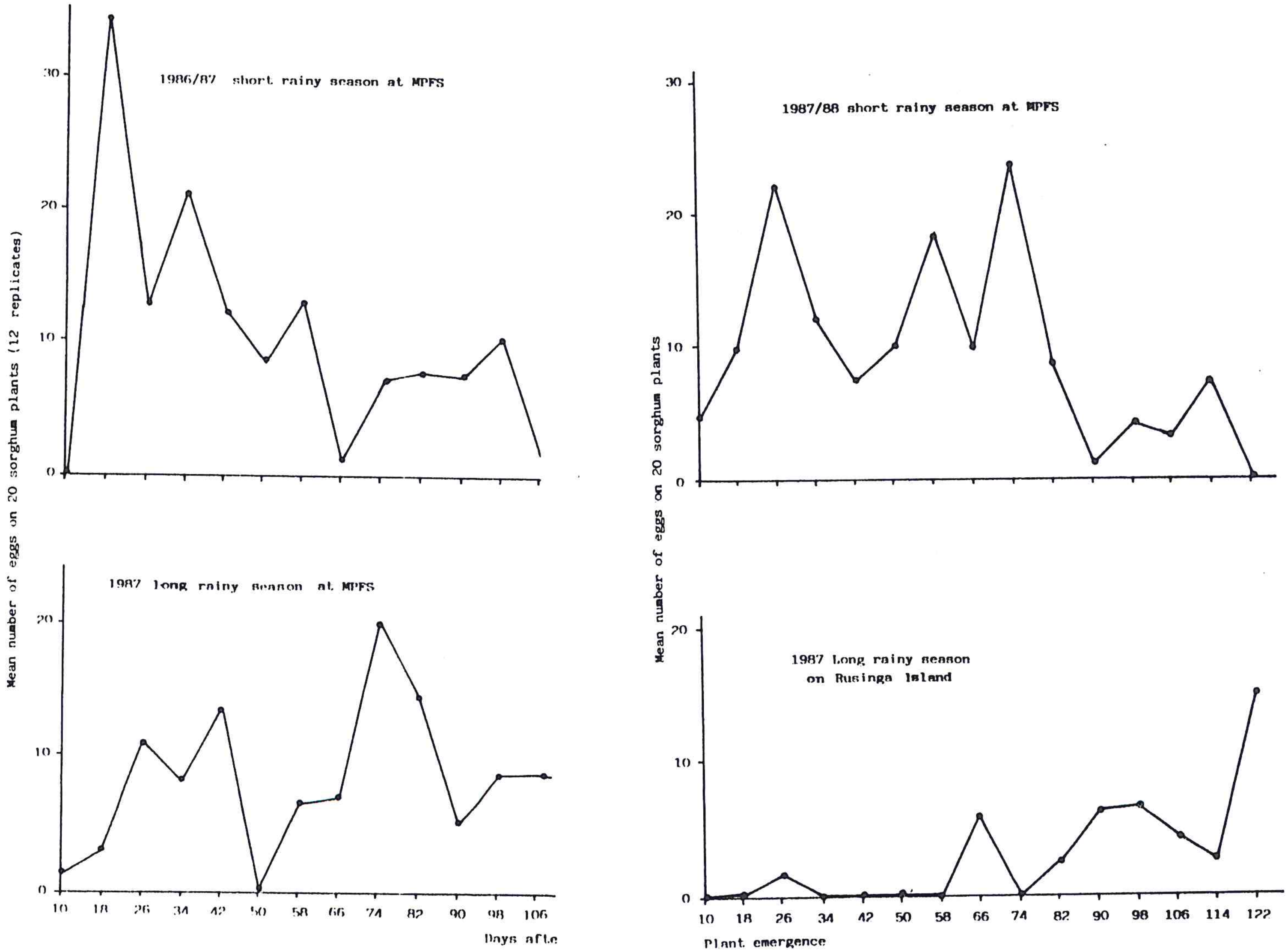
Effect of sorghum cropping pattern on *C. partellus* oviposition during 1986-88 period



Sorghum monocrop
Sorghum sown two weeks before cowpea
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks after cowpea
Mean number of eggs on 20 plants (12 replicates)
30
20
10
0
10 18 26 34 42 50 58 66 74 82 90 98 106 114 122
Days after plant emergence

FIGURE 3.2

C. partellus oviposition on sorghum in open field conditions in each season during 1986-88 period


1986/87 short rainy season at MPFS
1987/88 short rainy season at MPFS
1987 long rainy season at MPFS
1987 Long rainy season
on Rusinga Island
Mean number of eggs on 20 sorghum plants (12 replicates)
Mean number of eggs on 20 sorghum plants
0
10
20
30
10 18 26 34 42 50 58 66 74 82 90 98 106 114 122
Days after Plant emergence

also shown in Tables 4.1 and 4.2 respectively, and in Figs. 3.3-3.6. Significant differences were observed on the number of egg batches in the four cropping patterns at Mbita compared with Rusinga where the four cropping patterns were similar (Table 4.1). There were significantly (P=0.05) more egg batches on sorghum monocrop than the three intercrops (which were similar) in 1986/87. In 1987/88 short rainy season sorghum sown before cowpea had a significantly (P=0.05) lower number of egg batches than the other three cropping patterns while sorghum sown simultaneously with cowpea was not significantly (P=0.05) different from the other three cropping patterns. In 1987 long rainy season at Mbita both sorghum monocrop and that sown after cowpea had significantly (P=0.05) higher numbers of egg batches than the other two intercrops which were in turn similar.

A large proportion of the eggs were observed between 10 and 50DAE in 1986/87 except in sorghum sown after cowpea where most eggs were recorded between 38 and 90DAE (Fig. 3.3). In the 1987/88 short rain season the egg population pattern was continuous from 10 to 90DAE but as it was observed in 1986/87 season, sorghum sown after cowpea had most eggs between 38 and 118DAE (Fig. 3.4). During the 1987 long rains the majority of eggs at Mbita were observed between 14 and 82DAE in sorghum

Table 4.1 Mean number of *C. partellus* egg batches* on 20 sorghum plants in four cropping patterns during 1986-1988 planting seasons

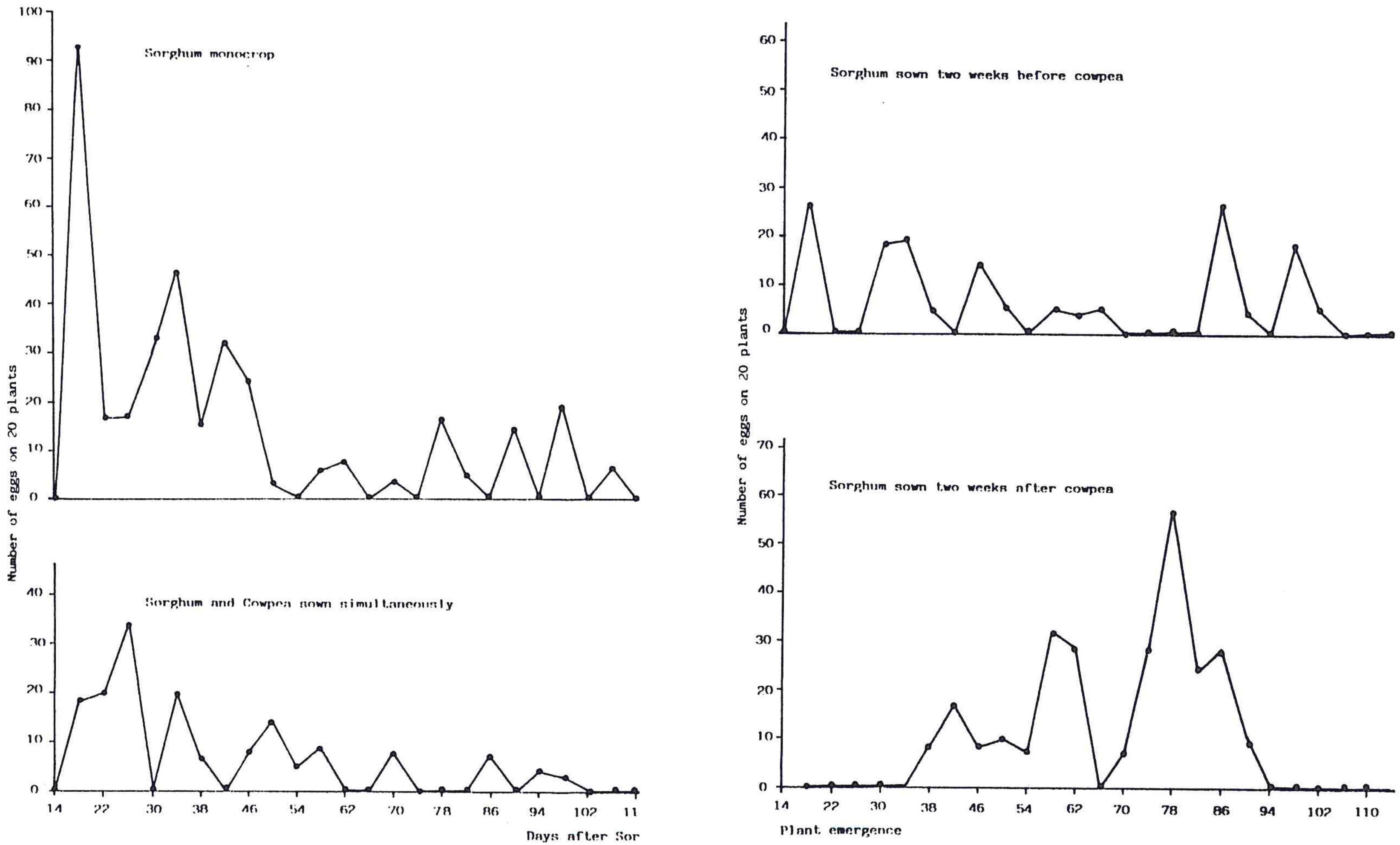
Cropping pattern	Short rain seasons		Long rain season		
	1986/87 MPFS	1987/88 MPFS	1987 MPFS	1987 RUSINGA	Mean ± S.E.
Sorghum monocrop	1.36[a]	1.31[a]	1.38[a]	1.13[a]	1.30 ± 0.06[a]
Sorghum and cowpea sown simultaneously	1.16[b]	1.20[ab]	1.08[b]	1.13[a]	1.14 ± 0.02[b]
Sorghum sown two weeks before cowpea	1.17[b]	1.13[b]	1.14[b]	1.05[b]	1.12 ± 0.03[b]
Sorghum sown two weeks after cowpea	1.23[b]	1.28[a]	1.31[a]	1.14[a]	1.24 ± 0.04[a]
Mean ± S.E	1.23±0.05[a]	1.23±0.04[a]	1.23±0.07[a]	1.11±0.02[a]	

* Data transformed to Log (x + 1) for analysis of variance and means retransformed after analysis

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

FIGURE 3.3

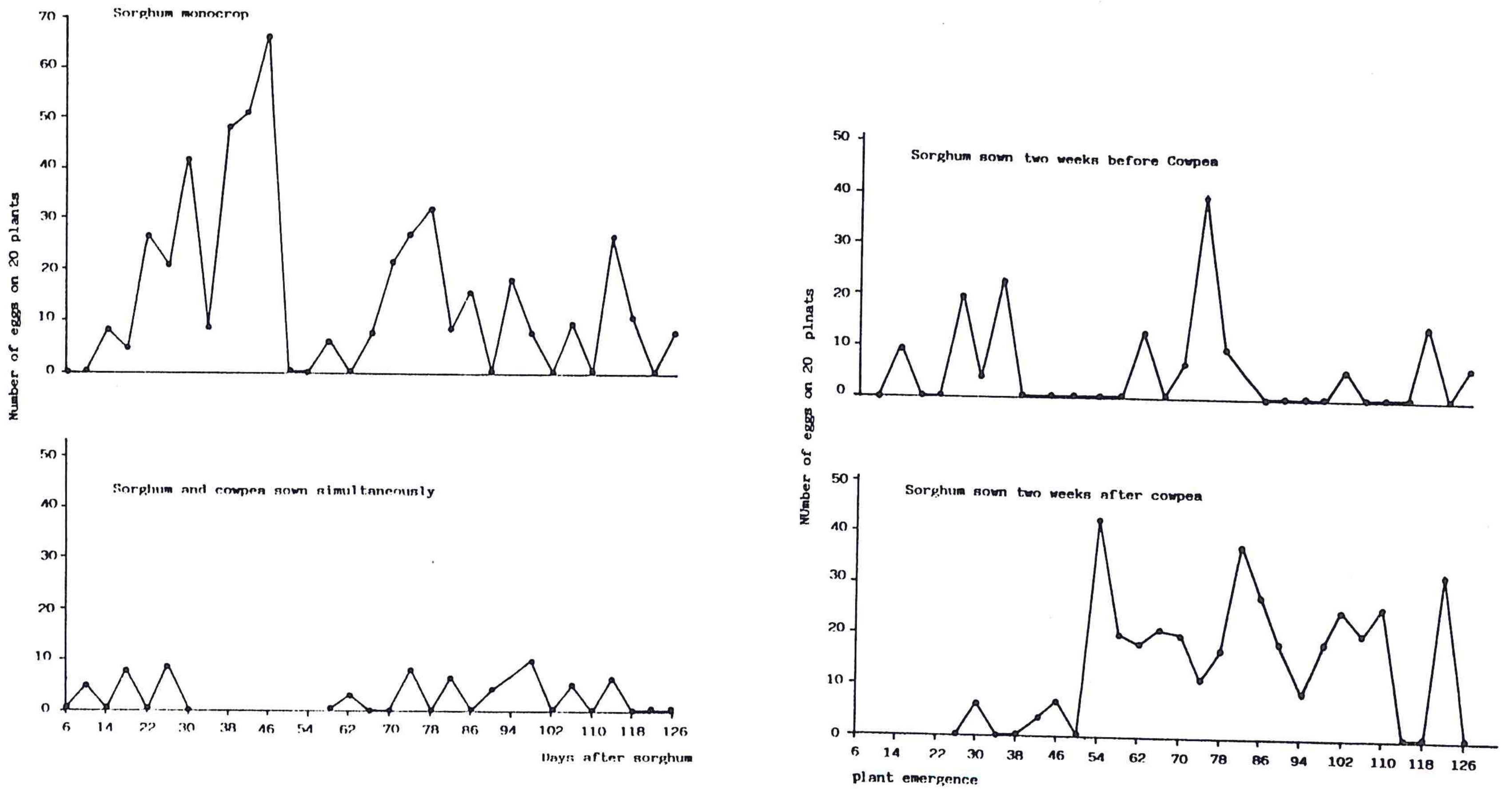
Mean number of *C. partellus* eggs on 20 sorghum plants in four cropping patterns at MPFS during 1986/87 short rainy season



Sorghum monocrop
Sorghum and Cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Number of eggs on 20 plants
Number of eggs on 20 plants
100
90
80
70
60
50
40
30
20
10
0
40
30
20
10
0
60
50
40
30
20
10
0
70
60
50
40
30
20
10
0
14 22 30 38 46 54 62 70 78 86 94 102 11
14 22 30 38 46 54 62 70 78 86 94 102 110
Days after Sor
Plant emergence

FIGURE 3.4

Mean number of *C. partellus* eggs on 20 sorghum plants in four cropping patterns at MPFS during 1987 long rainy season

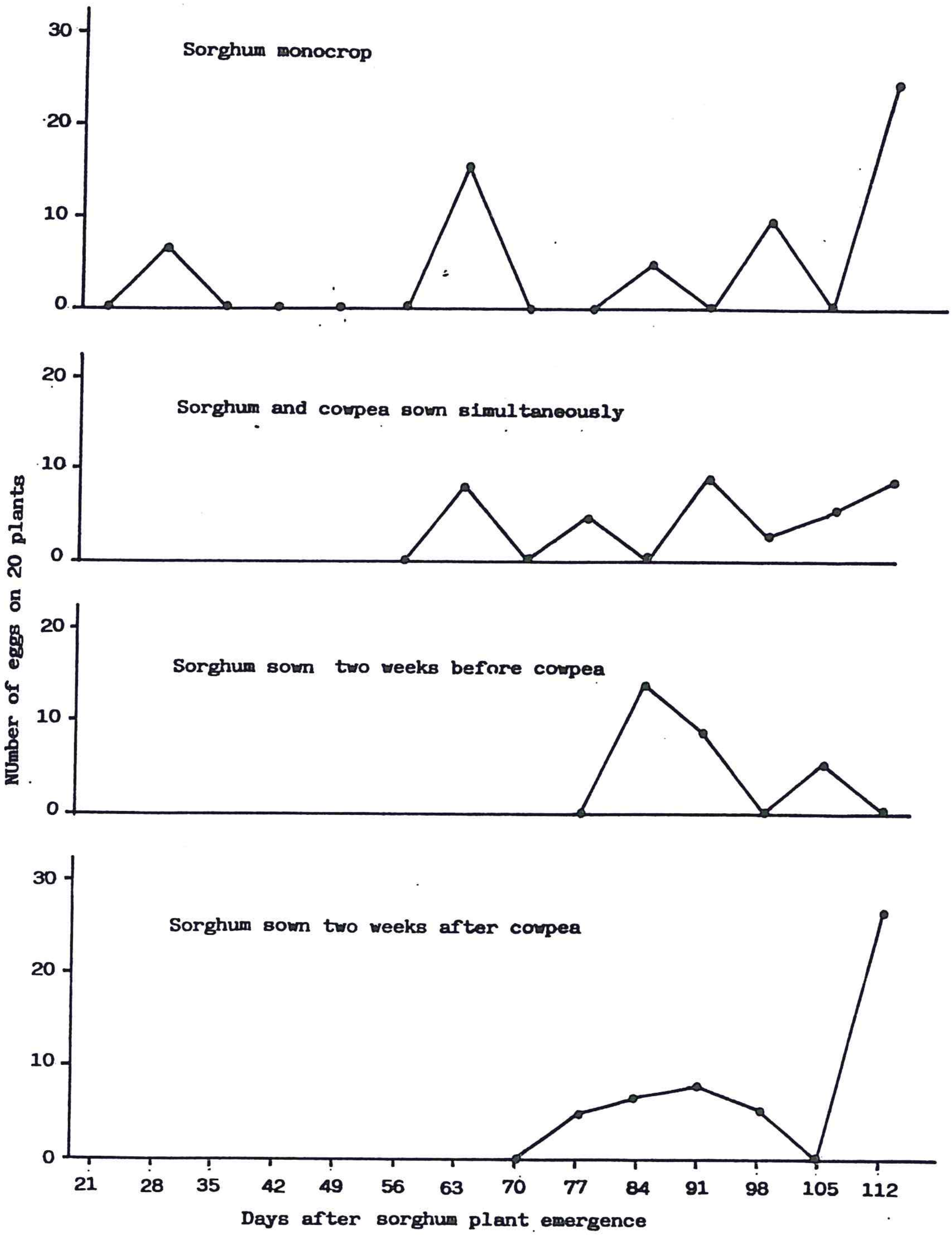

Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before Cowpea
Sorghum sown two weeks after cowpea
Number of eggs on 20 plants
NUmber of eggs on 20 plnats
Days after sorghum
plant emergence
0
10
20
30
40
50
60
70
6
14
22
30
38
46
54
62
70
78
86
94
102
110
118
126

monocrop and that sown before cowpea. Sorghum sown simultaneously with cowpea had more eggs between 74 and 114DAE than in the rest of cropping period. The bulk of the eggs in sorghum sown after cowpea was observed between 42 and 122DAE (Fig. 3.5). Practically no eggs were observed on sorghum in Rusinga until 63DAE. Generally the counts were erratic except in sorghum sown after cowpea where continuous counts were observed from 77DAE through harvest (Fig. 3.6).

There were significantly (P=0.05) more eggs on sorghum monocrop than on both sorghum sown simultaneously with cowpea and that sown before cowpea in 1986/87 (Table 4.2). Sorghum sown after cowpea was not significantly different from either the monocrop or the other two intercrops. In 1987/88 monocrop sorghum had a significantly (P=0.05) higher number of eggs than both sorghum sown simultaneoulsy with cowpea and that sown before cowpea. Sorghum sown after cowpea was similar to both monocrop and sorghum sown simultaneously with cowpea. During 1987 long rains at Mbita sorghum monocrop and that sown after cowpea were statistically similar and had significantly (P=0.05) higher numbers of eggs than the other two intercrops. On Rusinga Island however, there were no significant differences between the cropping patterns (Table 4.2).

FIGURE 3.5

Mean number of *C. partellus* eggs on 20 sorghum plants in four cropping patterns on Rusinga during 1987 long rainy season



Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
NUmber of eggs on 20 plants
Days after sorghum plant emergence
0
10
20
30
21
28
35
42
49
56
63
70
77
84
91
98
105
112

FIGURE 3.6

Mean number of *C. partellus* eggs on 20 sorghum plants in four cropping patterns at MPFS during 1987/88 short rainy season

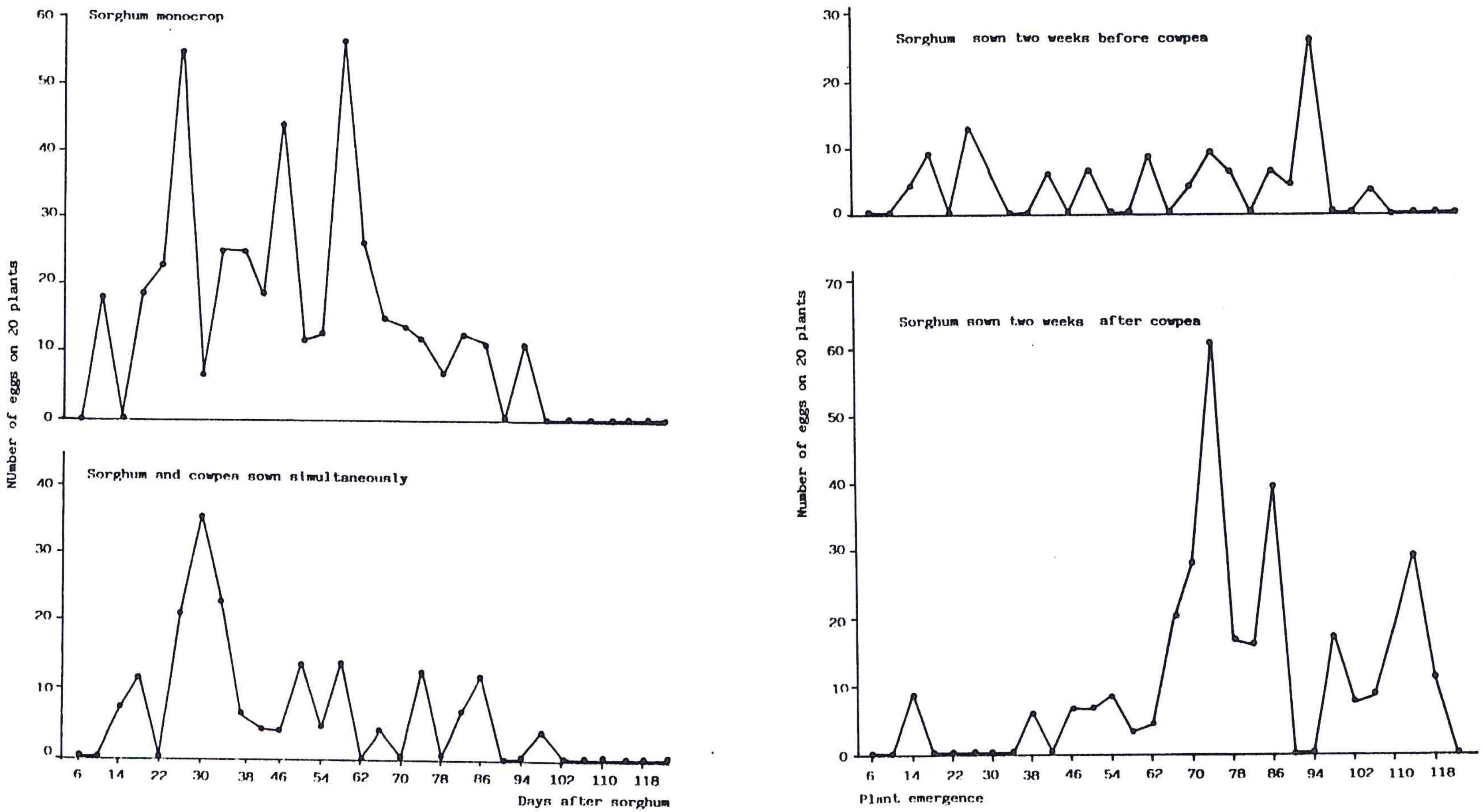

Sorghum monocrop
Sorghum and cowpea sown simultaneously
NUmber of eggs on 20 plants
Days after sorghum
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Number of eggs on 20 plants
Plant emergence
6
14
22
30
38
46
54
62
70
78
86
94
102
110
118
0
10
20
30
40
50
60
70

Table 4.2 Mean number of *C. partellus* eggs* on 20 sorghum plants in four cropping patterns during 1986-1988 planting seasons.

Cropping pattern	Short rain seasons 1986/87 MPFS	1987/88 MPFS	Long rain season 1987 MPFS	1987 RUSINGA	Mean ± S.E.
Sorghum monocrop	3.7[a]	3.5[a]	4.1[a]	1.7[a]	3.2 ± 0.5[a]
Sorghum and cowpea sown simultaneously	1.9[b]	2.1[bc]	1.4[b]	1.6[a]	1.8 ± 0.2[b]
Sorghum sown two weeks before cowpea	2.1[b]	1.7[c]	1.8[b]	1.4[a]	1.7 ± 0.1[b]
Sorghum sown two weeks after cowpea	2.6[ab]	2.9[ab]	3.7[a]	1.6[a]	2.7 ± 0.4[a]
Mean ± S.E	2.6±0.4[a]	2.6±0.4[a]	2.7±0.7[a]	1.6±0.1[b]	

* Data transformed to Log (x + 1) for analysis of variance and means retransformed after analysis.

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

4.3.2 *C. partellus* egg population on caged field plants in the 1987 season.

A low egg population was observed during the experimental period because of ant predation on some of the gravid moths which were introduced into the cage and also on the eggs laid by the moths. Most frequently up to 25% of the moths introduced into the cages would have been killed by ants in the following morning and only wing parts would remain behind.

The studies revealed that a total of 20 egg batches were recorded on sorghum plants in the four cropping patterns. Eleven out of these were on the sorghum monocrop, five on sorghum sown before cowpea, three on sorghum sown simultaneously with cowpea and one on sorghum sown after cowpea. There were significantly (P=0.05) more egg batches on sorghum monocrop than sorghum sown after cowpea (Table 4.3). The other two intercrops were statistically similar and were not significantly different from either the sorghum monocrop or sorghum sown after cowpea.

The total number of egg batches found on both crop plants in the four treatments was thirty seven. Six of these were in the combination of sorghum sown before cowpea, nine in sorghum and cowpea sown simultaneously and eleven each in the sorghum monocrop and sorghum sown after cowpea. The four treatments were not significantly different (Table 4.3).

In addition, the number of egg batches found on sorghum plants expressed as a percentage of total egg batches found in each cage in the four cropping patterns is shown in Table 4.3. The data was transformed according to Bartlett (1947). Sorghum plants in the monocrop had a significantly (P=0.001) higher percentage of egg batches than plants in both sorghum sown simultaneously with cowpea and that sown after cowpea. Sorghum sown before cowpea was statistically similar to both sorghum monocrop and the other two intercrops.

Further observations on the egg population revealed that there were 525 eggs on sorghum plants in the four cropping patterns. Sorghum monocrop had 321 eggs, sorghum sown before cowpea had 127, sorghum sown simultaneously with cowpea had 55 and 22 were on sorghum sown after cowpea. Sorghum monocrop had significantly (P=0.05) more eggs than both sorghum sown simultaneously with cowpea and that sown after cowpea (Table 4.4). Sorghum sown before cowpea was not significantly different from either the monocrop or the other two

Table 4.3. *C. partellus* egg batches on caged sorghum and cowpea plants at MPFS during 1987 long rainy season (Mean ± S.E.)

Cropping pattern	Number of egg batches on: Sorghum alone	Number of egg batches on: Sorghum and cowpea	Percentage egg batches on sorghum plants
Sorghum monocrop	0.9 ± 0.3^{a}		83.0 ± 16.5^{a}
Sorghum and cowpea sown simultaneously	0.3 ± 0.2^{ab}	0.8 ± 0.3^{a}	12.5 ± 7.6^{b}
Sorghum sown two weeks before cowpea	0.4 ± 0.2^{ab}	0.5 ± 0.2^{a}	66.5 ± 20.9^{ab}
Sorghum sown two weeks after cowpea	0.1 ± 0.0^{b}	0.9 ± 0.4^{a}	17.0 ± 0.0^{b}

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

intercrops.

Egg counts on both sorghum and cowpea gave a total of 1047 eggs of which 393 were on the combination of sorghum sown after cowpea, 321 on sorghum monocrop, 174 on sorghum and cowpea sown simultaneously and 159 on the sorghum sown before cowpea. There were no significant differences between the four treatments (Table 4.4).

The mean percentage eggs found on sorghum plants in the four treatments was determined. The percentages were transformed according to Bartlett (1947) and are shown in Table 4.4. There were significantly (P=0.05) more eggs on sorghum plants in monocrop than on sorghum in the three intercrops. The intercrops were statistically similar.

4.4 Discussion

The results from this study demonstrated that C. partellus eggs were observed on sorghum plants throughout the season. Eighty percent of the total number of eggs observed in the two year period were laid near the midrib on the upper surface of mature sorghum leaves, sixteen percent were near the midrib on the lower surface of mature leaves and the remaining four percent were on the

Table 4.4 *C. partellus* eggs on caged sorghum and cowpea plants at MPFS during 1987 long rainy season (Mean ± S.E.).

Cropping pattern	Number of eggs on: Sorghum alone	Number of eggs on: Sorghum and cowpea	Percentage eggs on sorghum plants
Sorghum monocrop	26.8 ± 8.5[a]		66.5 ± 14.1[a]
Sorghum and cowpea sown simultaneously	4.6 ± 4.4[b]	14.5 ± 6.2[a]	17.0 ± 11.1[b]
Sorghum sown two weeks before cowpea	10.6 ± 4.7[ab]	13.3 ± 4.9[a]	17.0 ± 11.1[b]
Sorghum sown two weeks after cowpea	1.8 ± 0.0[b]	32.8 ± 14.7[a]	8.8 ± 0.0[b]

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test.

upper exposed surfaces of mature leaf sheaths. These observations are consistent with those recorded at the Coast Province of Kenya by Mathez (1972) where corresponding values of 70%, 25% and 5% respectively, were observed. Alghali (1988) also observed C. partellus oviposition on leafblades and sheaths with a marked preference for leafblades compared with sheaths.

These findings contradict those reported by Ingram (1958) and Roome et al. (1977) that C. partellus eggs were most frequently found on the lower surfaces of mature leaves. In the present study eggs were found on the lower surfaces of mature leaves more frequently when the plants were less than 45 days old, and as the plants matured the eggs were almost always recorded on the upper exposed surfaces. In addition, no egg batches were found in creases on dead leaves as reported by Chadha and Roome (1980). Alghali (1988) reported that sorghum plant (Serena) age had no effect on the preference for upper or lower leaf surfaces except in plants aged 6WAE where there was a distinct preference for the upper leaf surface. He further observed that eighty percent of egg batches laid between the 10 and 12WAE were on leaves in the plants' middle segments with virtually no eggs on the lower plant segments.

The relatively fewer eggs on the farmer's field crop compared with the field station could be a result of the longer counting interval (8 days) as opposed to 4 days at the field station but it could also be a reflection of the small borer larval population counts on farmers' fields around the shores of Lake Victoria observed in the present (Chapter 6) and previous findings (Ogwaro, 1983). There is only one crop season per year on farmers' fields and also the frequent artificial infestations at the field station are absent on the farmers' fields.

High egg population peaks were observed earlier in the sorghum monocrop than intercrops. This could be regarded as an early recognition and preference of sorghum plants in the monocrop to those in the intercrops for oviposition by this insect. The consistently more egg batches and eggs recorded on the sorghum monocrop (though not always significant) compared with some of the intercrops in the three seasons is in line with observations made on C. partellus in sorghum and simsim intercrop (Kato et al., 1982), and on O. furnacalis in maize intercropped with peanuts (Raros, 1973; Hasse, 1981). Similar results were also recorded for P. xylostella in tomato and cabbage intercrop (Buranday and Raros, 1975) and in Brussels sprouts and tomato intercrop

(Perrin and Phillips, 1978).

When one day old gravid female moths were caged in the field between 24 and 54DAE, they oviposited significantly more egg batches on sorghum in monocrop than on sorghum sown after cowpea. The total number of egg batches on both sorghum and cowpea was not significantly different in the four cropping patterns, but the percentage egg batches on sorghum in the monocrop was significantly higher than on sorghum sown simultaneously with cowpea. This indicates that more egg batches were on cowpea than on sorghum when the two crops were sown simultaneously. Similar observations were made at the International Rice Research Institute (IRRI) on *O. furnacalis* egg masses in maize and peanut, and maize and soybean intercrops, both sown simultaneously (Raros, 1973).

There were significantly more eggs on sorghum monocrop than sorghum sown simultaneously with cowpea and that sown after cowpea. This could be that the egg batch sizes on sorghum sown after cowpea were small, thus giving rise to an egg count which was similar to that from the smaller number of egg batches laid when the two crops were sown simultaneously. The mean number of eggs on both sorghum and cowpea were not significantly different. Numerically however, the monocrop sorghum and sorghum sown after cowpea both had approximately twice the number of eggs found in the other two intercrops. In this case it is clear that when cowpea was sown before sorghum the moths laid as many eggs on cowpea and sorghum plants together as they laid on the sorghum plants in the monocrop. This means that caged moths were forced to lay more eggs on the non-host cowpea than on sorghum probably due to restricted movements in the cages and possible dilution of olfactory cues from the young sorghum plants.

The significantly higher percentage of eggs on sorghum monocrop compared with the intercrop patterns reveals the degree of C. partellus oviposition on non-host cowpea plants during the experimental period. Under natural conditions however, only a few eggs were located on cowpea throughout the three cropping seasons which could reflect the freedom of choice that the moths had in the open environment. Oviposition preference for monocrop plants in intercropping experiments has also been reported on Memestra brassicae L. in Brussels sprouts and spurry intercrops (Theunissen and Den Ouden, 1980), and also on P. xylostella in Brussels sprouts (Perrin and Phillips, 1978).

Observations on the natural field population at the field station showed *C. partellus* eggs on cowpea leaves in the intercrops on two occasions (134 eggs) and once on leaves of three common weed plants in Mbita area (*F. australasica* with 56 eggs, *C. olitorius* with 45 eggs and *S. verticillata* with 52 eggs) in intercrop plot guard rows. This further elucidates the role that the cowpea plants could have played in the intercrop plots. Roome *et al.* (1977) observed that *C. partellus* was non-specific in its oviposition behaviour, readily laying eggs on inert materials in cages, but when plant leaves were present they were preferred. Thus, there is some measure of recognition and preference.

The intercropping patterns used in the present study therefore appear to have interfered with *C. partellus* oviposition behaviour to the extent that the moths diverted some of the eggs to the non-host cowpea plants. Simultaneous planting of sorghum and cowpea maintained egg population at an average of less than 10 eggs to every 20 plants throughout the season whereas in sorghum monocrop the average was about 15 eggs. The effect of sowing sorghum before cowpea was almost similar to that of simultaneous planting. Sowing sorghum after cowpea resulted in an average egg population which was similar to that in the monocrop, but the advantage of this cropping pattern was that sorghum was protected from egg laying for up to 40DAE. This means that by the time first instar larvae were on the plants, the stage of plant development could sustain the infestation without severe losses.

CHAPTER 5

TITLE EFFECT OF TIME OF PLANTING SORGHUM AND COWPEA INTERCROPS ON STEM BORER POPULATION BUILD-UP

5.1 INTRODUCTION

Many farmers in Africa, Asia and Latin America still grow crops in mixed stands (Andrews and Kassam, 1976; Kass, 1978). Numerous reports of tropical subsistence agroecosystems where intercropping is most common have suggested that diversified cropping reduces insect pest infestation (Altieri *et al.*, 1978). Ecologists and crop pest managers have also theoretically argued for the possible advantages that might occur when crops are consciously grown in definite mixtures (Southwood and Way, 1970; Litsinger and Moody, 1976; Perrin, 1977; van Emden, 1977; Cromartie, 1981; Altieri and Letourneau, 1982; Mumford and Baliddawa, 1983).

Varying results can be arrived at from intercropping, apart from the reduction in insect pest abundance on crop plants. In a recent review of the literature on diversity in agroecosystems, Risch *et al.* (1983) reported that 53% of the herbivore species studied exhibited population decreases in diverse cropping patterns. It was further reported that 18% were more abundant in the diverse systems, while 9% showed no differences, and 20% showed variable responses.

Despite a fairly significant effort to document the benefits of intercropping for various crop combinations (e.g., Altieri et al., 1978; Theunissen and Den Ouden, 1980; Risch, 1980; Rheenen et al., 1982; Amoako-Atta et al., 1983; Ezueh and Taylor, 1984; Capinera et al., 1985; Omolo and Seshu Reddy, 1985), crop-weed combinations (e.g., Altieri et al., 1977, 1981; Latheef and Ortiz, 1983), and to determine the ecological basis for this phenomenon (e.g., Bach, 1980, 1981; Risch, 1981; Stanton, 1983; Baliddawa, 1984), the effects of varying the time of planting the intercrops has had little attention (Altieri et al., 1978). It was felt that further work on this aspect could elucidate the pest interactions in sorghum and cowpea intercrops. The objective of the present study was to investigate the effect of varying the time of planting the sorghum and cowpea in the intercrop on stem borer population build-up.

5.2 MATERIALS AND METHODS

Using the various crop combinations described under Chapter 3 namely: sorghum monocrop, sorghum and cowpea sown simultaneously, sorghum sown before and after cowpea; studies were made on stem borer population build-up in the field in 1986-88. Starting three weeks after sorghum plant emergence (WAE), weekly samples of five sorghum main stems were drawn from each plot. Every plant was carefully stripped of its leaves, recording all borer larvae and pupae found between the leaves, leaf sheaths and the stems. The stem was then split open and all borer larvae, pupae, pupal cases and exit holes were recorded for individual stems. Stem borer stages found on the plants were identified into species as far as possible by comparing them with standard specimens. Field larvae and pupae were collected and reared in the laboratory for cross identification at adult stage when necessary and also for the recovery of endoparasites.

Stem borer pupae, pupal cases and exit holes were recorded throughout the cropping seasons for the purpose of estimating the proportion of the larval population developing to pupation. The total number of larvae, pupae and pupal cases of the different species found in a stem were added separately for the five stems per plot. Exit holes were recorded where pupae and pupal cases were not observed. Larvae, pupae and pupal cases were sorted out into species but exit holes were bulked. There were three replicates and the plot means were used in the analysis of variance.

5.3 RESULTS

The observations on the stem borer larval populations at the two experimental sites revealed that the population was 42% higher at the field station (seasonal total of 1298 larvae) than on a farmer's field on Rusinga Island (seasonal total of 750 larvae) during 1987 long rainy season. The stem borer species composition and dominance were different in the two sites. On Rusinga Island only C. partellus and B. fusca were found on sorghum in almost equal proportions, 49.7% and 50.3% respectively. However, at the field station E. saccharina and S. calamistis were also observed even though in very small numbers, and their proportions were: C. partellus 63-67%, B. fusca 20-27%, E. saccharina 4-6% and S. calamistis 2-4%. During the short rains, the sorghum crop had 17-25% more stem borer larvae (1732 in 1986/87, 1564 in 1987/88) than the long rainy season (1298 in 1987).

The period of occurrence of the stem borer larvae in the four cropping patterns was similar in the four planting seasons but varied with species. C. partellus larvae were present on the plants from two weeks after plant emergence (2WAE) and continued for as long as the plants were in the field. *S. calamistis* appeared between 3WAE to 5WAE and again from the 12WAE through harvest. *B. fusca* was observed on the crop from 5WAE through harvest and some diapausing larvae were found in the dry stems after harvest. *E. saccharina* larvae were on the crop from 8WAE and remained through harvest.

Stem borer larval infestation over the study period was a steady rise in population from the second week after plant emergence through harvest in all the cropping patterns although the rise was at a lower pace in the intercrop patterns compared with the monocrop. Stem borer pupae, pupal cases and exit holes were generally observed on the crop from 6WAE through harvest.

5.3.1 Stem borer population build-up in four sorghum cropping patterns during 1986-88 period

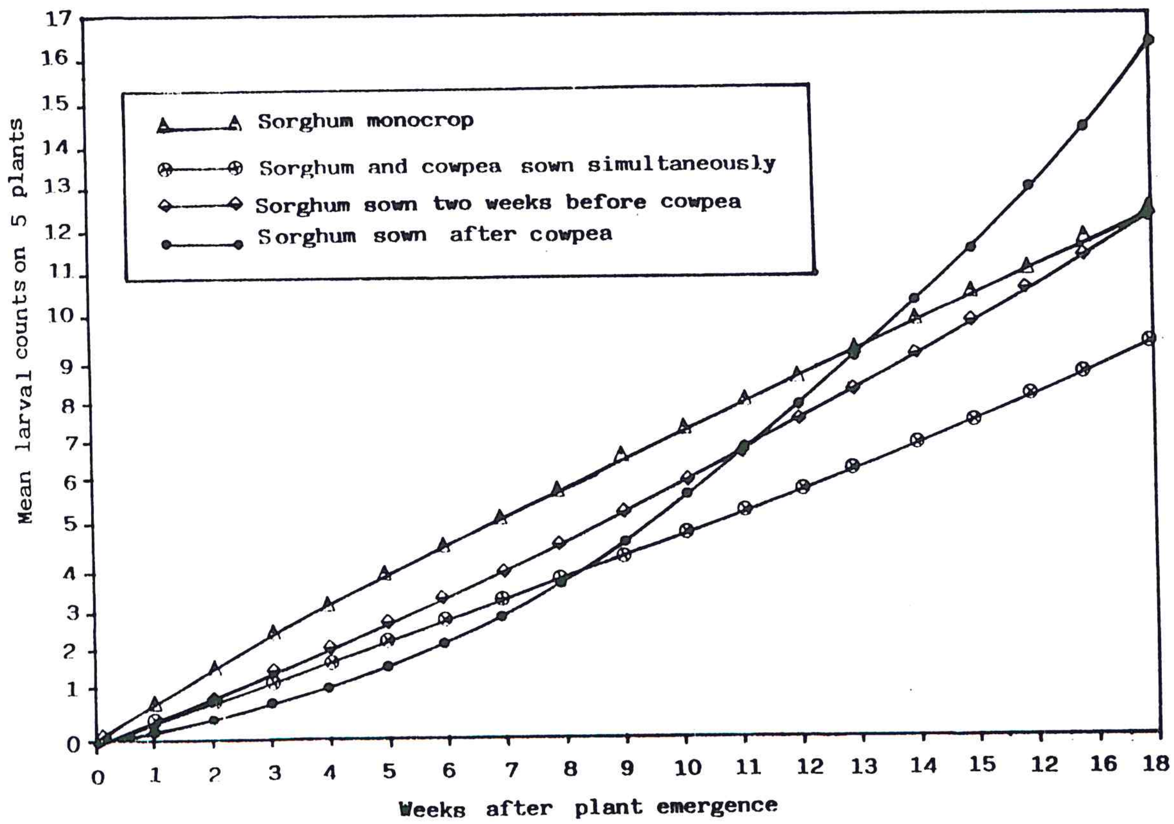
The four major sorghum stem borer species in East Africa i.e. *C. partellus*, *B. fusca*, *E. saccharina* and *S. calamistis* infested sorghum at varying stages of its growth in the two year period. Stem borer population trends during 1986-88 are shown in Figs. 4.1-4.9. The population trends in relation to plant age were described by the equation: Log (Mean larval count/5 plants) = Log

(a) + b.Log (WAE), derived from: Mean count= a $(WAE)^b$, where 'a' is the intercept and 'b' is the slope. Figure 4.1 shows the larval population build-up for all stem borer larvae in the four cropping patterns. Population build-up in sorghum monocrop showed a highly significant (r^2=0.86, P> 0.0001) linear increasing trend. Similarly sorghum sown before and that sown after cowpea followed the sorghum monocrop trend (r^2=0.86, P> 0.0001 and r^2=0.94, P> 0.0001 respectively). Sorghum sown simultaneously with cowpea showed a significant (r^2=0.57, P> 0.0017) linear increase in larval populations but not as highly as the other cropping patterns.

Seasonal trends in the pooled total number of stem borer pupae, pupal cases and exit holes are shown in Figs. 4.2-4.5. The four cropping patterns show a similar increasing trend of pupal, pupal cases and exit hole numbers with the age of sorghum as was observed with the larval stage. However, data for the three parameters was collected earlier (6WAE) on sorghum sown two weeks after cowpea than on the other three cropping patterns. Conversely, there was delay (until the 9WAE) in observing pupae, pupal cases and exit holes on sorghum sown simultaneously with cowpea compared with the other three cropping patterns.

FIGURE 4.1

Effect of sorghum cropping pattern on the general trend of stem borer larval populations during 1986-88 period



Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown after cowpea
Mean larval counts on 5 plants
Weeks after plant emergence
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 12 16 18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

FIGURE 4.2

Weekly mean number of stem borer larvae, pupae, pupal cases and exit holes at MPFS during 1986/87 short rainy season

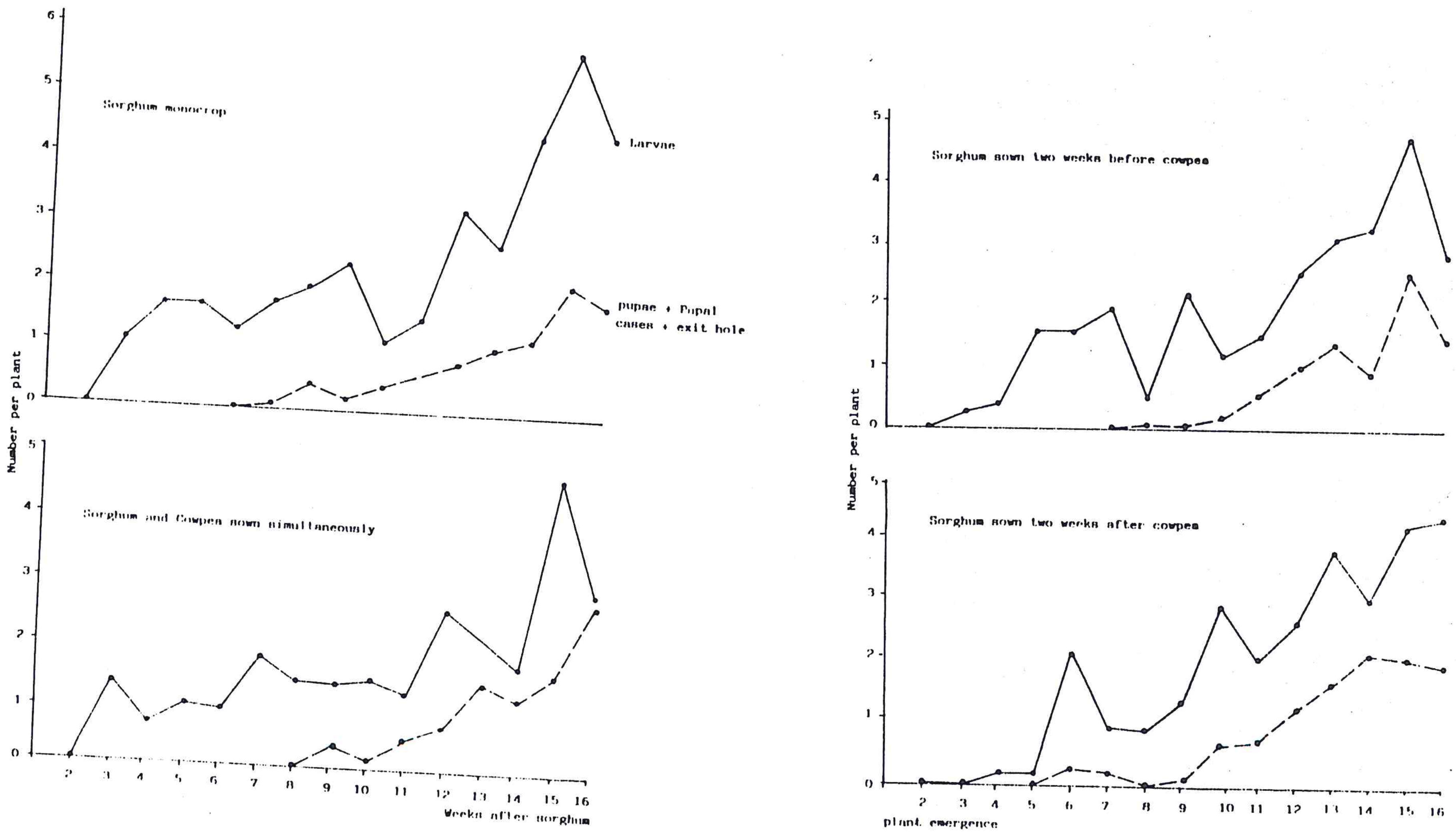

Sorghum monocrop
Larvae
pupae + Pupal
cases + exit hole
Number per plant
Sorghum and Cowpea sown simultaneously
Weeks after sorghum
Sorghum sown two weeks before cowpea
Number per plant
Sorghum sown two weeks after cowpea
plant emergence

FIGURE 4.3

Weekly mean number of stem borer larvae, pupae, pupal cases and exit holes at MPFS during 1987/88 short rainy season

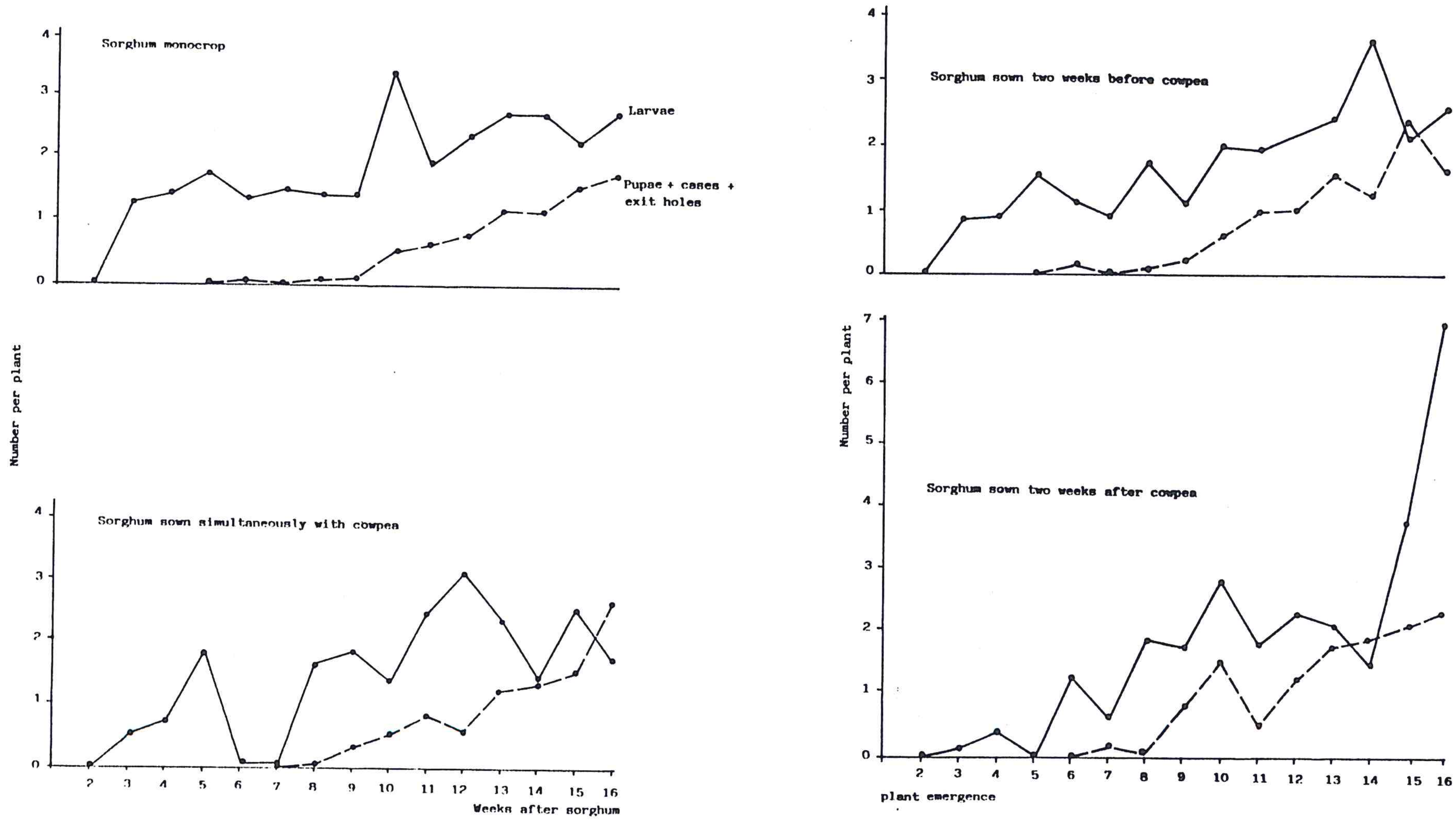
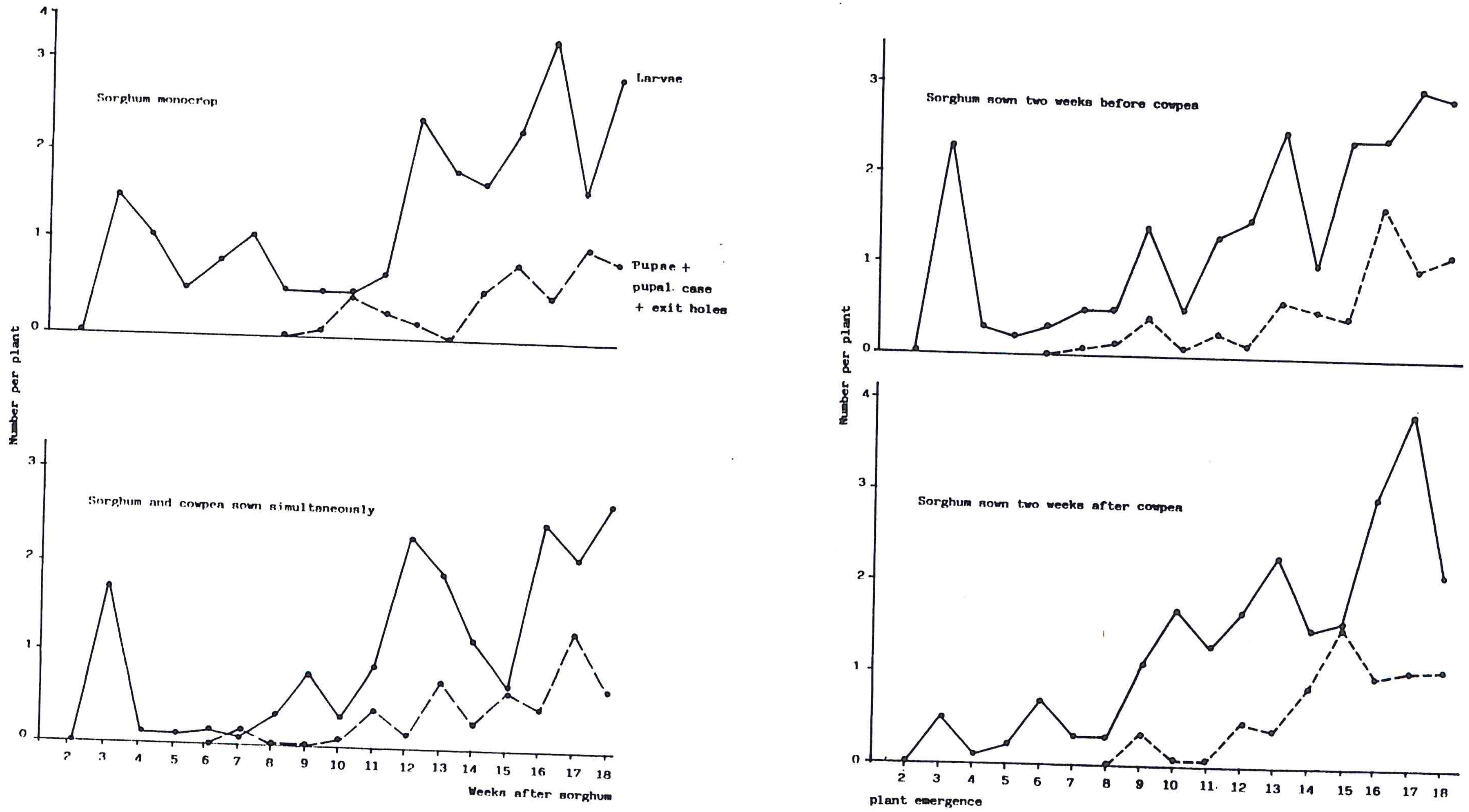

Sorghum monocrop
Larvae
Pupae + cases + exit holes
Sorghum sown two weeks before cowpea
Number per plant
Sorghum sown simultaneously with cowpea
Sorghum sown two weeks after cowpea
Weeks after sorghum
plant emergence
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

FIGURE 4.4

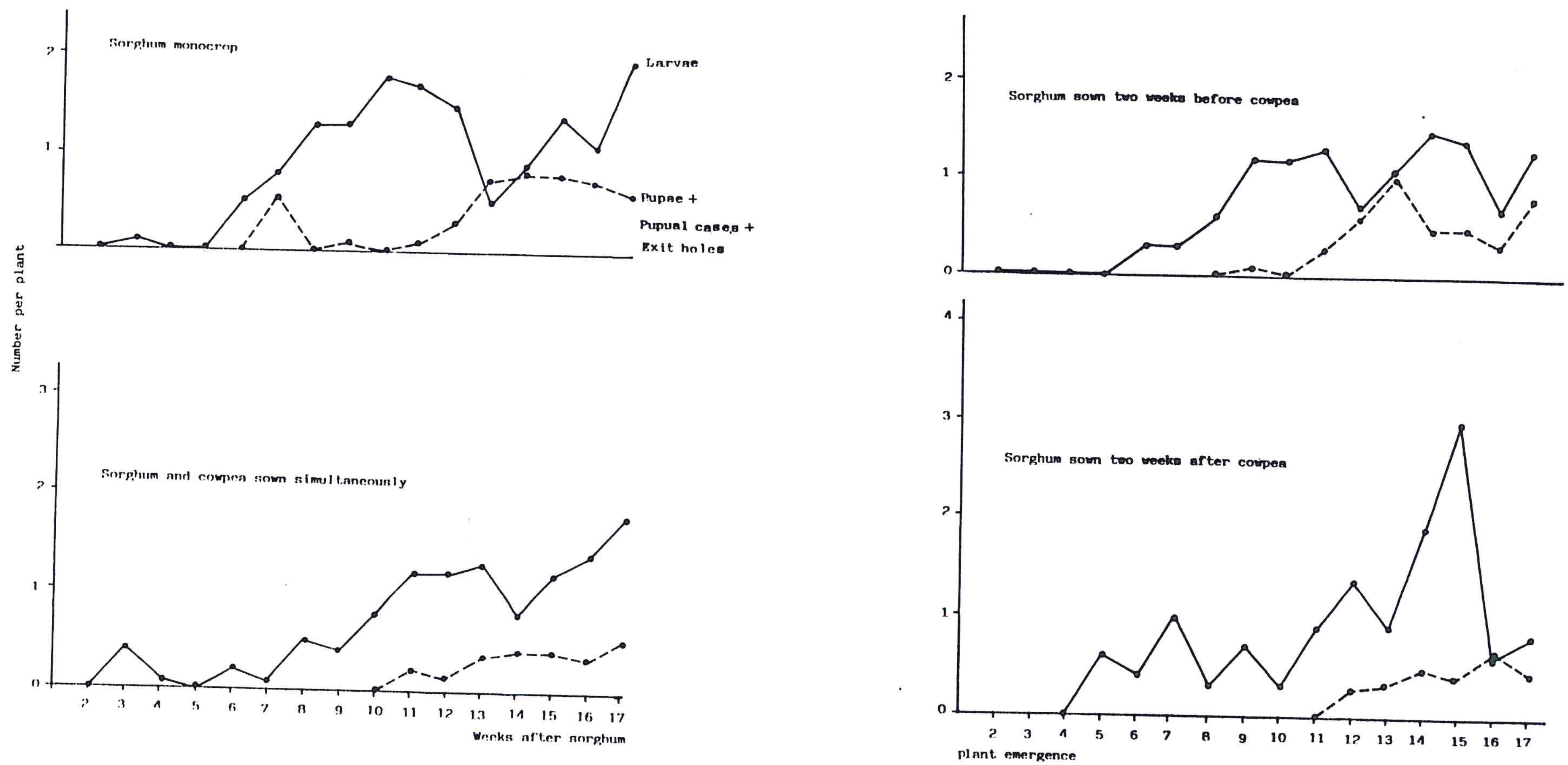
Weekly mean number of stem borer larvae, pupae, pupal cases and exit holes at MPFS during 1987 long rainy season



Sorghum monocrop
Larvae
Pupae +
pupal case
+ exit holes
Number per plant
Sorghum and cowpea sown simultaneously
Weeks after sorghum
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
plant emergence

FIGURE 4.5

Weekly mean number of stem borer larvae, pupae, pupal cases and exit holes on Rusinga during 1987 long rainy season


Number per plant
Sorghum monocrop
Larvae
Pupae +
Pupual cases +
Exit holes
Sorghum and cowpea sown simultaneously
Weeks after sorghum
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
plant emergence

C. partellus larval population build-up trends in 1986-88 are shown in Figure 4.6. In sorghum monocrop there was a gradual population increase from the beginning of the season (3WAE) through harvest. This was not a significant linear increase (r^2=0.29, P> 0.0462). Similarly sorghum sown simultaneously with cowpea showed an insignificant linear population increase in that period (r^2=0.39, P> 0.0168). Sorghum sown before cowpea showed a significant (r^2=0.58, P> 0.0014) linear increase while sorghum sown after cowpea showed a highly significant (r^2=0.79, P> 0.0001) linear increase in *C. partellus* larval populations.

B. fusca larval population trends for 1986-88 are shown in Figure 4.7. The four cropping patterns appear to show highly significant linear population increases (i.e. sorghum monocrop r^2=0.78, P> 0.0001; sorghum sown simultaneously with cowpea r^2=0.73, P> 0.0001; sorghum sown before cowpea r^2=0.81, P> 0.0001 and sorghum sown after cowpea r^2=0.77, P>0.0001).

E. saccharina larval population trends for 1986-88 are shown in Figure 4.8. Sorghum monocrop had a significant (r^2=0.74, P> 0.0006) linear population increase. A similar trend occurred in sorghum sown after cowpea (r^2=0.64, P> 0.0031). Sorghum sown before and that sown simultaneously with cowpea both had insignificant (r^2=0.42, P> 0.0311 and r^2=0.26, P> 0.1057 respectively) linear trends.

S. calamistis larval population trends for 1986-88 are shown in Figure 4.9. Sorghum sown simultaneously with cowpea was the only cropping pattern which showed a significant (r^2=0.62, P> 0.0009) linear population increase. Sorghum monocrop showed a population trend with r^2=0.20, P> 0.1088; sorghum sown before and that sown after cowpea had r^2=0.01, P> 0.7002 and r^2=0.44, P> 0.0095 respectively.

5.3.2 Seasonal trends in stem borer larval populations in 1986-88 period

The four stem borer species infested sorghum in 1986/87 short rainy season. *C. partellus* infested sorghum from two weeks after plant emergence (2WAE) through harvest. *B. fusca* infested the crop from the end of 5WAE, while *E. saccharina* activity was from the 8WAE through harvest. *S. calamistis* was observed from 14WAE through harvest. Stem borer larval population in 1987/88 short rainy season was 10.7% (1564) less than the 1986/87 (1732) population. Larval populations in the two seasons increased with the age of sorghum and in 1987/88 there

FIGURE 4.6

Effect of sorghum cropping pattern on *C. partellus* larval population trend during 1986-88 period.

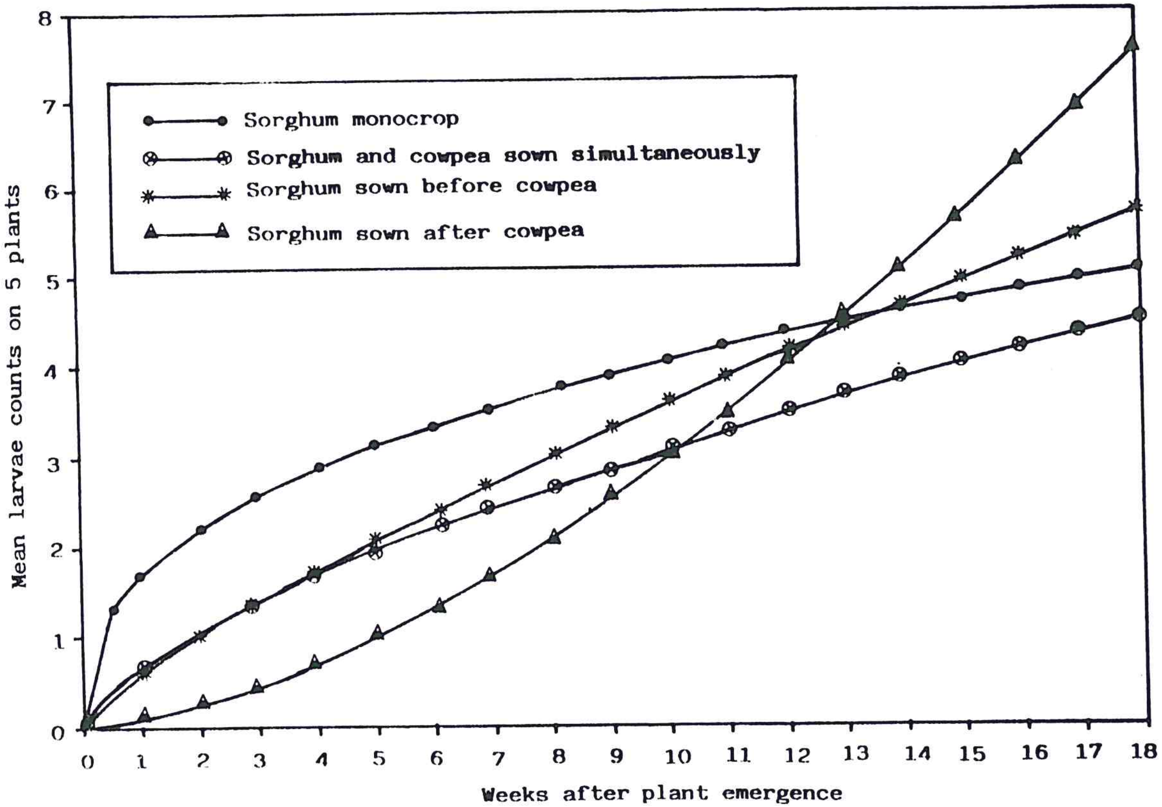
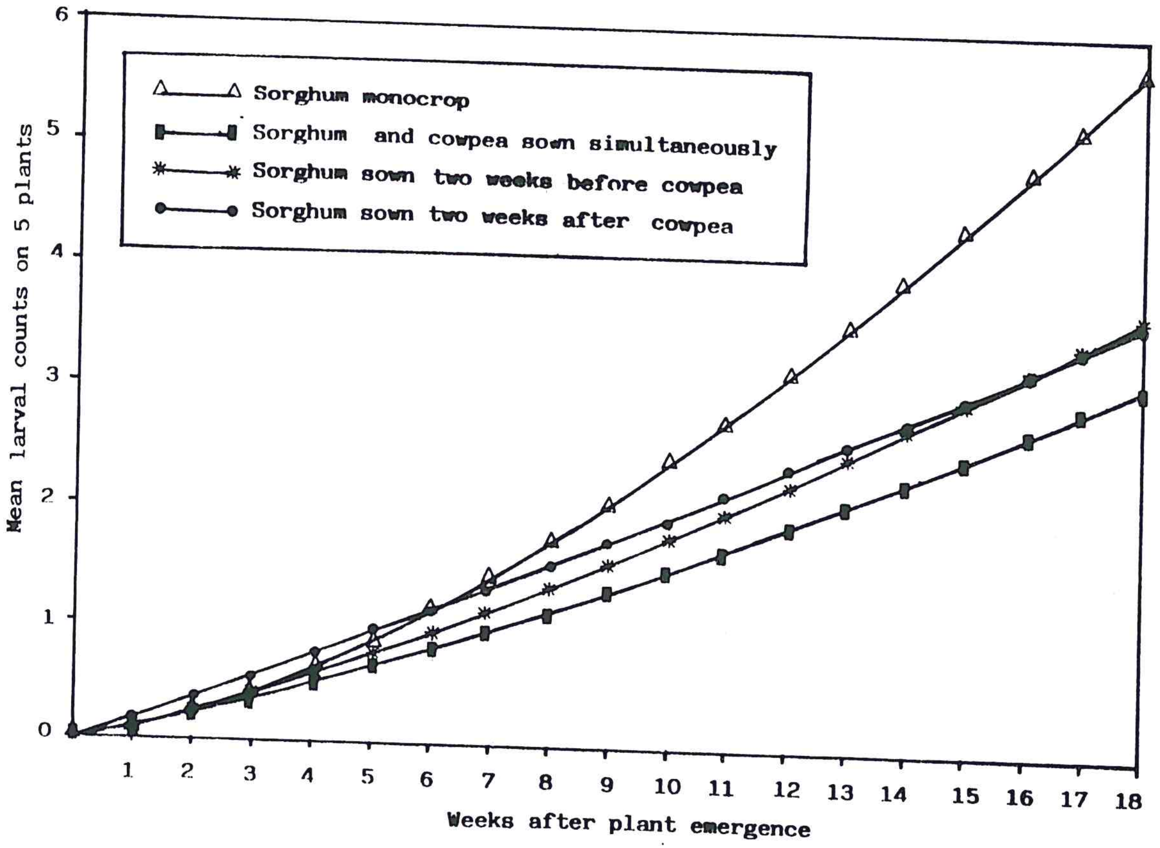

Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown before cowpea
Sorghum sown after cowpea
Mean larvae counts on 5 plants
Weeks after plant emergence
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

FIGURE 4.7

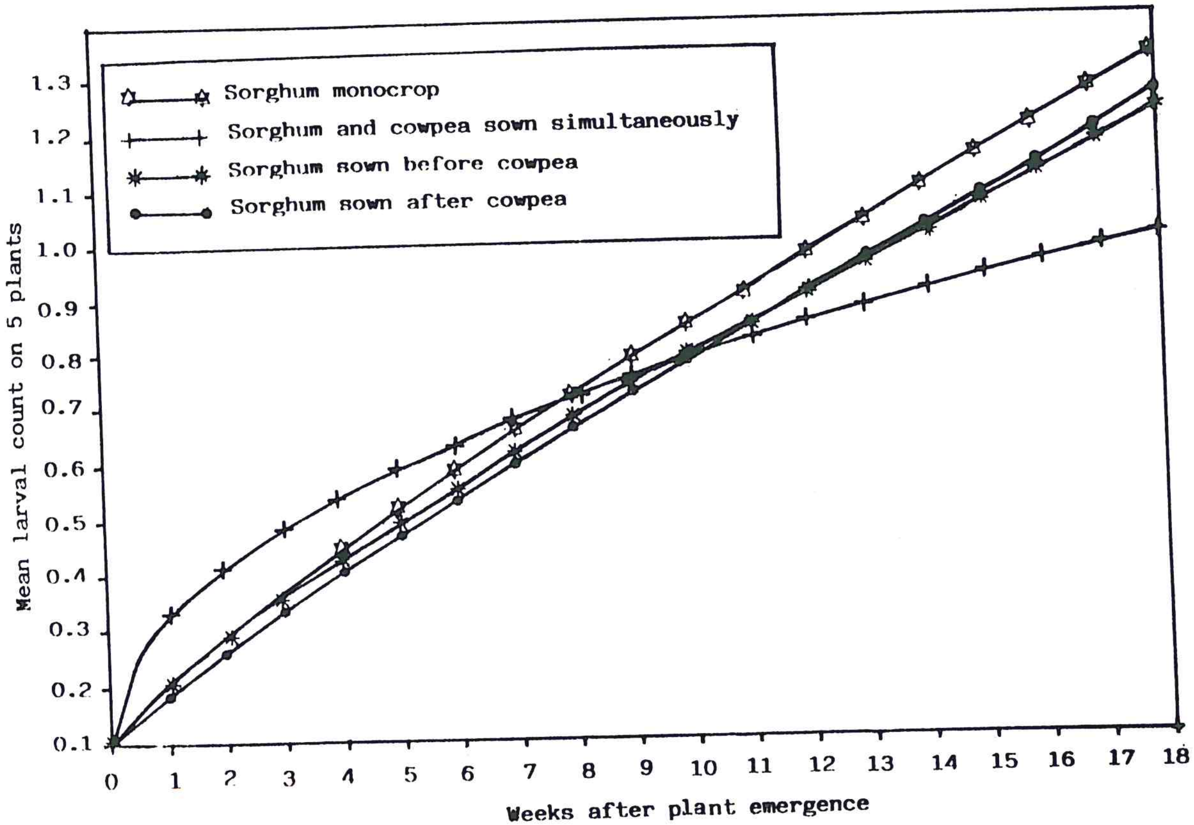
Effect of sorghum cropping pattern on B. fusca larval population trend during 1986-88 period.



Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Mean larval counts on 5 plants
Weeks after plant emergence
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

FIGURE 4.8

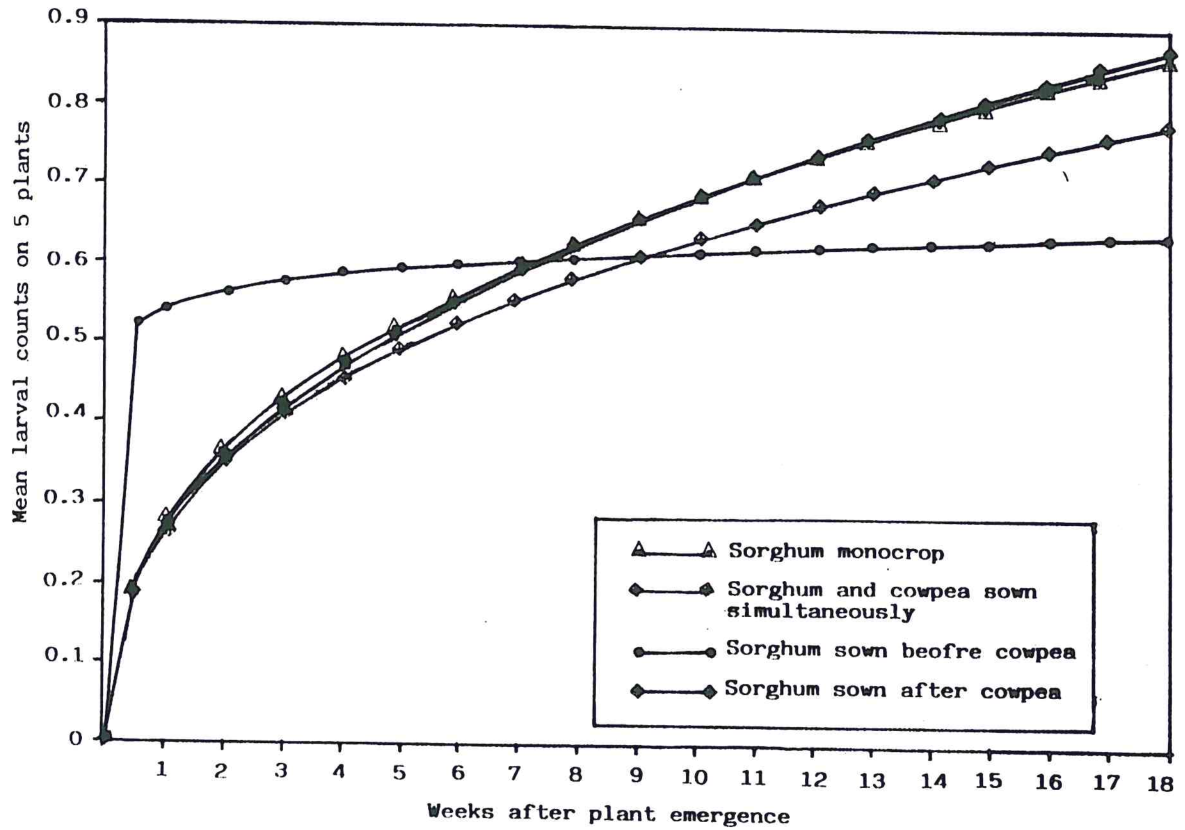
Effect of sorghum cropping pattern on *E. saccharina* larval population trend during 1986-88 period



Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown before cowpea
Sorghum sown after cowpea
Mean larval count on 5 plants
Weeks after plant emergence

FIGURE 4.9

Effect of sorghum cropping pattern on S. calamistis larval population trend during 1986-88 period


Mean larval counts on 5 plants
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Weeks after plant emergence
Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown beofre cowpea
Sorghum sown after cowpea

was an exceptionally sharp increase of borer larval numbers from about 1.5 larvae per plant in the 14WAE to an average of 7 larvae per plant at harvest. Cropping pattern and stem borer larval population trends in each of the three seasons at the two sites are shown in Appendix 1.

The mean number of stem borer larvae in individual seasons for the four cropping patterns are shown in Table 5.1. There were significantly (P=0.05) more larvae on sorghum monocrop than on both sorghum sown simultaneously with cowpea and that sown after cowpea in 1986/87. Sorghum sown before cowpea was similar to the monocrop and the other two intercrops. In 1987/88 monocrop sorghum had a significantly (P=0.05) higher number of larvae than sorghum sown simultaneously with cowpea. The other two intercrops were similar to the monocrop and sorghum sown simultaneously with cowpea.

In 1987 long rainy season the four stem borer species were observed on sorghum. C. partellus infested the crop from 2WAE through harvest and S. calamistis from 3-5WAE as mature larvae and again from 12WAE as first instar larvae. B. fusca infested the crop from 6WAE through harvest both at the station and on Rusinga Island. E. saccharina was observed from 8WAE through harvest. The long rainy season stem borer larval population was significantly (P=0.05) higher on sorghum monocrop than on sorghum sown simultaneously with cowpea (Table 5.1). The other two intercrops were similar and were not significantly different from either the sorghum monocrop or that sown simultaneously with cowpea. Stem borer larval population on Rusinga was higher (though not significantly) on sorghum monocrop than on the three intercrops (Table 5.1). Larval populations at the field station were 42.2% (1298) higher than on Rusinga Island (750) in 1987 long rainy season.

Seasonal trends show that there were significantly (P=0.05) more stem borer larvae in each of the two short rainy seasons than the long rainy season at the field station and on Rusinga Island (Table 5.1).

5.3.3 C. partellus larval population trends in 1986-88

The mean number of C. partellus larvae for the two year period is shown in Table 5.2. Sorghum monocrop had a significantly (P=0.05) higher C. partellus larval population than both sorghum sown simultaneously with and that sown after cowpea. Sorghum sown before cowpea was not significantly different from the monocrop or that sown simultaneously with cowpea. Seasonal borer species

Table 5.1 Effect of sorghum cropping pattern on stem borer larval population during 1986-88 planting seasons (mean* on 5 plants in three replicates)

Cropping pattern	Short rain seasons at MPFS		Long rain season 1987		
	1986/87	1987/88	MPFS	Rusinga	Mean ± S.E.
Sorghum monocrop	3.4^{a}	3.3^{a}	2.7^{a}	2.3^{a}	2.9 ± 0.3^{a}
Sorghum and cowpea sown simultaneously	2.9^{b}	2.7^{b}	2.3^{b}	2.1^{a}	2.5 ± 0.2^{c}
Sorghum sown 14 days before cowpea	3.0^{ab}	3.1^{ab}	2.6^{ab}	2.0^{a}	2.7 ± 0.2^{b}
Sorghum sown 14 days after cowpea	2.8^{b}	2.9^{ab}	2.5^{ab}	2.1^{a}	2.6 ± 0.2^{bc}
Mean ± S.E.	3.0 ± 0.1^{a}	3.0 ± 0.1^{a}	2.5 ± 0.1^{b}	2.1 ± 0.1^{c}	

* Data transformed to $\sqrt{x + 0.5}$ for analysis of variance and means retransformed after analysis.

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

composition show that C. partellus accounted for 63.3%, 67.3% and 66.8% of the total stem borer larvae in 1986/87, 1987 and 1987/88 seasons respectively, at the field station. On Rusinga it accounted for 49.7%.

Seasonal population means show that there were significantly (P=0.05) more C. partellus larvae on sorghum monocrop than on the three intercrops in 1986/87 (Table 5.2). Larval populations in the three intercrops were similar. In 1987/88 monocrop sorghum had a significantly (P=0.05) higher larval population than sorghum sown simultaneously with cowpea (Table 5.2). The other two intercrops had similar populations and were not significantly different from either the monocrop or sorghum sown simultaneously with cowpea. In 1987 long rainy season the four cropping patterns were similar both at the field station and on Rusinga Island. The two short rainy seasons had similar C. partellus larval populations which were significantly (P=0.05) higher than the 1987 long rainy seasons at the two sites (Table 5.2).

5.3.4 B. fusca, E. saccharina and S. calamistis larval populations in 1986-88 period.

The pooled larval populations for the three stem borer species in 1986-88 period are shown in Table 5.3.

Table 5.2 Effect of sorghum cropping pattern on *C. partellus* larval population during 1986-88 planting seasons (mean* on 5 plants in three replicates)

Cropping pattern	Short rain seasons at MPFS		Long rain season 1987		
	1986/87	1987/88	MPFS	Rusinga	Mean ± S.E.
Sorghum monocrop	2.9[a]	2.7[a]	2.3[a]	1.7[a]	2.4±0.3[a]
Sorghum and cowpea sown simultaneously	2.5[b]	2.3[b]	2.0[a]	1.6[a]	2.2±0.2[bc]
Sorghum sown 14 days before cowpea	2.5[b]	2.6[ab]	2.3[a]	1.6[a]	2.3±0.2[ab]
Sorghum sown 14 days after cowpea	2.3[b]	2.4[ab]	2.1[a]	1.6[a]	2.1±0.2[c]
Mean ± S.E.	2.6±0.1[a]	2.5±0.1[a]	2.2±0.1[b]	1.6±0.0[c]	

* Data transformed to $\sqrt{x + 0.5}$ for analysis of variance and means retransformed after analysis

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Sorghum monocrop and that sown after cowpea had similar larval populations which were significantly (P=0.05) higher than those in the other two intercrops. Similarly the two intercrops were not significantly different from each other (Table 5.3)

Seasonal trends show that in 1986/87 short rainy season the four cropping patterns had similar larval populations while in 1987/88 sorghum monocrop was similar to that sown after cowpea and both had significantly (P=0.05) higher larval numbers than sorghum sown simultaneously with cowpea (Table 5.3). Sorghum sown before cowpea was not significantly different from either the sorghum monocrop or that sown simultaneously with cowpea. In 1987 long rainy season sorghum monocrop and that sown after cowpea were similar and both had significantly (P=0.05) higher borer larvae than the other two intercrops at both sites (Table 5.3). The 1987 long rainy season at the field station had significantly (P=0.05) lower larval population than both populations on Rusinga and at the field station in the two short rainy seasons (Table 5.3). The mean stem borer larval populations for the four cropping patterns in the four seasons are shown in Table 5.4, while the seasonal means are shown in Table 5.5.

5.3.5 Stem borer pupae, pupal cases and exit holes in four sorghum cropping patterns in 1986-88

The mean number of stem borer pupae, pupal cases and exit holes observed in the four cropping patterns in 1986-88 period are shown Tables 5.6-5.8. There were no significant differences in stem borer pupal populations observed in the four cropping patterns in 1986-88 period (Table 5.6). Pupal populations in individual seasons show that in 1986/87 sorghum sown before cowpea had a significantly (P=0.05) higher number of pupae than sorghum sown after cowpea. These two intercrops were not significantly different from either the sorghum monocrop or that sown simultaneously with cowpea. In 1987/88 sorghum sown before cowpea had a significantly (P=0.05) higher number of pupae than sorghum sown simultaneously with cowpea and the two were not significantly different from either the sorghum monocrop or that sown after cowpea. Pupal populations in the different cropping patterns were not significantly different at the two sites in 1987 long rainy season. Seasonal means show that the two short rainy seasons were similar and had significantly (P=0.05) higher stem borer pupal populations than 1987 long rainy season at both sites. In addition, pupal population on Rusinga was significantly (P=0.05) lower than that observed at the

Table 5.3 Effect of sorghum cropping pattern on *B. fusca*, *E. saccharina* and *S calamistis* pooled larval population during 1986-88 planting seasons (mean* on 5 plants in three replicates)

Cropping pattern	Short rain seasons at MPFS		Long rain season 1987		
	1986/87	1987/88	MPFS	Rusinga	Mean ± S.E.
Sorghum monocrop	0.5^{a}	0.6^{a}	0.4^{a}	0.6^{a}	0.5 ± 0.0^{a}
Sorghum and cowpea sown simultaneously	0.4^{a}	0.4^{b}	0.3^{b}	0.4^{b}	0.4 ± 0.0^{b}
Sorghum sown two weeks before cowpea	0.5^{a}	0.5^{ab}	0.4^{b}	0.4^{b}	0.4 ± 0.0^{b}
Sorghum sown two weeks after cowpea	0.5^{a}	0.6^{a}	0.5^{a}	0.5^{a}	0.5 ± 0.0^{a}
Mean ± S.E.	0.5 ± 0.0^{a}	0.5 ± 0.0^{a}	0.4 ± 0.0^{b}	0.5 ± 0.0^{a}	

* Data transformed to $\sqrt{x + 0.5}$ for analysis and means retransformed after analysis.

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Table 5.4 Effect of sorghum cropping pattern on stem borer larval abundance during 1986-88 period (Mean ± S.E. per 5 plants in three replicates)

Cropping pattern	All stem borer larvae	*C. partellus* larvae	Others*
Sorghum monocrop	2.9 ± 0.3^{a}	2.4 ± 0.3^{a}	0.5 ± 0.1^{a}
Sorghum and cowpea sown simulataneously	2.5 ± 0.2^{c}	2.2 ± 0.2^{bc}	0.3 ± 0.1^{b}
Sorghum sown two weeks before cowpea	2.7 ± 0.2^{b}	2.3 ± 0.2^{ab}	0.4 ± 0.1^{b}
Sorghum sown two weeks after cowpea	2.6 ± 0.2^{bc}	2.1 ± 0.2^{bc}	0.5 ± 0.1^{a}

* Pooled mean for *B. fusca*, *E. saccharina* and *S. calamistis*

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Table 5.5 Seasonal mean number of stem borer larvae in four sorghum cropping patterns during 1986-88 period (Mean $\pm$ S.E. per five plants in three replicates)

Planting season	All stem borer larvae	*C. partellus* larvae	Others *
1986/87 short rain season at MPFS	3.0 ± 0.1^{a}	2.5 ± 0.1^{a}	0.5 ± 0.1^{a}
1987/88 short rain season at MPFS	3.0 ± 0.1^{a}	2.5 ± 0.1^{a}	0.5 ± 0.1^{a}
1987 long rain season at MPFS	2.6 ± 0.1^{b}	2.2 ± 0.1^{b}	0.4 ± 0.1^{a}
1987 long rain season on Rusinga	2.1 ± 0.1^{c}	$1.6 + 0.1^{c}$	0.5 ± 0.1^{a}

* Pooled mean for *B. fusca*, *E. saccharina* and *S. calamistis*.

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

field station (Table 5.6).

The mean number of stem borer pupal cases observed in the four cropping patterns in 1986-88 are shown in Table 5.7. There were no significant differences between the four cropping patterns in the two year period. Individual seasons show that there were no significant differences between the cropping patterns in the two short rainy seasons and the long rainy season at the field station. However, sorghum sown before cowpea at Rusinga had a significantly (P=0.05) lower number of pupal cases than both sorghum sown simultaneously with cowpea and that sown after cowpea. Sorghum monocrop was not significantly different from the three intercrops. The two short rainy seasons had significantly (P=0.05) more pupal cases than the long rainy season at both sites. Furthermore, the number of pupal cases at the field station in 1987 was significantly (P=0.05) higher than on Rusinga Island (Table 5.7).

The mean number of exit holes in the four cropping patterns for 1986-88 are shown in Table 5.8. Sorghum sown before cowpea had a significantly (P=0.05) higher number of exit holes than the other three cropping patterns which were similar. Similarly, sorghum sown before cowpea had significantly (P=0.05) more exit holes

Table 5.6 Effect of sorghum cropping pattern on stem borer pupae during 1986-88 planting seasons (mean per 5 plants in three replicates).

Cropping pattern	Short rain seasons at MPFS		Long rain season 1987		
	1986/87	1987/88	MPFS	Rusinga	Mean $\pm$ S.E.
Sorghum monocrop	0.7^{ab}	1.0^{ab}	0.7^{a}	0.2^{a}	0.8 ± 0.2^{a}
Sorghum and cowpea sown simultaneously	0.9^{ab}	0.7^{b}	0.4^{a}	0.2^{a}	0.6 ± 0.2^{a}
Sorghum sown two weeks before cowpea	1.1^{a}	1.6^{a}	0.4^{a}	0.2^{a}	0.8 ± 0.3^{a}
Sorghum sown two weeks after cowpea	0.6^{b}	1.3^{ab}	0.8^{a}	0.2^{a}	0.7 ± 0.2^{a}
Mean $\pm$ S.E.	0.8 ± 0.1^{ab}	1.2 ± 0.2^{ab}	0.6 ± 0.1^{b}	0.2 ± 0.0^{c}	

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05); Duncan's [1955] multiple range test.

Table 5.7 Effect of sorghum cropping pattern on stem borer pupal cases during 1986-88 planting seasons (mean per 5 plants in three replicates).

Cropping pattern	Short rain seasons at MPFS		Long rain season 1987		
	1986/87	1987/88	MPFS	Rusinga	Mean ± S.E.
Sorghum monocrop	2.3[a]	2.3[a]	0.6[a]	0.3[ab]	1.4 ± 0.5[a]
Sorghum and cowpea sown simultaneously	2.1[a]	2.0[a]	0.8[a]	0.5[a]	1.3 ± 0.4[a]
Sorghum sown two weeks before cowpea	2.6[a]	2.6[a]	0.8[a]	0.1[b]	1.5 ± 0.6[a]
Sorghum sown two weeks after cowpea	2.3[a]	2.2[a]	0.8[a]	0.6[a]	1.5 ± 0.4[a]
Mean ± S.E.	2.3±0.1[a]	2.3±0.1[a]	0.7±0.1[b]	0.4±0.1[c]	

Cropping pattern means within a column and season means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

than the other cropping patterns in the two short rainy seasons and in 1987 long rainy season at the field station. Sorghum sown simultaneously with cowpea had a significantly (P=0.05) of stem borer exit holes than sorghum monocrop in 1987 long rainy season in Rusinga. The other two intercrops were similar and were not significantly different from either the sorghum monocrop or that sown simultaneously with cowpea. There were no significant differences in the number of borer exit holes observed in the three seasons (Table 5.8).

5.4 DISCUSSION

Stem borer larval populations were higher at the field station than on farmer's field in Rusinga Island. The higher population at the field station could be explained by the continuous cropping even during the dry season making use of irrigation facilities, thus providing an uninterrupted supply of suitable food for the stem borers throughout the year. Increasing the frequency of sorghum cropping at the field station increased the chances of survival for the pests; and by irrigation, fertilizer application and timely weed control the plants become healthier and therefore supplies good quality food for the pests. In the farmer's field there is only one cropping season per

Table 5.8 Effect of sorghum cropping pattern on stem borer exit holes during 1986-88 planting seasons (mean per 5 plants in three replicates).

Cropping pattern	Short rain seasons at MPFS		Long rain season 1987		
	1986/87	1987/88	MPFS	Rusinga	Mean ± S.E.
Sorghum monocrop	0.4[b]	0.4[b]	0.7[b]	0.4[b]	0.5 ± 0.1[b]
Sorghum and cowpea sown simultaneously	0.6[b]	0.6[b]	0.5[b]	1.3[a]	0.8 ± 0.2[b]
Sorghum sown two weeks before cowpea	5.2[a]	5.1[a]	3.2[a]	0.7[ab]	3.6 ± 1.1[a]
Sorghum sown two weeks after cowpea	0.6[b]	0.6[b]	0.9[b]	1.0[ab]	0.8 ± 0.1[b]
Mean ± S.E.	1.7±1.2[a]	1.7±1.2[a]	1.3±0.6[a]	0.9±0.2[a]	

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test.

year. Furthermore, the frequent artificial infestations at the field station are likely to increase the borer populations and the absence of diapause at Mbita as opposed to Mombasa and other places in Kenya (Scheltes, 1978) could explain C. partellus prevalenceat the field station.

The composition of the borer species varied between the field station and the farmer's field which is only about 10 km away, thereby suggesting marked variability in the areas surrounding the shores of Lake Victoria. At the field station there were four stem borer species i.e. C. partellus, B. fusca, E. saccharina and S. calamistis, while in Rusinga Island only C. partellus and B. fusca were observed. There is a patch of sugarcane plants at the field station and this may explain the incidence of E. saccharina in the crop cycle at this site. Ogwaro (1983) also reported B. fusca and C. partellus in Sindo (about 12 km west of the field station) and he related the absence of E. saccharina on farmer's field to the scarcity of its principal host plant sugarcane.

C. partellus accounted for 63-67% of the stem borer larval species complex at the field station in the two year period (1986-88) while in the farmer's field it was in almost equal proportion to *B. fusca*. The predominance of *C. partellus* at the field station could be explained by the frequent releases during artificial infestation experiments but could also suggest that the biology and life cycle of this pest is more closely adapted to the phenology of the crop. The predominance of *C. partellus* larval population at the field station and its almost equal proportion with *B. fusca* on farmer's field were similarly observed by Ogwaro (1983).

The results on stem borer larval populations for 1986-88 showed that sorghum monocrop had a higher population than the intercrops. They also indicated that the intercropping patterns had a profound effect in reducing the larval population of the predominant borer species, *C. partellus*. The response was, however, not uniform for the three intercropping patterns which would support the suggestions by Southwood and Way (1970) and Way (1971) that the right kind of diversity is fundamental to pest control in different situations.

Sorghum monocrop had a significantly higher stem borer larval population than the three intercrops. Sorghum sown simultaneously with cowpea had the lowest stem borer larval population compared with the other intercrops but it was not significantly different from sorghum sown after cowpea. The low larval population in the intercrops could have been due to the low C. partellus egg population and larval establishment observed in Chapters 4 and 6 respectively, and the high stem borer larval mortality observed in Chapter 8.

Interestingly all four stem borer species were found cohabiting in the same host plant at the same time particularly towards harvest. The sequence of colonising the crop was C. partellus from 2WAE, S. calamistis from 3-5WAE and from 12WAE, followed by B. fusca from 5WAE and finally E. saccharina from 8WAE. All larval instars stages of the borers were found on the crop after initial infestation through harvest indicating that there was continuous oviposition from the time the borers infested the crop to the end of the cropping season. S. calamistis appeared as first instar larvae at the end of 1986/87 short rainy season (14WAE) but during 1987 long rainy season it was observed on volunteer sorghum tillers and planted seedlings (3-5WAE) as mature larvae and later (12WAE) as young larvae, suggesting that the short rainy season population survived on volunteer sorghum tillers to infest the newly planted crop in the succeeding long rainy season as mature larvae.

Girling (1978) reported that the four stem borer species were found in the same host plant without interspecific competition and he attributed this to the fact that they occupied different ecological niches. He observed that B. fusca and S. calamistis prefered sorghum and maize of medium age (after 4WAE) and that the population of S. calamistis reached a peak when B. fusca population was declining. C. partellus on the other hand was found on sorghum at all stages of plant growth although it had some preference for mature sorghum. E. saccharina was found to prefer mature sugarcane, sorghum or maize. Similar late E. saccharina infestations on maize cultivars have also been reported at Mbita (Ampofo, 1986).

The higher stem borer larval populations in the short rainy seasons compared with the long rainy season could be due to high build-ups from previous rainy seasons. In addition, the early season mortality due to diseases in the long rainy season is not so intensive in the short rainy season and also the other natural enemies do not seem to have established fully in the short rains. Furthermore, the short rainy season crop at the field station acts as an isolated patch of healthy plants in dry surroundings. Thus the borer population surviving on crop volunteers and wild hosts around the field station have fewer cultivated plants to infest during the short rainy season than in the long rainy season when every farmer cultivate cereals.

Similar observations of high borer populations in the short rainy season compared with the long rainy season have been reported by earlier workers here at ICIPE and elsewhere in Eastern Africa in general (Coaker, 1956; Ingram, 1958; Mathez, 1972; Amoako-Atta et al., 1983; Omolo and Seshu Reddy, 1985). Several theories were advanced for this observation. Coaker (1956) reported that crops grown under adequate rainfall were apparently unaffected by stem borer attacks. Ingram (1958) stated that second season crops were exposed to a population of borers that had built up considerably at the previous season and were therefore severely attacked. Mathez (1972) suggested that lower stem borer larval populations in the long rain season was a result of high larval mortality during the rains which he associated mainly with unidentified fungal and bacterial diseases. These results emphasize the need to set up experiments covering both short and long rain seasons as far as possible in order to get reasonably conclusive comparisons of stem borer populations in a particular location.

The lower stem borer larval population in the 1987/88 season compared with that of 1986/87 season may have been due to a slightly heavier and more evenly distributed rainfall in 1987/88. This may have resulted in higher mortality of the young first generation larvae prior to their establishment on the sorghum plants as well the significantly higher larval mortality observed on the older larvae in Chapter 8. The increase in larval infestation from 14WAE on sorghum sown two weeks after cowpea in 1987/88 season could be explained by possible migration of young larvae from the relatively older plants in the surrounding areas or those arising from oviposition by earlier generations of the pest. This suggestion is based on the observations made in Chapter 6 on *C. partellus* larval establishment on neighbouring sorghum plants. The late planted sorghum therefore provided a continuous supply of a relatively better quality food for the larvae. This would support the temporal diversity aspect put forward by Perrin (1980) that plants of the same species planted in adjacent plots, but at different time intervals could provide the pest with some nutritionally better food due to the staggered maturity periods.

There was an earlier (at the 6WAE) observation of pupae, pupal cases and exit holes in sorghum sown after cowpea compared with sorghum in the other three cropping patterns. This could have been the result of later larval instars' migration from the nearby older plants. It is likely that the late planted sorghum crop was able to support some of the early larval stages from earlier generations of the pest. Such migrations could have been through wind dispersal as reported by Van Hamburg (1980).

Pupal populations showed small variations in the four cropping patterns although sorghum sown simultaneously with cowpea showed a lower (but not significantly) population mean for 1986-88. This low population could be related to the low larval population observed above and in Chapter 6. Pupal populations in the long rainy season were lower (significantly at Rusinga) than in the two short rainy seasons. The lower larval populations observed above in the long rainy season at both sites compared with the short rainy seasons could explain the low pupal populations. Similar trends were observed on stem borer pupal cases for the two year period suggesting that pupal case numbers were related to the pupal population.

The number of exit holes were significantly higher on sorghum sown before cowpea than the other cropping patterns. This could reflect that larval survival to maturity was high in that cropping pattern but the resulting pupae and pupal cases were not as high. In addition, there is some evidence from larval establishment (Chapter 6) and larval mortality (Chapter 8) to support the high number of exit holes. Furthermore, the exit holes could possibly have been from B. fusca in diapause towards harvest, which could have disappeared due to such factors as predation. In that case there would not be pupae or pupal cases to reflect larval populations.

Planting sorghum and cowpea simultaneously in an intercrop resulted in significantly lower stem borer population compared with that on the sorghum monocrop. This cropping pattern appears to have suppressed larval population build-up during the vegetative growth stage of sorghum (0-8WAE) when the plants are susceptible to damage. Planting sorghum after cowpea seemed to protect the sorghum plant from infestation until 5WAE. Thus the sorghum would escape the first larval population peak (2-5WAE). In contrast subsequent population build-up does not seem to affect plant growth severely because the plants are well established by that time. This cropping pattern delayed both stem borer colonisation and its population build-up, but seemed to provide suitable food sources for the borers towards the end of the season.

This observation is evident from the abrupt increases in borer populations just before the relatively older plants were harvested (Fig. 4.3). Planting sorghum before cowpea seemed to have some borer population regulation from the middle of the first larval population peak (4WAE) but the effect was not as high as in the other two intercrop patterns. The intercropping patterns used in this study therefore demonstrated their potential in delaying borer colonisation and build-up which resulted in lower leaf damage and stem tunnelled length particularly in sorghum sown simultaneously with cowpea and that sown after cowpea, observations which are further substantiated in Chapter 6.

CHAPTER 6

TITLE *C. PARTELLUS* LARVAL ESTABLISHMENT AND DAMAGE ON SORGHUM INTERCROPPED WITH COWPEA

6.1 INTRODUCTION

When potential pests have succeeded in colonising the crop, appropriate intercropping may limit their development or survival rates and thus, minimise the likelihood that their populations will exceed an economic threshold of damage. Movement of both soil-living and aerially-borne pests may be impeded where host and non-host grow together, particularly where there is wider spacing than normal to accommodate an intercrop (Perrin and Phillips, 1978). Trenbath (1976) regards the main process by which pest problems are reduced in mixed culture as (a) the loss of dispersing individuals through their settling on non-host components (the "fly-paper effect") and (b) the compensatory growth by unattacked components which strengthens the fly-paper effect. The former is likely to operate where the dispersal phase of a pest's life cycle involves passive transportation or random, undirected movement, such that the number of individuals contacting non-host depends on the relative abundance of the exposed surface.

The primary movement of a newly hatched *C. partellus* larva is from oviposition site to the whorl where they feed (Bernays *et al*., 1985). The dispersal behaviour of *C. partellus* larvae in the field has been reported by Ingram (1958), Roome (1980), Van Hamburg (1980), Bernays *et al*. (1983, 1985), and Chapman *et al*. (1983).

Sorghum plant damage starts as the young larva makes its way up the funnel of the plant, mining the leaf sheath and tunnelling inside the midrib for several days while making characteristic holes on the leaf blade (Swaine, 1957). Subsequently it bores down inside the funnel of the plant or it may leave this plant and migrate down the stem, before entering it, just above an internode, and proceed tunnelling the stem. In older sorghum plants, the whole larval life may be spent in the developing head (Ingram, 1958).

Estimates of losses due to borer damage vary greatly from cultivar to cultivar, place to place and from season to season. Such losses are also difficult to assess precisely because of the number of borer species, the various types of damage, the stages of plant development when attacked and often the associated presence of other insects and micro-organisms (Whitney, 1977). According to Duerden (1953) the ultimate loss in yield is a cumulative effect of a series of separate forms and stages of loss due to the activity of the stem borers.

Reports on sorghum grain losses due to *C. partellus* infestation alone are very few. Starks (1969) observed in Uganda that this borer caused 56% grain loss to sorghum when plants were infested 20 days after emergence. Seshu Reddy (1985) reported grain losses of 75-88% when sorghum plants were infested 10 days after emergence and that severe foliar damage, dead hearts and stem tunnelling were associated with the infestation and subsequent yield losses when plants were infested between 10 and 30 days after emergence. Alghali (1987) observed that sorghum yield components were slightly reduced when infestation occurred 2-4 weeks after germination.

Since most of the work reported on *C. partellus* establishment and borer damage were conducted on monocropped sorghum, the present experiments were designed to study *C. partellus* larval establishment on sorghum in the four cropping patterns and monitor stem borer damage and subsequent grain yield performance.

6.2 MATERIALS AND METHODS

The experimental plants were established as described in Chapter 3 on general materials and methods namely: sorghum monocrop, sorghum and cowpea sown simultaneously, sorghum sown before and after cowpea. *C. partellus* larval establishment studies were carried out between the fourth and ninth week after sorghum plant emergence (4-9WAE). Stem borer damage to sorghum plants was assessed at weekly intervals from the third week after sorghum plant emergence (3WAE) through harvest. Samples of sorghum grain were taken for each cropping pattern for the assessment of yield performance at the end of the cropping seasons.

6.2.1 Studies on *C. partellus* larval establishment

At four weeks after sorghum plant emergence (4WAE) three neighbour plants in a row of one of the inner plot cells were selected for this study. A group of 20 *C. partellus* black head stage eggs from a laboratory culture (on a piece of wax paper) were securely glued near the midrib on the lower surface of the third leaf of each of the two outer sorghum plants in the group of three so that a plant without eggs separated the two with eggs. Five days before and every other day after the introduction of the eggs, the sorghum plants in the infested row of the cell together with those immediately opposite them in the two neighbouring rows, were inspected for C. partellus natural population eggs which were then destroyed if found. Two days after infestation the eggs on the wax paper were carefully checked for hatchability. Ten days after infestation five sorghum plants, the infested two and their immediate neighbours on the same row were uprooted. The plants were dissected and the number of larvae found in them recorded separately for the infested and neighbouring plants. Larvae arising from field populations were easily distinguishable from the introduced larvae because the date of infestation was known.

The infestations were repeated on a new row of sorghum plants in the same cell at the 6 and 8WAE. In the 6WAE the eggs were fixed near the midrib on the lower surface of the fourth leaf while at the 8WAE they were glued near the midrib at one third distance from the stem on the upper surface of the sixth leaf. The position for gluing the eggs was according to previous natural population observations during this study in the same location.

6.2.2 Stem borer damage and grain yield assessment in sorghum plants

Damage assessment was carried out by weekly destructive samplings in each treatment starting three weeks after sorghum plant emergence (3WAE) through harvest. Five sorghum plants per cell in each treatment plot were selected at random and uprooted. Uprooting was only done before stem elongation (5WAE), thereafter the main stem in a sampling hill was cut at soil surface level. A new cell was sampled every week. Stem borer damage to sorghum plants was assessed by comparing the damage of plant leaves being sampled with a standardized chart of 1-9 scale adopted from Guthrie et al. (1960):

class 1: no visible damage

class 2: a small amount of short-hole type lesions on a few plant parts

class 3: short-hole injury common on several plants parts

class 4 several plants and areas with short-holes and elongated lesions

class 5 several plant parts with elongated lesions (smaller than 2.5cm)

class 6 several plant parts with elongated lesions (larger than 2.5cm)

class 7: long lesions common on about one half of the plant parts

class 8: long lesions common on about two thirds of the plants

class 9: most of the plant parts with long lesions-the plant is (almost) destroyed.

Each plant was assessed individually and the mean score for the plot was determined from these figures.

Stem length tunnelled was obtained by stripping off all leaves from individual sorghum plants and taking the total length of the stem including the sorghum head portion. The stem was then split open and the portion(s) which had been tunnelled by the borers was measured. The percentage of stem length tunnelled for every plant was determined from the two measurements. The mean of five plants from each plot was calculated from these measurements and the data was subjected to analysis of variance to compare damage among the cropping patterns.

Grain yields were assessed at the end of each planting season. This was done by taking the sorghum heads from plants in the plot cells which had initially been earmarked for yield assessment. Each replicate yield was kept separately. After drying, the replicate sorghum heads were carefully threshed, winnowed and the clean grain was weighed at about 14% moisture content.

Replicate yield figures for each of the four treatments were subjected to analysis of variance to compare cropping pattern yields.

6.3 RESULTS

On the basis of the observations reported below, high losses of newly hatched C. partellus larvae occurred in intercrops. Larval establishment was higher on sorghum monocrop than sorghum intercrops. Leaf damage was low (class 2 and 3) and appeared uniform in the four cropping patterns. Small variations also occurred in stem tunnelled length. Similarly there were slight variations in sorghum grain yields except in late planted sorghum where the crop was adversely affected by weather during 1987 long rainy season.

6.3.1 C. partellus larval establishment and loss in four cropping patterns at three dates of infestation

The mean percentage C. partellus larval establishment and loss at three dates of infestation are shown in Table 6.1. Sorghum monocrop had a significantly (P=0.05) higher percentage larval recovery on infested than on neighbouring plants as well as larval loss.

Sorghum sown simultaneously with cowpea had a significantly (P=0.05) higher percentage of larval loss than recovery on infested and neighbouring plants. In addition, larval recovery on infested plants was significantly higher than that on the neighbouring plants. In sorghum sown before cowpea larval recovery on infested plants was statistically similar to larval loss and the two were significantly (P=0.05) higher than larval recovery on neighbouring plants. Sorghum sown after cowpea had a significantly (P=0.05) higher loss than establishment on either the infested or neighbouring plants. Furthermore, larval establishment on infested plants was significantly (P=0.05) higher than that on neighbouring plants.

Larval establishment and loss in the four cropping patterns at the three dates of infestation are shown in Table 6.2. Larval establishment on infested plants in sorghum monocrop in the 6 and 8WAE was significantly (P=0.05) higher than in the 4WAE. Larval establishment on neighbouring plants in this cropping pattern was significantly (P=0.05) higher in the 6WAE than 8WAE but, the establishment in the 4WAE was statistically similar to the 6 and 8WAE. Larval loss in sorghum monocrop was significantly higher in the 4WAE than in the 6 and 8WAE.

Larval establishment on infested plants in sorghum sown simultaneously with cowpea was significantly (P=0.05) higher in the 6WAE than in the 4 and 8WAE. In addition, there was a statistically higher larval establishment on neighbouring plants in the 6WAE than in the 4 and 8WAE. Larval loss was significantly (P=0.05) higher in the 4 and 8WAE than in the 6WAE.

Larval establishment in sorghum sown before cowpea was similar for the three dates of infestation. Furthermore, larval establishment on neighbouring plants and larval loss were not significantly different in the three dates of infestation. In sorghum sown after cowpea there was a significantly (P=0.05) higher larval establishment on infested plants in the 8WAE than in the 4 and 6WAE. However, larval establishment on neighbouring plants in this cropping pattern was similar for the three dates and larval loss was significantly (P=0.05) higher in the 4 and 6WAE than in the 8WAE.

C. partellus larval establishment and loss in individual cropping patterns at each date of infestation are shown in Table 6.3. Sorghum monocrop had a significantly (P=0.05) higher percentage larval loss than establishment in the 4WAE. Establishment on neighbouring plants was significantly (P=0.05) lower than that on

Table 6.1 Mean percentage *C. partellus* larval recovery from infested and neighbouring sorghum plants and larval loss in the four cropping patterns (Mean ± S.E.)

Cropping pattern	Larval recovery from:		Larval loss
	Infested plants	Neighbouring plants	
Sorghum monocrop	60.01 ± 5.1^{a}	13.00 ± 2.5^{b}	27.55 ± 6.0^{b}
Sorghum and cowpea sown simultaneously	32.30 ± 5.2^{b}	9.26 ± 2.0^{c}	58.08 ± 5.8^{a}
Sorghum sown two weeks before cowpea	45.86 ± 5.8^{a}	15.80 ± 3.0^{b}	38.34 ± 4.7^{a}
Sorghum sown two weeks after cowpea	26.60 ± 9.8^{b}	2.57 ± 1.0^{c}	70.82 ± 4.8^{a}

Means within a row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Table 6.2 Mean percentage *C. partellus* larval establishment and loss in four cropping patterns at the 4, 6 and 8WAE dates of infestation.

Cropping pattern	Larval establishment on:						Larval loss		
	Infested sorghum plants			Neighbouring sorghum plants					
	4WAE	6WAE	8WAE	4WAE	6WAE	8WAE	4WAE	6WAE	8WAE
Sorghum monocrop	38.14[b]	71.78[a]	69.56[a]	11.90[ab]	17.67[a]	8.44[b]	49.96[a]	10.55[b]	22.00[b]
Sorghum and cowpea sown simultaneously	16.42[b]	48.90[a]	31.20[b]	6.40[b]	16.80[a]	4.96[b]	77.18[a]	34.30[b]	63.84[a]
Sorghum sown two weeks before cowpea	37.25[a]	52.98[a]	47.35[a]	11.14[a]	21.54[a]	14.73[a]	51.61[a]	25.48[a]	37.92[a]
Sorghum sown two weeks after cowpea	23.27[b]	15.40[b]	41.14[a]	1.37[a]	3.50[a]	2.86[a]	75.36[a]	81.10[a]	56.00[b]

Three cropping pattern means within a row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

infested plants. Similar trends were observed in sorghum sown simultaneously with cowpea at that date of infestation. In sorghum sown before cowpea however, percentage larval loss and establishment on infested plants were statistically similar and significantly (P=0.05) higher than establishment on neighbouring plants. Sorghum sown after cowpea had a significantly (P=0.05) higher larval loss than establishment and the establishment on infested plants was in turn significantly (P=0.05) higher than that on neighbouring plants.

In the 6WAE both sorghum monocrop and that sown before cowpea had similar higher larval establishments on infested plants than on neighbouring plants. Larval losses in both cropping patterns were not significantly different from their larval establishments on neighbouring plants. Sorghum sown simultaneously with cowpea had a sgnificantly (P=0.05) higher percentage of larval establishment on infested plants than on neighbouring plants. Larval loss in this cropping pattern was statistically similar to the two establishments. Sorghum sown after cowpea had a significantly (P=0.05) higher larval loss than establishment. Establishment on infested plants was in turn significantly (P=0.05) higher than that on neighbouring plants.

In the 8WAE sorghum monocrop had a significantly (P=0.05) higher percentage larval establishment on infested plants than either establishment on neighbouring plants or larval loss. Larval loss was in turn significantly higher than establishment on neighbouring plants. Sorghum sown simultaneously with cowpea and that sown after cowpea both had significantly (P=0.05) higher larval losses than establishments. The establishments on infested plants were significantly (P=0.05) higher than those on neighbouring plants. Sorghum sown before cowpea had similar larval loss and establishment, and the two were significantly (P=0.05) higher than establishment on neighbouring plants.

6.3.2 Stem borer damage to sorghum plants and grain yields in four cropping patterns

6.3.2.1 Stem borer damage to sorghum plants in four cropping patterns

The percentage borer infested sorghum plants during 1987 long rainy season at MPFS and on Rusinga is shown in Fig. 5.1 and 5.2 respectively. The number of infested plants increased with the age of sorghum crop and

Table 6.3 Mean percentage *C. partellus* larval recovery and loss at three dates of infestation

Cropping pattern	4WAE			6WAE			8WAE		
	I.P.*	N.P.**	Loss	I.P.*	N.P.**	Loss	I.P.*	N.P.**	Loss
Sorghum monocrop	38.14[b]	11.90[c]	49.96[a]	71.78[a]	17.67[b]	10.55[b]	69.56[a]	8.44[c]	22.00[b]
Sorghum and cowpea sown simultaneously	16.42[b]	6.40[c]	77.18[a]	48.90[a]	16.80[b]	34.30[ab]	31.20[b]	4.96[c]	63.84[a]
Sorghum sown two weeks before cowpea	37.25[a]	11.14[b]	51.61[a]	52.98[a]	21.54[b]	25.48[b]	47.35[a]	14.73[b]	37.92[a]
Sorghum sown two weeks after cowpea	23.27[b]	1.36[c]	75.37[a]	15.40[b]	3.50[c]	81.10[a]	41.14[b]	2.86[c]	56.00[a]

I.P.* = infested plants, N.P.** = neighbouring plants

Three cropping pattern means within a row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

FIGURE 5.1

Weekly mean percentage infested sorghum plants in four cropping patterns at MPFS during 1987 long rainy season

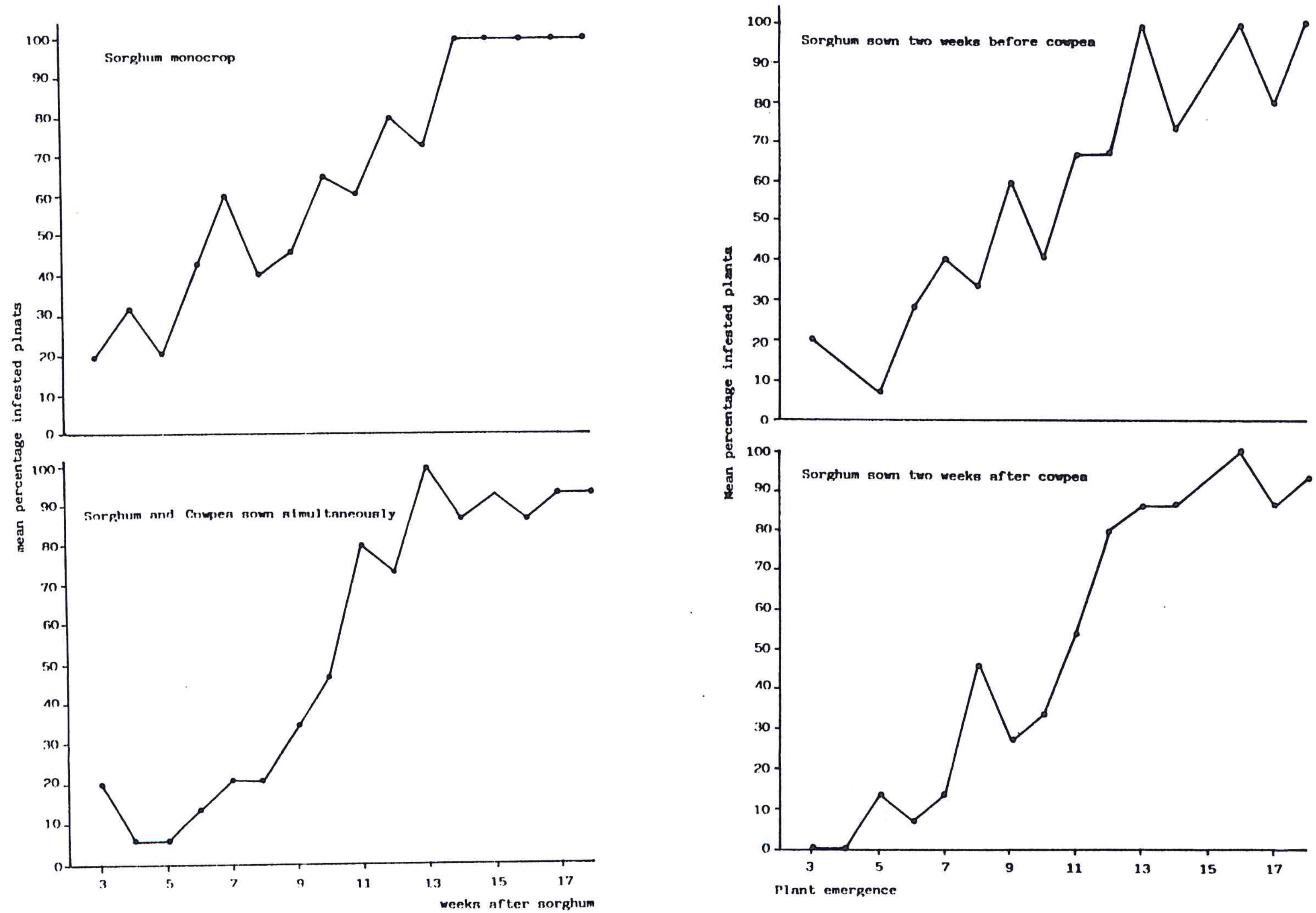

Sorghum monocrop
Sorghum and Cowpea sown simultaneously
mean percentage infested plnats
weeks after sorghum
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Mean percentage infested plants
Plant emergence

FIGURE 5.2

Weekly mean percentage infested sorghum plants in four cropping patterns on Rusinga during 1987 long rainy season

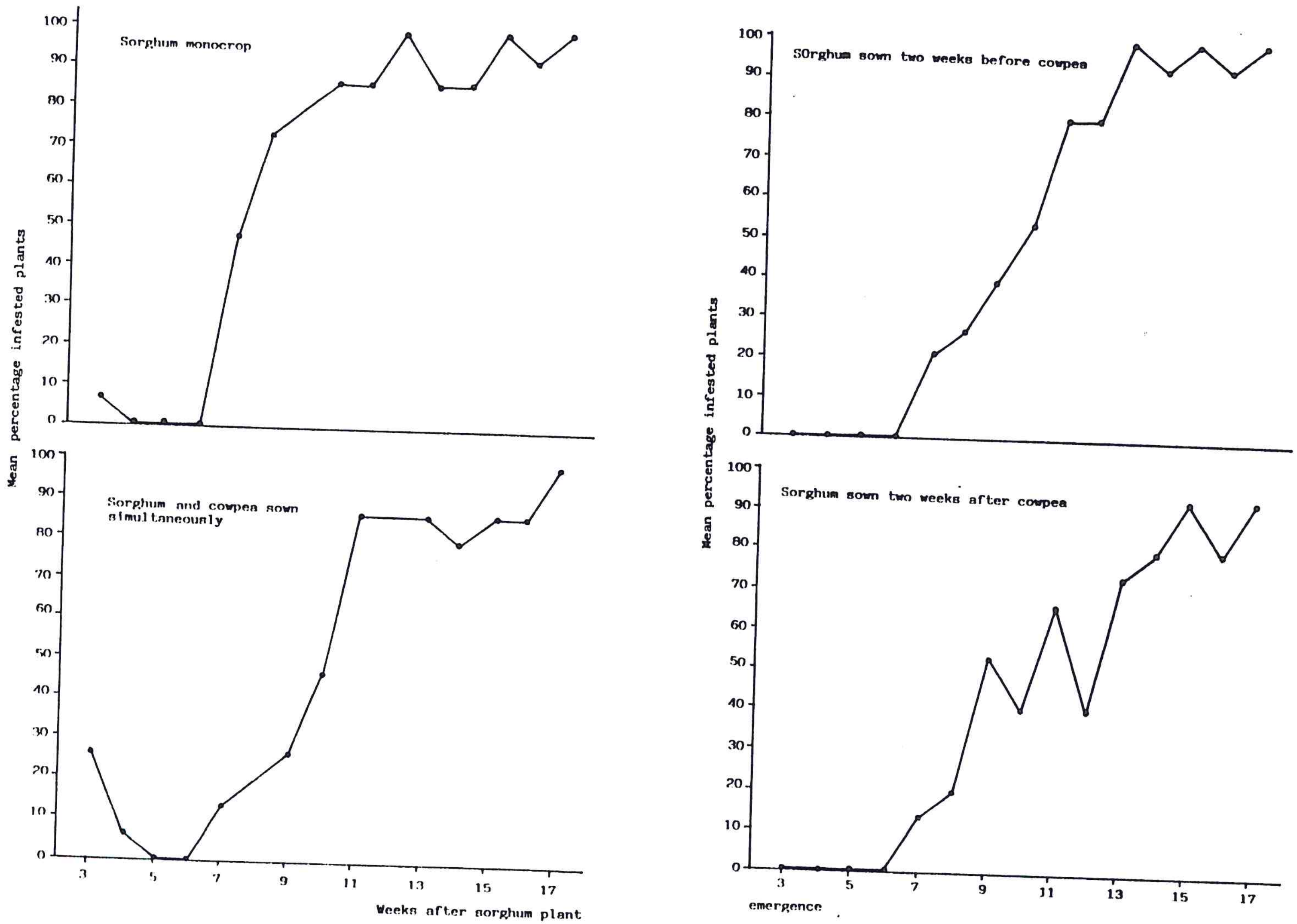
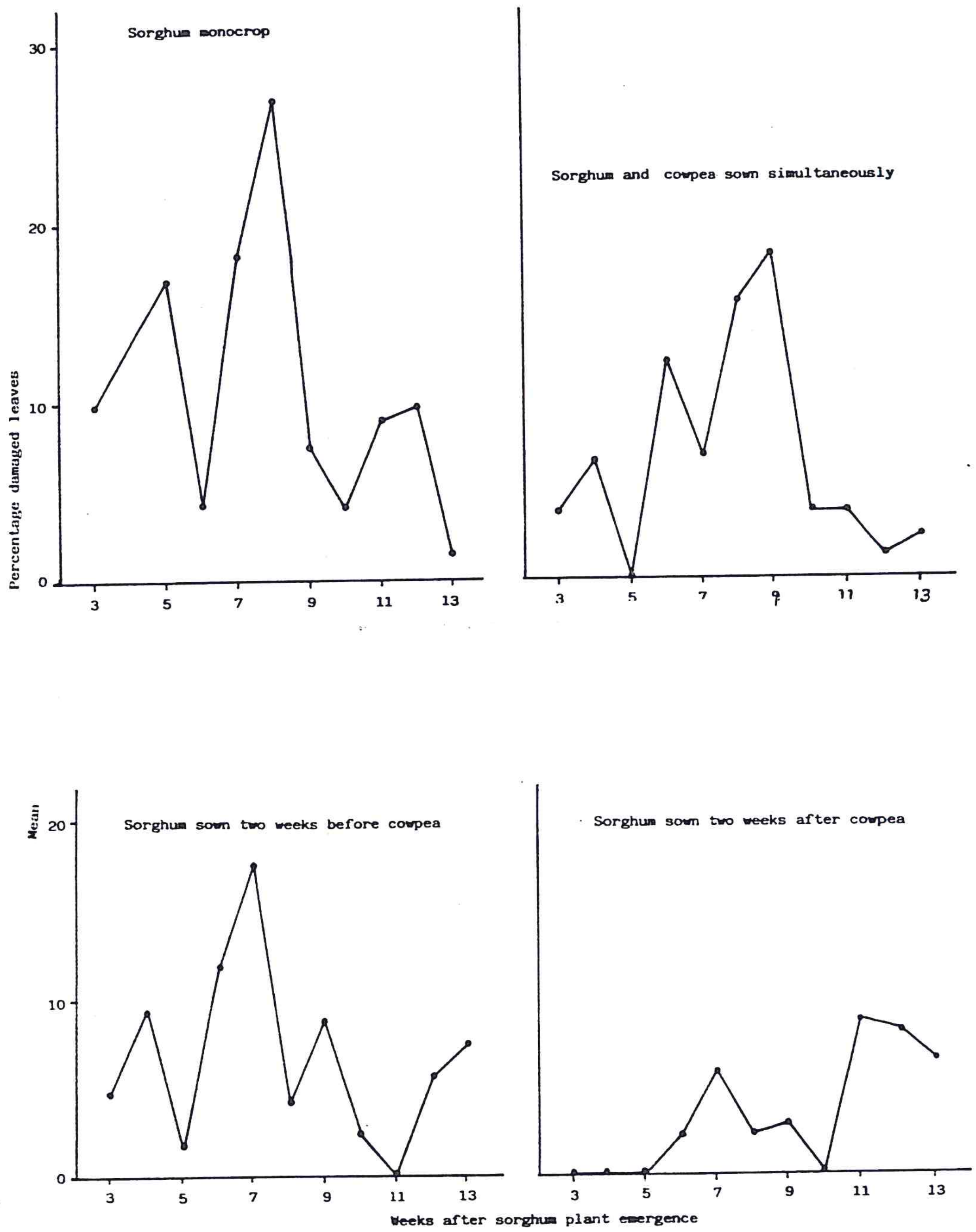

Sorghum monocrop
Sorghum and cowpea sown simultaneously
SOrghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Mean percentage infested plants
Weeks after sorghum plant emergence
100
90
80
70
60
50
40
30
20
10
0
3
5
7
9
11
13
15
17

FIGURE 5.3

Weekly mean percentage sorghum plant leaves with stem borer damage at MPFS during 1987 long rainy season



Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Percentage damaged leaves
Mean
Weeks after sorghum plant emergence
30
20
10
0
3
5
7
9
11
13

after the 10WAE almost all plants in the four cropping patterns were infested. The number of damaged leaves on the infested plants expressed as a percentage of total leaves per plant is shown in Fig. 5.3. Peak leaf damage was observed between the 6 and 9WAE in three of the four cropping patterns while in sorghum sown after cowpea high leaf damages were observed between the 11 and 13WAE.

The mean percentage infested sorghum plants and leaf damage in the four cropping patterns are shown in Table 6.4. Significantly (P=0.05) more plants were infested in sorghum monocrop than sorghum sown simultaneously with cowpea at the field station. The other two intercrops were statistically similar and were not significantly different from either the sorghum monocrop or sorghum sown simultaneously with cowpea. On Rusinga Island however, sorghum monocrop had a significantly (P=0.05) higher number of infested plants than the three intercrops. The second highest number of infested plants was in sorghum sown before cowpea while the lowest was in sorghum sown after cowpea. Sorghum sown simultaneously with cowpea was not significantly different from either sorghum sown before or that sown after cowpea.

Weekly percentage stem borer tunnelled length in sorghum plants in the four cropping patterns is shown in

Table 6.4 Mean percentage infested sorghum plants and damaged leaves in four cropping patterns in during 1987 long rainy season (Mean* $\pm$ S.E.).

Cropping pattern	Percentage infested plants: at MPFS	Percentage infested plants: on Rusinga	Percentage damaged leaves at MPFS
Sorghum monocrop	59.6 ± 6.3^{a}	54.0 ± 9.0^{a}	17.0 ± 2.5^{a}
Sorghum and cowpea sown simultaneously	48.7 ± 7.5^{b}	44.8 ± 8.2^{bc}	11.3 ± 2.2^{ab}
Sorghum sown two weeks before cowpea	52.0 ± 6.6^{ab}	46.2 ± 9.4^{b}	12.2 ± 2.1^{ab}
Sorghum sown two weeks after cowpea	52.0 ± 7.7^{ab}	37.9 ± 7.9^{c}	6.5 ± 1.8^{b}

* Data subjected to Arcsine transformation for analysis of variance.

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Figs. 5.4-5.6. The proportion of stem tunnelled increased steadily until the 10WAE in the four cropping patterns for the three planting occasions. From the 10WAE stem tunnelled length increased sharply till harvest. There was a higher (though not significant) proportion of stem tunnelled length in the short rain season crop (Fig. 5.4) than in the long rain season crops (Figs. 5.5 and 5.6).

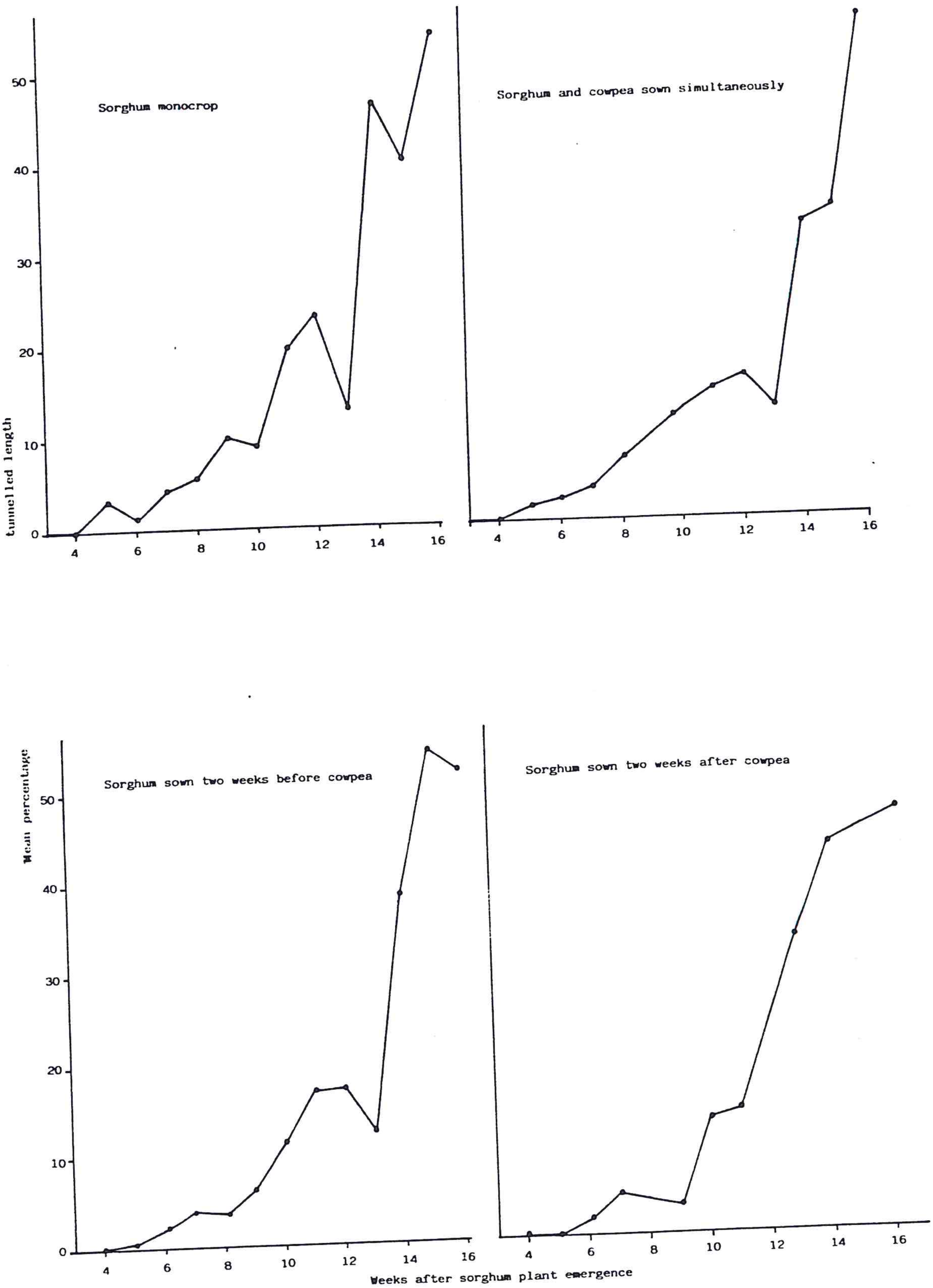
Mean percentage tunnelled length just after the first borer larval population peak and at milky-seed stage (about 11WAE), and shortly before harvest when borer populations were at their highest peak (16WAE) in the four cropping patterns is shown in Table 6.5. There were no significant differences in the proportion of stem tunnelled between the four cropping patterns at both stages of plant growth.

6.3.2.2 Sorghum grain yields in four cropping patterns

The sorghum grain yields from the four cropping patterns in the 1986-1988 planting seasons are shown in Table 6.6. Sorghum sown after cowpea had a significantly (P=0.05) lower yield than the other three cropping patterns in 1986-88 period. The 1987 long rainy season at the field station had a significantly (P=0.05) higher

FIGURE 5.4

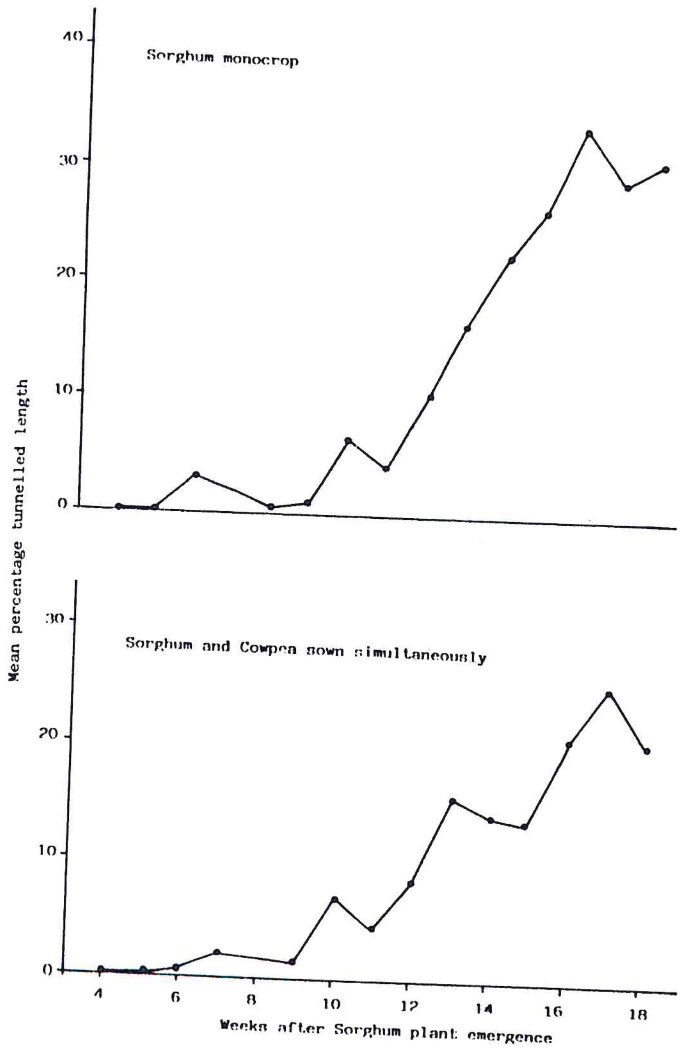
Weekly mean percentage stem borer tunnelled length in sorghum plants at MPFS during 1986/87 short rainy season



Sorghum monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Mean percentage tunnelled length
Weeks after sorghum plant emergence
0
10
20
30
40
50
4
6
8
10
12
14
16

FIGURE 5.5

Weekly mean percentage stem tunnelled length in sorghum plants at MPFS during 1987 long rainy season


Sorghum monocrop
Sorghum and Cowpea sown simultaneously
Mean percentage tunnelled length
Weeks after Sorghum plant emergence
0
10
20
30
40
4
6
8
10
12
14
16
18

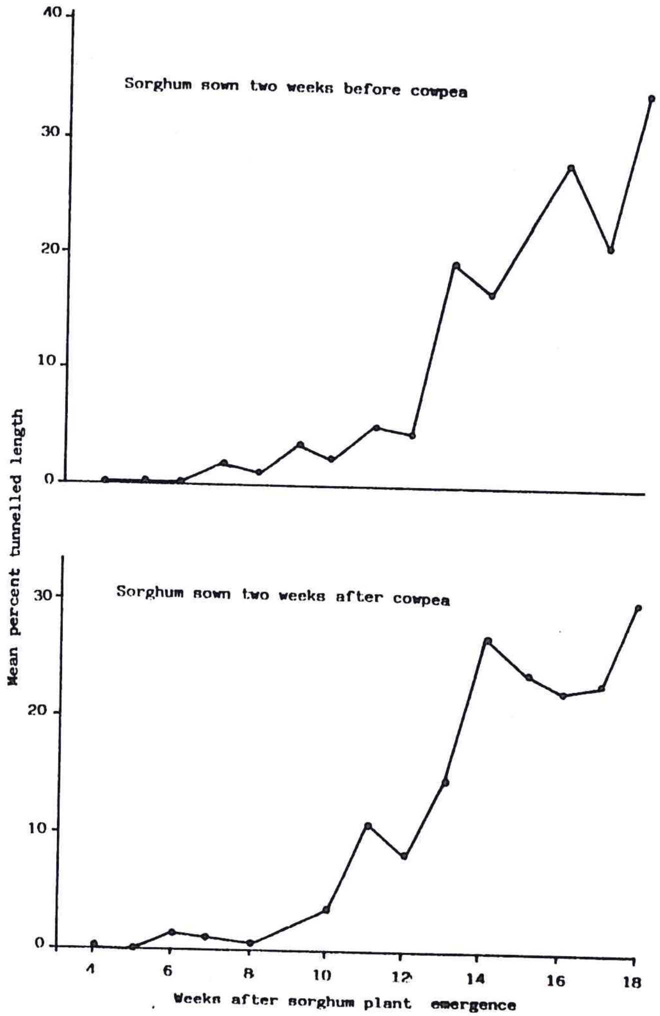
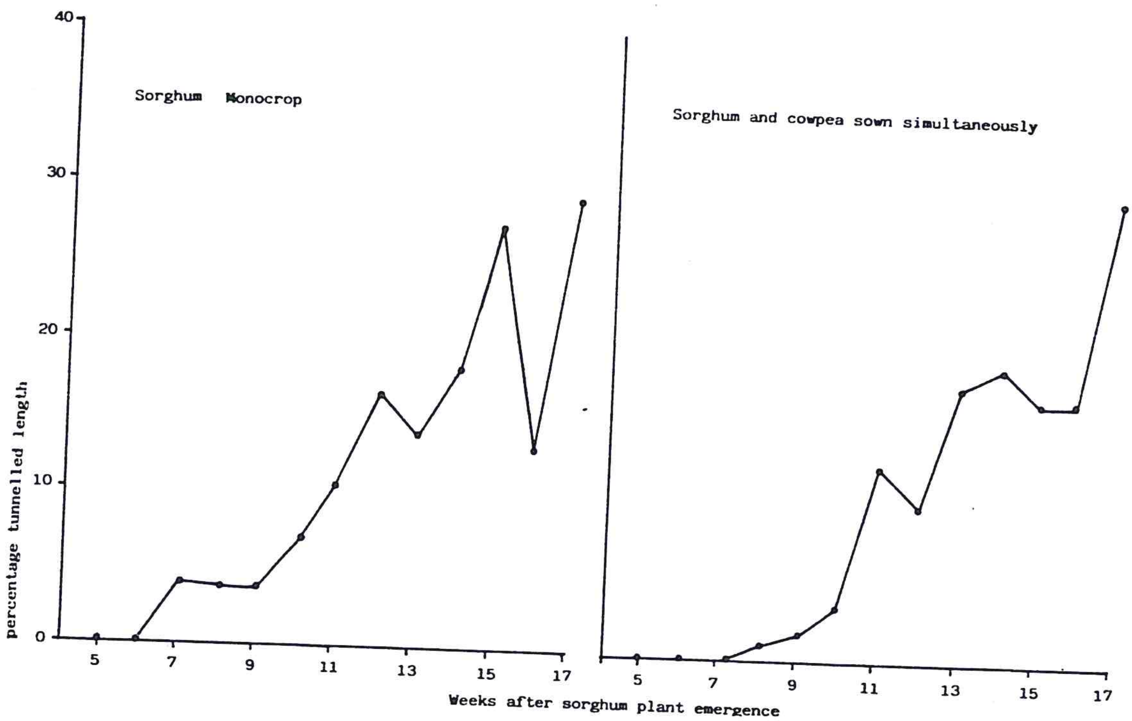
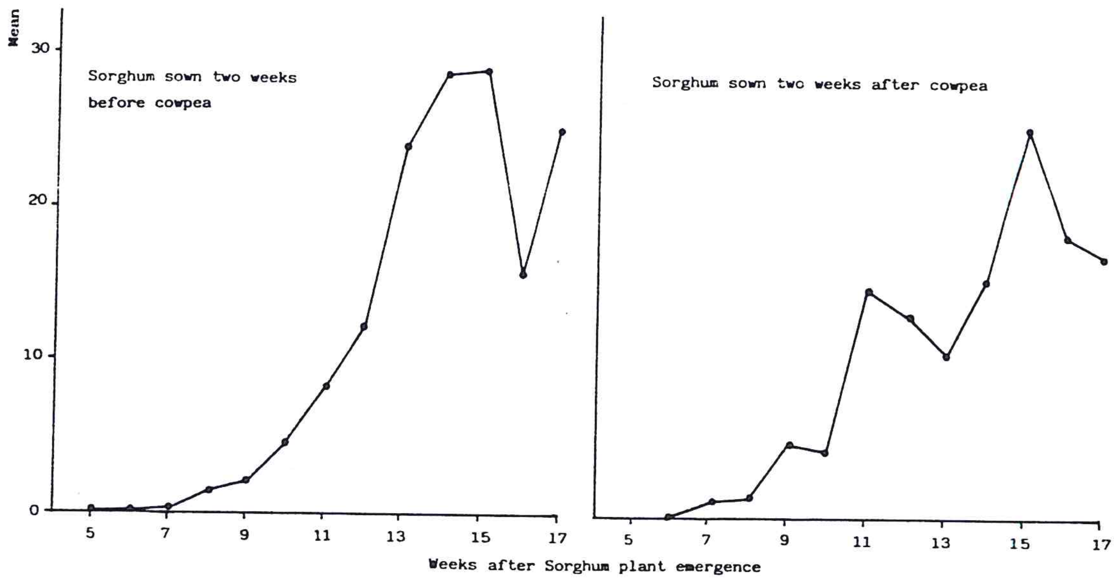

Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Mean percent tunnelled length
Weeks after sorghum plant emergence
0
10
20
30
40
4
6
8
10
12
14
16
18

FIGURE 5.6

Weekly mean percentage stem tunnelled length in sorghum plants on Rusinga during 1987 long rainy season



Sorghum Monocrop
Sorghum and cowpea sown simultaneously
percentage tunnelled length
Weeks after sorghum plant emergence



Mean
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Weeks after Sorghum plant emergence

Table 6.5 Mean percentage stem borer tunnelled length in four sorghum cropping patterns (Means ± S.E.).

Cropping pattern	11 WAE	16 WAE
Sorghum monocrop	17.5 ± 1.9^{a}	38.0 ± 4.5^{a}
Sorghum and cowpea sown simultaneously	16.0 ± 1.6^{a}	35.5 ± 6.0^{a}
Sorghum sown two weeks before cowpea	19.9 ± 2.5^{a}	37.1 ± 4.7^{a}
Sorghum sown two weeks after cowpea	12.1 ± 1.9^{ab}	30.2 ± 4.6^{ab}

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

grain yield than the other three seasons. The second highest grain yield was from Rusinga also in 1987 long rainy season and this was significantly (P=0.05) higher than the remaining three seasons' crops which were not significnatly different from each other.

The grain yields from the different cropping patterns in individual seasons (Table 6.6) show that at the field station in 1986/87 sorghum sown simultaneously with cowpea and that sown before cowpea both had a significantly (P=0.05) higher grain yield than the other two cropping patterns. However, sorghum sown before cowpea had a similar yield to the sorghum monocrop and that sown after cowpea. In 1987/88 short rainy season at the field station sorghum sown after cowpea had a significantly (P=0.05) lower grain yield than the other three cropping patterns. Sorghum sown before cowpea had a higher (but not significantly) grain yield than the monocrop and that sown simultaneously with cowpea.

Grain yields from the four cropping patterns in 1987 long rainy season at the field station were statistically similar although those from the sorghum monocrop and that sown simultaneously with cowpea were slightly higher than those in the other two intercrops. In Rusinga sorghum sown after cowpea had a significantly (P=0.05) lower

Table 6.6 Mean sorghum grain yields in Kg/ha from four cropping patterns during 1986-88 planting seasons (Mean ± S.E.).

Cropping pattern	1986/87 MPFS	1987/88 MPFS	1987 Rusinga	1987 MPFS	1988 MPFS	Mean ± S.E.
Sorghum monocrop	1064.8^{b}	992.5^{ab}	1731.5^{a}	1779.4^{a}	1092.6^{b}	1332.2 ± 111.8^{a}
Sorghum and cowpea sown simultaneously	1240.7^{a}	1053.8^{ab}	1527.8^{ab}	1891.4^{a}	1101.9^{b}	1363.1 ± 98.8^{a}
Sorghum sown two weeks before cowpea	1212.9^{ab}	1134.7^{a}	1685.2^{a}	1641.9^{ab}	1324.1^{a}	1399.8 ± 72.9^{a}
Sorghum sown two weeks after cowpea	972.2^{b}	541.4^{c}	842.6^{c}	1692.7^{ab}	1027.8^{b}	1015.3 ± 107.4^{b}
Mean	1122.7 ± 57.2^{c}	930.6 ± 96.9^{c}	1446.8 ± 107.2^{b}	1751.4 ± 41.5^{a}	1136.6 ± 45.7^{c}	

Cropping pattern means in each season and in the last column, and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

grain yield than the other three cropping patterns which were in turn similar. In the 1988 long rainy season sorghum sown before cowpea had a significantly (P=0.05) higher grain yield than the other three cropping patterns which were in turn statistically similar.

6.4 DISCUSSION

The results on C. partellus establishment clearly show that there was substantial larval loss in the period between enclosion of eggs and larval establishment at feeding sites. The slightly wider row spacing used on sorghum to accommodate the intercrop increased the distance of contact for the dispersing larvae which resulted in a significantly higher larval loss at the early growth stage (4WAE) of the sorghum plants than at the later two dates of infestation. A significantly higher larval loss occurred in the three intercrop patterns (38.3-70.8%) than in the sorghum monocrop (27.0%).

Larval loss in sorghum sown after cowpea was higher than in the other two intercrops because the sorghum plants had very few tillers due to shading by the already established cowpea plants and thus, the surface area of contact for dispersing larvae was less than in the other cropping patterns where the sorghum rows had more tillers leading to more spreading-out leaves. Sorghum sown simultaneously with cowpea had the second highest larval loss due to cowpea cover along the rows which could have disrupted the movement of the larvae migrating from the area of infestation. In addition, dispersing larvae in the intercrops could have been confused by the chemical signals from both plants and this could have lead to larvae failing to choose their destination.

The above observations are in agreememt with those reported by Roome (1980) that a 40% mortality of C. partellus larvae occurred within 24 hours after hatching. This mortality was associated with dispersal. Mathez (1972) also reported that up to 100% of the larvae may disappear during dispersal phase.

C. partellus larval establishment on neighbouring sorghum plants was significantly lower than that on infested plants in the four cropping patterns. This is clear evidence that movement to neighbouring plants take place but the establishment is lower than either the loss or the establishment on infested plants. Larval establishment was higher in the 6 and 8WAE than in the 4WAE except in sorghum sown after cowpea where establishment was high in the 8WAE only. The explanation for the higher larval establishment in sorghum sown after cowpea in the 8WAE could be due to more larvae settling on the sorghum plants which were at that time more free from the ground covering cowpea and therefore sorghum chemical signals could have been more effective in arresting the larvae on the plants than at the 4 and 6WAE when the sorghum plants were younger and intermingled with the cowpea.

C. partellus larval establishment has also been observed by Ingram (1958), Van Hamburg (1980) and Chapman et al. (1983). Van Hamburg (1980) reported that 100% of the sorghum plants in a field became infested although eggs were laid on only 18% of the plants. Furthermore, he observed that dates of infestation affected larval survival in that infestations made before the 4WAE resulted into fewer C. partellus larval survival compared with higher mean larval survival when the plants were infested at the 7WAE. Similar C. partellus larval dispersal behaviour has been reported on different maize cultivars at Mbita (Ampofo, 1986).

Leaf damage in sorghum plants increased with plant age until the 13WAE. This coincided with the peak larval population at the earlier growth stage of the plants when such larvae were feeding in the leaf whorls. Subsequent to that period the larvae fed within the stems but the leaves continue unfolding and the damage becomes visible later in the season. In sorghum sown after cowpea the leaf damage was delayed and lower (but not significantly) than in the other cropping patterns because larval infestation occurred late in that treatment. The percentage infested sorghum plants also increased with plant age as was observed on the larval population.

The increase in infested sorghum plants and damaged leaves with the age of sorghum has also been reported by Amoako-Atta et al. (1983) on sorghum and cowpea cropping patterns. The significantly higher number of infested plants and damaged leaves in the sorghum monocrop than in some of the intercrops has also been reported in corn, cucumber and broccoli intercrops (Bach, 1980); on Brussels sprouts and spurry (Theunissen and Den Ouden, 1980); and in cowpea and sorghum (Dissemond and Weltzien, 1986). Dissemond and Weltzien (1986) observed that leaf damage in the short rain season (about 12%) was significantly lower than that recorded for the long rain season (25%) with no marked differences between monocrops and intercrops as observed in the present study.

The mean percentage stem tunnelled length was not significantly different in the four cropping patterns, but the three intercrops had lower stem tunnelled length during the early part of crop's growth (up to 10WAE) compared with the sorghum monocrop. The explanation for the small difference in tunnelled length between the cropping patterns could be that some of the larvae might have migrated from the main stems to the tillers (there were up to four tillers per healthy plant) which are inherent to the sorghum cultivar Serena, especially when grown on fertile soils and seedlings thinned early (between 15 and 21 days after sorghum plant emergence). Thus, the damage which would have been confined to one stem was distributed to two or more stems. The higher (although not significantly) stem tunnelled length observed in the short rainy season compared with the long rainy season could be related to the larval populations which were higher in the short rains than in the long rains. Similar findings were reported by Coaker (1956) and he concluded that crops grown under adequate rainfall were apparently unaffected by stem borer attacks.

The generally slight variation in sorghum grain yields between the cropping patterns may be associated with the cultivar used in the experiment. Sorghum cultivar Serena has a high tillering capacity which seems to have compensated for any damaged main stems but in the late planted sorghum there were few tillers due to cowpea shading at the early stages of sorghum growth. Tillers in this treatment were mainly formed towards the end of the season and could not contribute to harvestable grain yield.

Cropping pattern grain yields in the five planting occasions show that sorghum sown after cowpea had a significantly lower grain yield than the other three cropping patterns which were in turn statistically similar. The capability of cultivar Serena to form tillers and the dispersal behaviour of C. partellus which could have enabled damage to be distributed among the stems on a hill might have levelled off most of the yield differences which would have been expected. Edje (1981) also reported that sorghum grain yields were not significantly affected when sorghum was sown simultaneously with beans. These observations would support the findings reported by Omolo and Ollimo (unpublished) that physiologically sorghum does not compete with the legume crops (especially cowpea) due to the differences in the time in which each crop requires most of its growth materials.

Seasonal yield variation was primarily a result of pest severity and adverse weather conditions. Higher larval populations had been observed in the two short rain season crops (1986/87 and 1987/88) and these could have reduced the yielding capacity of the plants as reported by Ingram (1958). Similar lower sorghum yields in the short rainy season compared with the long rainy season have also been reported at Mbita Point Field Station and the surrounding areas (Amoako-Atta and Omolo, 1983). During 1987 the crop on Rusinga was severely affected by a dry spell during the emergence stage of the late planted sorghum followed by some flooding during and after thinning of both early and late planted sorghum. Consequently, the vigour of the plants in some of the plots was adversely affected. Flooding and soil erosion in a third of the experimental field at the field station in 1988 due to an unexpected continuous heavy rain, followed by heavy Aphid infestations on some of the sorghum plants, resulted in many sorghum plants with chaffy heads in some plots.

Despite these problems there was an average sorghum yield increase of 2.3 and 5.1% during 1986-88 planting seasons from intercropping with cowpea simultaneously and sorghum before cowpea respectively, compared with sorghum monocrop. However, sorghum sown after cowpea yielded 23.8% less than sorghum monocrop which further elucidates the disadvantage of planting sorghum late within the environment in which the present study was carried out.

The present study therefore showed that intercropping sorghum and cowpea resulted in higher C. partellus larval loss and lower establishment than the monocrop. Consequently, there were lower mean percentage infested plants and damaged leaves, but insignificant differences in tunnelled stem length. Planting sorghum simultaneously with and after cowpea resulted in significantly lower larval establishments. Planting sorghum after cowpea also resulted in delayed larval establishment and subsequent leaf damage and stem tunnelling. However, this treatment yielded an unexpectedly low grain due to adverse weather and mid cropping season (after 5WAE) infestations of the other borers, i.e. B. fusca, E. saccharina and S. calamistis. Planting sorghum before cowpea showed similar trends to the monocrop in that larval populations, plant infestation and damage, and the grain yields were only slightly affected by this cropping pattern. These observations on larval establishment could partly help to explain the larval population trends observed in Chapter 5. Conclusive explanations could be drawn if the larval establishment of the other stem borers was available.

CHAPTER 7

TITLE *M. TESTULALIS* POPULATION BUILD-UP AND DAMAGE ON COWPEA INTERCROPPED WITH SORGHUM.

7.1 INTRODUCTION

M. testulalis which is found throughout the African continent is known to cause serious losses in cowpea yields (Singh and van Emden, 1979). Taylor (1968) reported yield losses ranging from 30-70% on different cowpea varieties in Nigeria and showed that one larva can destroy 3-4 flowers and cause up to 30% pod damage. Up to 100% damage has been reported on susceptible varieties (Usua, 1975).

Mixed-cropping or intercropping has been reported to have the advantage of some decreased incidences of crop losses from insects and diseases (Perrin, 1977; Way, 1977) which is most probably due to different crop canopies creating less favourable environments for certain pests of one or both of the component crops (Gerard, 1976). Raheja (1973), reported less severe insect attack on cowpea intercropped with sorghum than on the sole crop in northern Nigeria. Amoako-Atta and Omolo (1983) reported significantly fewer *M. testulalis* larvae and subsequently less damage to cowpea plants in sorghum and cowpea intercrop than monocrop cowpea when the two crops were sown simultaneously in south western Kenya. In addition, Omolo and Seshu Reddy (1985) reported that M. testulalis infestation on cowpea plants in the monocrop was higher (73.2%) than on cowpea intercropped with sorghum (53.8% of the cowpea plants were infested).

Ezueh and Taylor (1984) also reported that planting cowpea as an intercrop with maize at 12 weeks after the establishment of maize, significantly reduced insect damage (including that of M. testulalis) to cowpea in Nigeria. Furthermore, Kyamanywa and Ampofo (1988) reported significantly lower populations of the legume flower thrips (Megalurothrips sjostedti Trybom) in a maize and cowpea intercrop than in the cowpea monocrop and they attributed this to reduced light intensity in the intercrop.

Generally research into the technology of intercropping is directed at identifying those crop combinations and associated management practices that maximize productivity per unit area of land (Gomez and Gomez, 1983). The index commonly used to evaluate an intercropping technology is the land equivalent ratio (LER), which is defined as:

$$L\ E\ R = \sum_{i-1}^{n} \left(\frac{X_i}{Y_i} \right)$$

where 'X_i' is the yield of crop '*i*' in intercropping and 'Y_i' is the yield of crop '*i*' in pure stand.

The LER index essentially compares productivity in intercropping with that in the monocrop, with high values (i.e. more than one) of LER indicating the advantage of intercropping. It is in this context that other authors (Wahua and Miller, 1978; May and Misangu, 1980) prefer to use the term Relative Yield Total (RYT) to mean the same as LER. Willey (1979), however, discussed various methods of assessing yield advantage of an intercrop and concluded that the LER provided a more practical yardstick.

More recently, however, Adetiloye *et al*. (1983) pointed out two major discrepancies arising from the use of LER that:

(1) the mixture LER value obscures the extent to which the yield of a component crop has been modified by the presence of the other component crop(s) or the reciprocal effects of component crops on one another. For example,

a mixture LER value of 1.20 derived from 100 percent sole crop land equivalent for one component (La) and 20 percent for the other component (Lb) (i.e. La + Lb = 1.00 + 0.20 = 1.20) does not reflect the magnitude of the competition that existed between the components.

(2) the mixture LER value fails to indicate the minimum level of reasonable contribution in terms of yield that is expected from the least productive crop component within a given mixture. For example, an LER value of 1.20 for a two-crop mixture can be obtained from one mixture with 0.60 plus 0.60 intercrop LER contributions i.e. La + Lb = 0.60 + 0.60 = 1.20, and from another mixture with 1.00 plus 0.20 contributions, i.e. La + Lb = 1.00 + 0.20 = 1.20. Hence, the LER concept fails to differentiate between the productivities of such mixtures with different competitive relationships but the same mixture LER value.

As a modification the authors presented the land equivalent coefficient (LEC) concept which is defined as the product of the LERs of the intercrop components i.e. ya/Ya x yb/Yb. The LEC can therefore be regarded as a measure of association or interaction when the concern is with the strength of relationship. Thus the LEC is a measure of the proportion of yield in one mixture component explained by the presence of the other component(s). In a two-crop mixture the minimum expected value before a yield advantage is obtained is an LEC greater than 0.25, i.e. a productivity coefficient (PC) greater than 25 percent, obtained from theoretical 50:50 yield where interspecific competition equalled intraspecific competition, i.e.

LEC = La x Lb = 0.5 x 0.5 = 0.25 (i.e. 25%).

In view of the importance of *M. testulalis* on cowpea growth and production, and the little information available on the mechanisms that operate in certain intercrop patterns to reduce its impact on the crop, this study was proposed to examine the population build-up of this pest on different cowpea cropping patterns at the ICIPE Mbita Point Field Station (MPFS) and on a farmer's field on Rusinga Island.

7.2 MATERIALS AND METHODS

M. testulalis populations were studied in the field in the various crop mixtures described in Chapter 3 namely: cowpea monocrop, cowpea and sorghum sown simultaneously, cowpea sown before and cowpea sown after sorghum. Six cowpea plants per plot, three in each of two inner plot cells in the monocrop; and four plants, two in each of two inner cells in the intercrop plots were randomly selected and used for M. testulalis egg counts and larval sampling. Egg counts and larval sampling were carried out at weekly intervals on Rusinga and at MPFS in 1986/87 and 1987. At MPFS in the 1988 long rainy season however, egg counts were made every three days starting 20 days after cowpea plant emergence (DAE) and larval sampling was carried out at four days interval starting at 25DAE. Eggs were counted on the standing plants and larval sampling was done by randomly picking twelve flower buds, flowers or pods (depending on the growth stage of the plants) from one inner cell per plot in the monocrop while the sample size was eight in the intercrops. All M. testulalis larvae observed in the samples together with their stage of development were recorded. A new cell was used on each sampling date.

Pupae were sampled by using two corrugated carton paper pieces (40cm x 40cm) per plot, each placed in the middle of two plot cells directly under the cowpea canopy and held in place by a sprinkle of soil on the upper surface. The corrugated surface of the paper faced the soil and the depressions were the prefered site for hiding and spinning of cacoons by the pre-pupa. Pupae were sampled every five days starting 35DAE. Cowpea pod borer larvae and pupae collected from the field were maintained individually in labelled rearing dishes and larvae supplied with fresh flower buds, flowers or green pods (depending on avalability) every day. Daily records of larval pupation, parasitism or disease incidences; pupal parasitism or diseased cases; and adult emergence were maintained.

Cowpea pod damage was assessed at 65DAE (when most of the first pods to develop were at the ripening stage) by randomly selecting twenty four pods from each of the monocrop plots and sixteen pods from intercrop plots. The pods with *M. testulalis* larvae and damage signs (including entry and exit holes) were recorded per plot and the percentage damage determined. The assessment was repeated at 75DAE on pods formed in successive flowerings. This was after harvesting (at 70DAE) the pods on which the first assessment had been done. At harvest all pods from plants in plot cells initially earmarked for grain yield assessment were kept separately for each cropping pattern. Grain yield assessment was done at the end of each planting season. After drying, the pods were threshed and winnowed. The clean grain was weighed and converted into Kg/ha. The data were subjected to analysis of variance to compare the cropping patterns.

7.3 RESULTS

M. testulalis population seem to have been affected by the presence of sorghum in the intercrops. Cowpea monocrop had a significantly higher number of eggs, larvae and pupae than all the intercrop patterns at the field station and on Rusinga Island. The outstanding feature about *M. testulalis* oviposition and larval population is that records of both egg and larval population were higher at the field station than on the farmer's field. The eggs laid on cowpea in the field on Rusinga (259) were 38.2% and 63.2% lower than the 1986/87 (420) and 1987 (703) records at the field station respectively.

The total number of eggs observed at MPFS in 1986/87 short rainy season was 40% lower than that observed in 1987 long rainy season (703). Counting eggs twice (instead of once a week as in 1986/87 and 1987) in 1988 long rainy season resulted in about twice the number observed in 1987 long rainy season (1429 eggs compared with 703 eggs). Larval counts on Rusinga were also lower than those observed at MPFS in 1986/87 (244) and 1987 (308), being 68.9% and 75.3% less respectively. Increasing the frequency of sampling for larval counts does not seem to have affected the number of larvae observed at MPFS in 1988 (243) as was the case with egg counts. Higher pod borer damage was observed in cowpea monocrop compared with the three intercrop patterns. Cowpea grain yields were quite variable in the four cropping patterns in different planting seasons but the monocrop cowpea and that sown before sorghum both had higher yields than the other two intercrops.

7.3.1 M. testulalis egg, larval and pupal populations in four cropping patterns during 1986-88

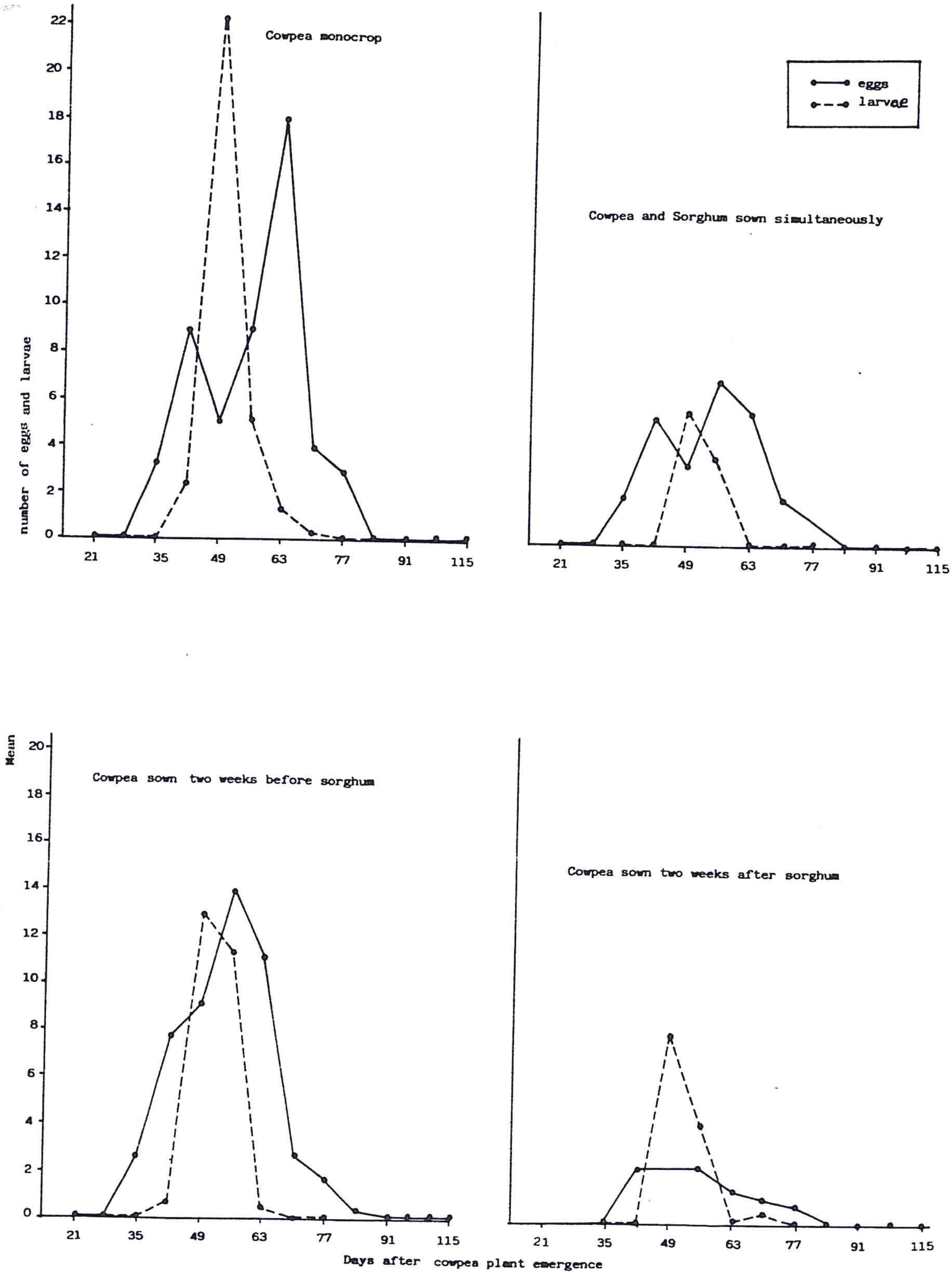
M. testulalis egg and larval population trends in the four cropping patterns during 1986-1988 planting seasons are shown in Figs. 6.1-6.4. The mean number of eggs, larvae and pupae are shown in Tables 7.1, 7.2 and 7.3 respectively. Eggs were observed on cowpea plants between 28-77DAE while larvae were recorded between 30-66DAE in the four cropping patterns in almost all the seasons. Peak larval counts were in most cases observed before egg population reached a peak (Figs. 6.1-6.4). Peak larval populations in the four cropping patterns in 1986/87 was at 49DAE while egg population peak varied with cropping pattern (Fig. 6.1). In 1987 at MPFS, the larval population peak was at 42DAE except in cowpea sown simultaneously with sorghum where it was at 35DAE (Fig. 6.2). Egg population peaks occurred at various plant growth stages in the four cropping patterns (Fig. 6.2). On Rusinga Island the peak larval population occurred at 42DAE in all treatments except in cowpea sown after sorghum where it was observed at 70DAE. It was only in cowpea sown after sorghum where the highest egg population peak occurred before the larval population peak (Fig. 6.3).

Although the larval population in 1988 appeared to be low due to lack of high single peaks as observed in the previous seasons, the larvae were present for a relatively longer period in all the cropping patterns and the small peaks were observed at different stages of cowpea plant growth in the four cropping patterns (Fig. 6.4). Pupae were observed for a relatively shorter period in the intercrops compared with the monocrop cowpea (Fig. 6.4).

There were significantly (P=0.05) more *M. testulalis* eggs laid on both cowpea in monocrop and cowpea sown before sorghum than on cowpea in the other two intercrops during 1986/87 (Table 7.1). Cowpea sown simultaneously with sorghum had the second highest mean number of eggs which was significantly (P=0.05) higher than that on cowpea sown after sorghum. In 1987 at MPFS cowpea monocrop had a significantly (P=0.05) higher

FIGURE 6.1

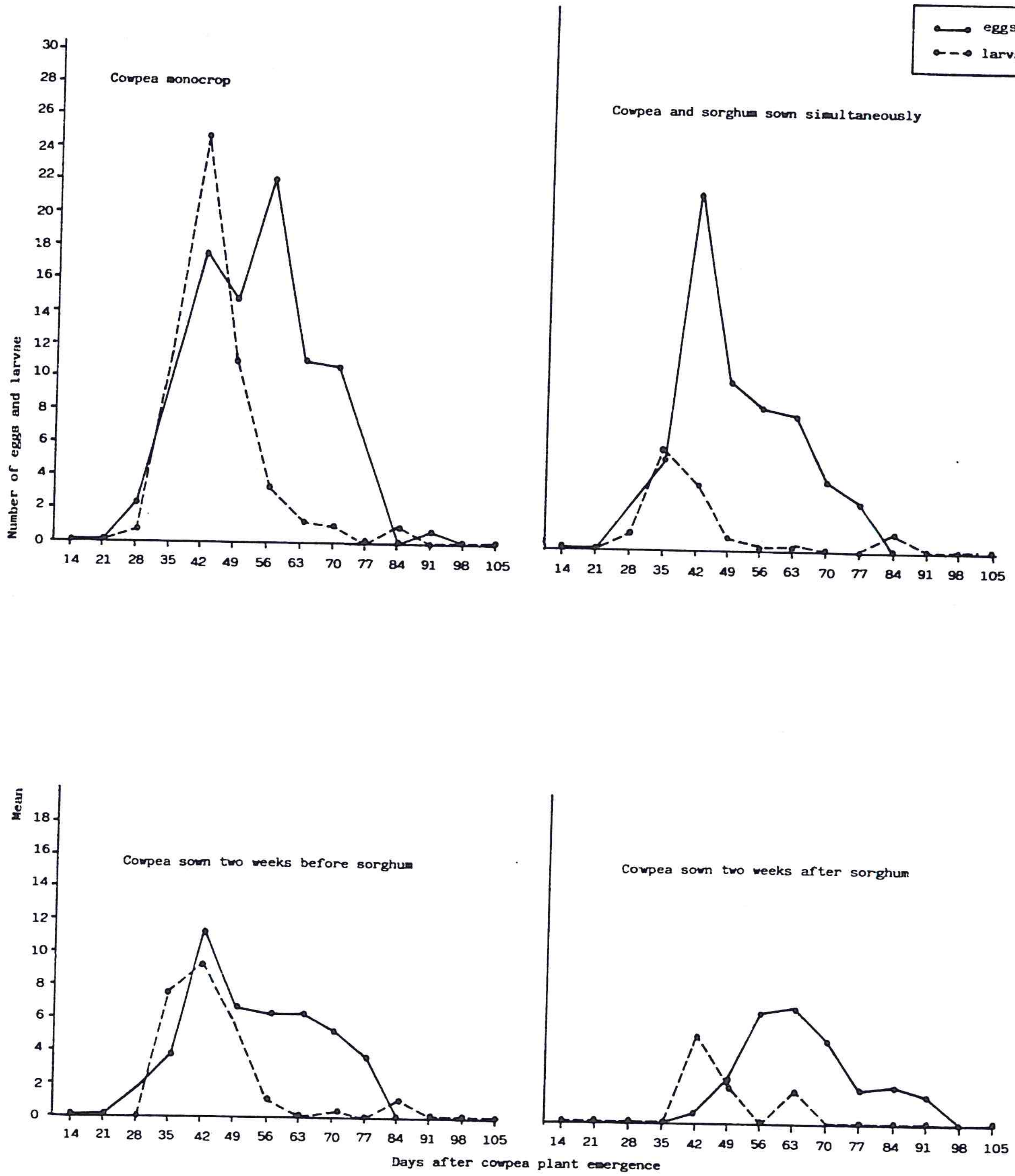
Mean number of *M. testulalis* eggs and larvae at MPFS during 1986/87 short rainy season



Cowpea monocrop
eggs
larvae
Cowpea and Sorghum sown simultaneously
Cowpea sown two weeks before sorghum
Cowpea sown two weeks after sorghum
number of eggs and larvae
Mean
Days after cowpea plant emergence
21
35
49
63
77
91
115
0
2
4
6
8
10
12
14
16
18
20
22

FIGURE 6.2

Mean number of *M. testulalis* eggs and larvae at MPFS during 1987 long rainy season



eggs
larvae
Cowpea monocrop
Cowpea and sorghum sown simultaneously
Cowpea sown two weeks before sorghum
Cowpea sown two weeks after sorghum
Number of eggs and larvae
Mean
Days after cowpea plant emergence

FIGURE 6.3

Mean number of *M*. *testulalis* eggs and larvae on Rusinga during 1987 long rainy season

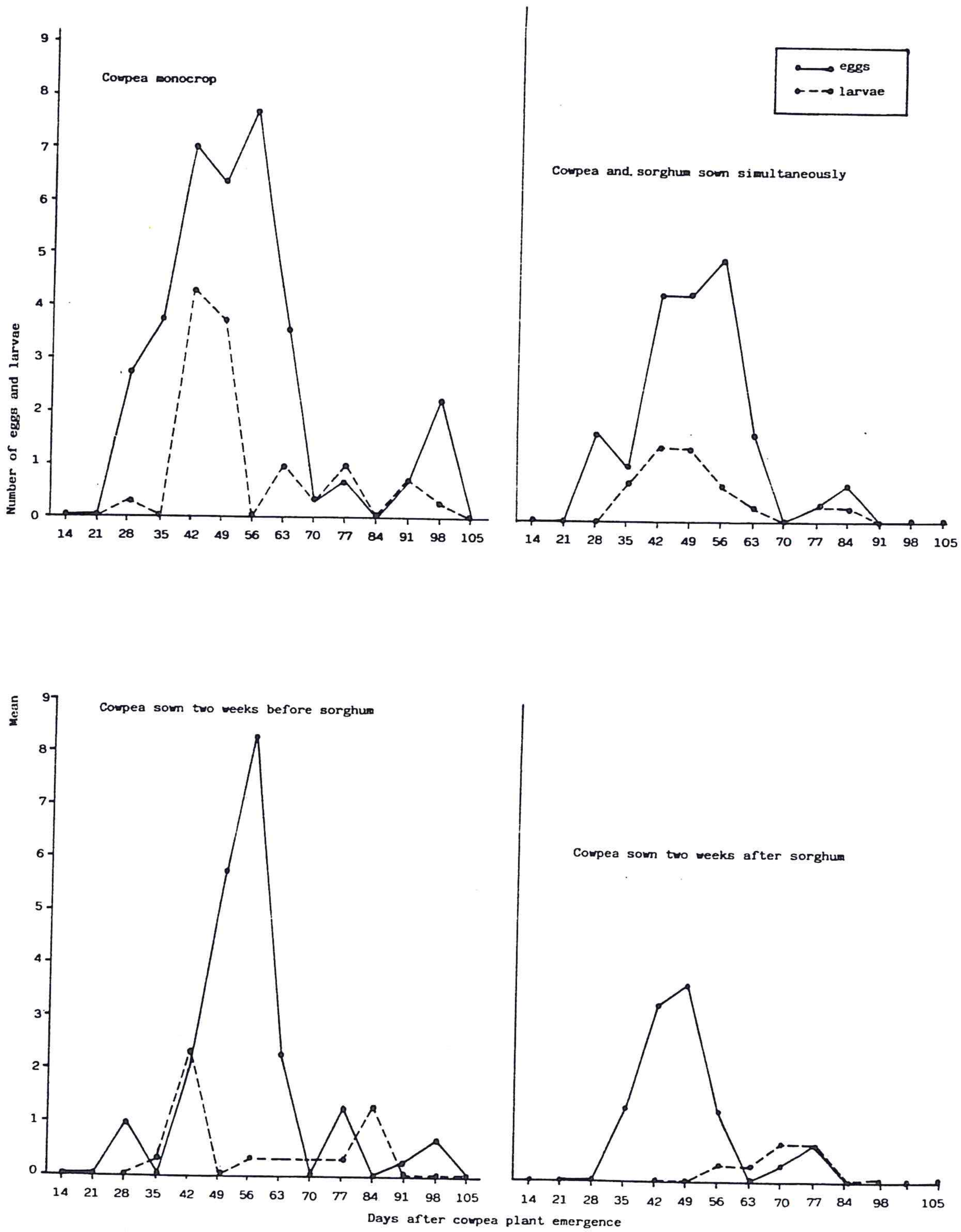
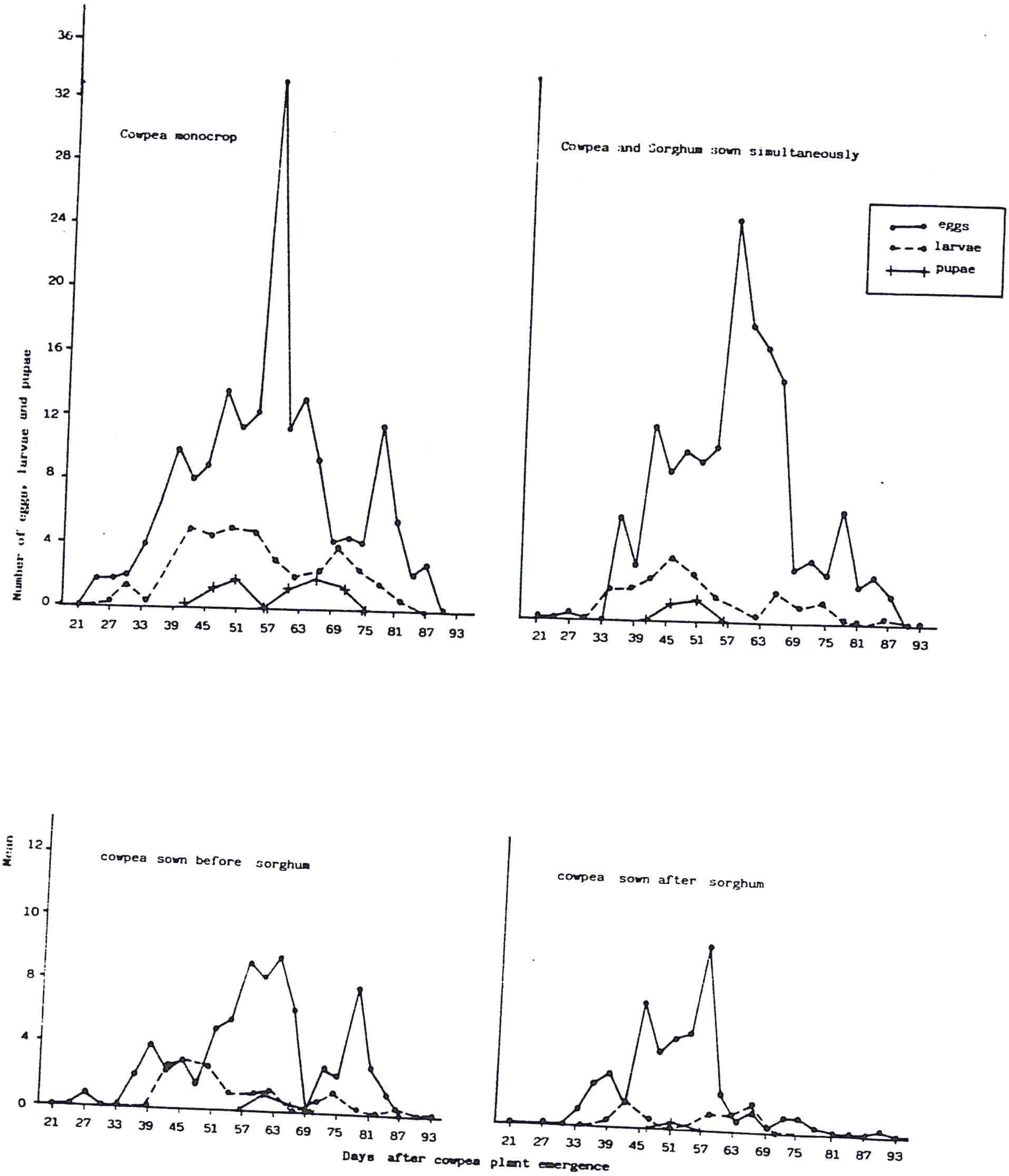

Cowpea monocrop
Cowpea and sorghum sown simultaneously
Cowpea sown two weeks before sorghum
Cowpea sown two weeks after sorghum
eggs
larvae
Number of eggs and larvae
Mean
0
1
2
3
4
5
6
7
8
9
14 21 28 35 42 49 56 63 70 77 84 91 98 105
14 21 28 35 42 49 56 63 70 77 84 98 105
Days after cowpea plant emergence

FIGURE 6.4

Mean number of *M. testulalis* eggs, larvae and pupae at MPFS during 1988 long rainy season


Number of eggs, larvae and pupae
Cowpea monocrop
Cowpea and Sorghum sown simultaneously
eggs
larvae
pupae
Mean
cowpea sown before sorghum
cowpea sown after sorghum
Days after cowpea plant emergence

number of eggs than the three intercrops. Cowpea sown after sorghum had a significantly (P=0.05) lower mean number of eggs than the other two intercrops which were in turn statistically similar. *M. testulalis* egg population in the four cropping patterns on Rusinga was similar to that observed at MPFS during 1987 (Table 7.1). In 1988 the four cropping patterns were significantly (P=0.05) different from one another, with cowpea monocrop having the highest mean number of eggs (Table 7.1) and the second highest mean was in cowpea sown simultaneously with sorghum. The lowest number of eggs was on cowpea sown after sorghum.

In 1986/87 the mean number of *M. testulalis* larvae was significantly (P=0.05) higher and similar in both cowpea monocrop and cowpea sown before sorghum than in the other two intercrops which were also statistically similar (Table 7.2). The results at MPFS during 1987 indicated that the four cropping patterns had similar trends to those of 1986/87. On Rusinga however, cowpea monocrop had a significantly (P=0.05) higher mean number of larvae than cowpea sown after sorghum. The other two intercrops were statistically similar and were not significantly different from either the cowpea monocrop or cowpea sown after sorghum (Table 7.2). Cowpea monocrop had a significantly (P=0.05) higher mean number

Table 7.1 Mean* number of *M. testulalis* eggs on cowpea plants** in four cropping patterns at MPFS and on Rusinga Island during 1986-88 planting seasons

Cropping pattern	MPFS 1986/87	MPFS 1987	Rusinga 1987	MPFS 1988	Mean $\pm$ S.E.
Cowpea monocrop	3.4^{a}	6.0^{a}	2.4^{a}	6.1^{a}	4.5 ± 0.1^{a}
Cowpea and sorghum sown simultaneously	1.9^{b}	4.1^{b}	1.5^{b}	4.9^{b}	3.1 ± 0.8^{b}
Cowpea sown two weeks before sorghum	3.2^{a}	3.4^{b}	1.6^{b}	2.6^{c}	2.7 ± 0.4^{b}
Cowpea sown two weeks after sorghum	1.1^{c}	2.2^{c}	1.0^{c}	1.8^{d}	1.5 ± 0.3^{c}
Mean $\pm$ S.E.	2.4 ± 0.6^{b}	3.9 ± 0.8^{a}	1.6 ± 0.3^{c}	3.8 ± 1.0^{a}	

* Six and four plants per plot in monocrop and intercrops respectively, replicated thrice

** Data transformed to $\sqrt{x + 0.5}$ for analysis of variance and means retransformed after analysis.

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly (P=0.05; Duncan's [1955] multiple range test).

of larvae than the intercrops during 1988 season. Cowpea sown simultaneously with sorghum and that sown before sorghum both had the second highest mean number of larvae and were significantly (P=0.05) different from cowpea sown after sorghum. Monocrop cowpea had a significantly (P=0.05) higher *M. testulalis* pupae than the three intercrop patterns which were in turn similar (Table 7.2).

7.3.2 *M. testulalis* larval damage on cowpea pods

The mean percentage damaged cowpea pods from *M. testulalis* larval feeding in the four cropping patterns are shown in Table 7.3. Monocrop cowpea had a significantly (P=0.05) higher percentage damaged pods than both cowpea sown before and after sorghum. Cowpea sown simultaneously with sorghum was not significantly different from either the monocrop or that sown before sorghum. Furthermore, cowpea sown before sorghum was not significantly different from that sown after sorghum.

7.3.3 Cowpea grain yield in four cropping patterns during 1986-88

Mean cowpea grain yields in the four cropping patterns at MPFS and on Rusinga during 1986-1988 planting seasons are shown in Table 7.4. Both cowpea monocrop and

Table 7.2 Mean* number of *M. testulalis* larvae (1986-1988) and pupae (1988) on cowpea plants** in four cropping patterns at MPFS and on Rusinga Island.

Cropping pattern	Larvae					Pupae
	MPFS 1986/87	MPFS 1987	Rusinga 1987	MPFS 1988	Mean ± S.E.	MPFS 1988
Cowpea monocrop	2.2^{a}	2.3^{a}	1.5^{a}	2.3^{a}	2.1 ± 0.2^{a}	1.4 ± 1.1^{a}
Cowpea and sorghum sown simultaneously	1.3^{b}	1.4^{b}	1.3^{ab}	1.7^{b}	1.4 ± 0.1^{b}	1.1 ± 1.1^{b}
Cowpea sown two weeks before sorghum	1.9^{a}	1.9^{a}	1.3^{ab}	1.5^{b}	1.6 ± 0.2^{ab}	1.1 ± 1.0^{b}
Cowpea sown two weeks after sorghum	1.4^{b}	1.3^{b}	1.1^{b}	1.2^{c}	1.2 ± 0.1^{b}	1.0 ± 1.0^{b}
Mean ± S.E.	1.7 ± 0.2^{a}	1.7 ± 0.2^{a}	1.3 ± 0.1^{b}	1.7 ± 0.2^{a}		

* Data transformed to Log (x + 1) for analysis of variance and means retransformed after analysis.
** Six and four plants per plot in monocrop and intercrops respectively, replicated thrice.

Cropping pattern means in a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Table 7.3 Mean percentage cowpea pod damage by *M. testulalis* larvae on cowpea in four cropping patterns (Mean* $\pm$ S.E.)

Cropping pattern	Percentage damaged pods**
Cowpea monocrop	56.5 ± 2.3^{a}
Cowpea and sorghum sown simultaneously	41.2 ± 5.7^{ab}
Cowpea sown two weeks before sorghum	31.2 ± 2.8^{bc}
Cowpea sown two weeks after sorghum	16.9 ± 8.9^{c}

* Data subjected to Arcsine transformation for analysis of variance.
** Twenty four and sixteen pods per plot in monocrop and intercrops respectively, replicated thrice.

Means followed by the same letter are not significantly different (P= 0.05; Duncan's [1955] multiple range test).

cowpea sown two weeks before sorghum had significantly (P=0.05) higher yields compared with one or both of the other two intercrops in different seasons. Overall mean of each cropping pattern in the five seasons (Table 7.4, last column) shows that both cowpea monocrop and cowpea sown before sorghum had significantly (P=0.05) higher grain yields than the other two intercrops. Cowpea sown simultaneously with sorghum had the second highest grain yield and was significantly (P=0.05) different from cowpea sown after sorghum.

The seasonal means show that the grain yield during 1986/87 at MPFS was significantly (P=0.05) higher than in the other four seasons. The 1987 season at MPFS had the second highest grain yield and was significantly (P=0.05) higher than that from Rusinga in the same year. Grain yields at MPFS during 1987/88 and 1988 seasons' crops were statistically similar and were not significantly different from either Rusinga or MPFS during 1987.

7.3.4 Estimation of land productivity under four cropping patterns using land equivalent ratio (LER) index and land equivalent coefficient (LEC)

Land productivity under intercropping reflects the

Table 7.4 Mean cowpea grain yield (Kg/ha) from four cropping patterns during 1986-88 planting seasons

Cropping pattern	MPFS 1986/87	MPFS 1987	Rusinga 1987	MPFS 1987/88	MPFS 1988	Mean $\pm$ S.E.
Cowpea monocrop	555.6^{ab}	454.9^{a}	211.7^{a}	262.4^{a}	239.8^{a}	345.1 ± 1.1^{a}
Cowpea and sorghum sown simultaneously	198.3^{b}	42.9^{cd}	47.9^{c}	115.6^{bc}	62.8^{c}	93.5 ± 1.3^{b}
Cowpea sown two weeks before sorghum	1074.9^{a}	217.0^{b}	139.8^{b}	149.9^{b}	184.9^{ab}	353.3 ± 1.2^{a}
Cowpea sown two weeks after sorghum	65.4^{c}	70.1^{c}	13.6^{d}	16.6^{d}	19.3^{d}	37.0 ± 1.3^{c}
Mean $\pm$ S.E.	473.6 ± 1.4^{a}	196.2 ± 1.4^{b}	103.5 ± 1.4^{c}	136.1 ± 1.4^{bc}	126.7 ± 1.4^{bc}	

* Data transformed to Log (x) for analysis of variance and means retransformed after analysis.

Cropping pattern means within a column and seasonal means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

yield performance of individual crops in their monocrop and intercrop patterns. Since yield can be affected by pest populations, it was thought convenient to show the mean: borer larval population, damage to both cowpea and sorghum, and grain yields observed for the crops in the four cropping patterns during 1986-88 so that they could be related to the resulting land productivity (Table 7.5). Apart from the sorghum stem tunnelling where the four cropping patterns were not significantly different, the cowpea and sorghum monocrops show significant (P=0.05) differences from one or all the intercrops in the above parameters. Land productivity using the land equivalent ratio (LER) was higher in all the intercrops compared with the monocrops, being 18, 35, and 71% more in cowpea sown two weeks after sorghum, cowpea and sorghum sown simultaneously and cowpea sown before sorghum respectively. Using the land equivalent coefficient (LEC) however, it seems that sowing cowpea two weeks after sorghum had no yield advantage because the productivity coefficient (14%) was below the expected value for two crops (25%) (Table 7.5).

7.4 DISCUSSION

The higher *M. testulalis* egg and larval population counts at the field station compared with the farmer's

Table 7.5 Mean stem and pod borer damage to sorghum and cowpea plants and subsequent yield, land equivalent ratio (LER) and coefficient (LEC) in four cropping patterns during 1986-88 period

	Sorghum				Cowpea			Land equivalent and coefficient ratios	
Cropping pattern	Mean borer larvae	Mean leaf damage	Mean %age stem tunnelling	Mean grain yield (Kg/ha)	Mean pod borer larvae	Mean %age damaged pods	Mean grain yield (Kg/ha)	LER	LEC
Cowpea monocrop					2.09[a]	56.5[a]	345.1[a]	1.00	1.00
Sorghum monocrop	2.9[a]	17.0[a]	19.6[a]	1332.2[a]				1.00	1.00
Cowpea and sorghum sown simultaneously	2.5[c]	11.3[ab]	17.3[a]	1363.1[a]	1.43[b]	41.2[ab]	93.5[b]	1.35	0.34
Cowpea sown two weeks before sorghum	2.6[bc]	6.5[b]	18.1[a]	1015.3[b]	1.62[ab]	31.2[bc]	353.3[a]	1.71	0.72
Cowpea sown two weeks after sorghum	2.7[b]	12.2[ab]	18.4[a]	1399.8[a]	1.24[b]	16.9[c]	37.0[c]	1.18	0.14
% C.V.	3.8	66.6	30.7	17.7	13.2	22.5	12.5		

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

field on Rusinga Island is a reflection of the continuouscowpea cropping even in the dry season using irrigation and the frequent artificial infestations at the field station. Egg and larval populations at MPFS were higher during 1987 long rainy season than 1986/87 short rainy season probably due to a more evenly distributed rainfall during 1987 long rainy season which maintained a continuous flush of new shoots and flowers on the cowpea plants where the insects survived. In 1988 long rainy season however, larval population was lower than that of 1987. This could mostly be due to a slightly heavier rainfall and flooding during the establishment and early growth of the crop which coincided with the establishment period of the pest (between 21 and 35DAE).

The general observation that larval populations in almost all the four cropping patterns in the different seasons reached a peak before the egg population peak could suggest that more eggs were hatching into surviving larvae before 35DAE but after that period the bulk of the eggs were unaccounted for. They could have been predated upon or perhaps they did not hatch. Alternatively they could have hatched but the young larvae did not establish due to predation and diseases observed in Chapter 8, or poor food quality as the plants were growing older.

The results on *M. testulalis* egg counts indicate that the moths were attracted more to cowpea plants in monocrop where they laid a significantly higher number of eggs than in one or all the three intercrops in different seasons. Higher oviposition incidences in monocrop cowpea could be explained by the fact that there were 33% more plants in the monocrop compared with intercrop plots and also that the attractive signals from those plants in the monocrop were stronger than in the intercrops where such signals could have been obstructed by the sorghum plants.

There were significantly more *M. testulalis* larvae on cowpea plants in monocrop than in one or more of the intercrop patterns in different seasons and the overall mean resulted in the same trend (Table 7.2). The lower larval incidence in the intercrop patterns compared with the monocrop is in agreement with findings reported from northern Nigeria (Raheja, 1973) that cowpea and sorghum intercropping reduced insect pest incidences on cowpea. Similar observations on *M. testulalis* in Mbita and the surrounding areas have been reported (Amoako-Atta and Omolo, 1983) on cowpea and sorghum sown simultaneously. Furthermore, Omolo and Seshu Reddy (1985) reported that *M. testulalis* infestation on cowpea in the monocrop was almost 20% higher than on plants in a cowpea and sorghum intercrop. Thus, it seems that the presence of sorghum in some of the intercrop patterns could have created some unfavourable environmental conditions for M. testulalis establishment (Gerard, 1976; Kyamanywa and Ampofo, 1988).

The total number of pupae observed in the four cropping patterns during 1988 long rainy season (36 pupae) is quite small compared with the larval population and the area covered by the crop. There were even less pupae in the intercrops where only 13 (i.e. 36.1%) pupae were observed while the rest (i.e. 23 or 63.9%) were from the monocrop cowpea. The generally low number of pupae was a result of predation by ants whose population was constantly high in the field throughout the season (Chapter 8, soil arthropod populations) particularly after the heavy rains had subsided (after about 40DAE). The paper traps were also harvested by termites, which had in the previous short rainy season resulted in zero catches in all the cropping patterns. Thus, the exceptionally wet conditions during 1988 rainy season accounted for the relatively good though still small pupal catches.

Percentage cowpea pod damage was significantly higher on cowpea monocrop than on both cowpea sown before and after sorghum. This can be explained by the higher

M. testulalis larval counts observed in cowpea monocrop compared with the intercrops. Lower cowpea pest damage on cowpea intercropped with sorghum compared with the monocrop has also been reported in northern Nigeria (Raheja, 1973). Ezueh and Taylor (1984) further reported from Nigeria that cowpea planted as an intercrop with maize at 12 weeks after maize establishment had a significantly lower damage from *M. testulalis* and other insect pests. Amoako-Atta and Omolo (1983) reported significantly less *M. testulalis* damage to cowpea when cowpea and sorghum were sown simultaneously and compared with cowpea in monocrop. The results reported here show that cowpea sown simultaneously with sorghum had less cowpea pod damage, but it was not significantly different from the monocrop cowpea or that sown before sorghum.

Mean cowpea grain yields for the five seasons in the four cropping patterns were statistically similar in both cowpea monocrop and that sown before sorghum. In addition, the two cropping patterns' yields were significantly higher than the yields from the other two intercrops. Cowpea sown simultaneously with sorghum had a significantly higher yield than cowpea sown after sorghum. Grain yields were as high in cowpea sown before sorghum as in the monocrop although plant population in the intercrops was 33% less than that in monocrop plots.

The explanation for this could be that the semi-erect local cowpea cultivar enjoyed the wider spacing used in the intercrop to produce longer branches which were not shaded by the late planted sorghum and therefore produced healthier pods compared with the monocrop. The plants in the monocrop were exposed to the open environment and also they became bushy in areas with fertile soils. This created some humid conditions which promoted leaf growth and many flower buds and pods were destroyed by thrips before *M. testulalis* infested the crop. Cowpea sown simultaneously with sorghum had a lower yield compared with the monocrop because it had to compete for space and light for its extensive branches which would normally trail the sorghum stems. The cowpea sown after sorghum had the lowest yield because it was shaded by the taller and already established sorghum plants. Ezueh and Taylor (1984) reported that cowpea is sensitive to shading which in the present work resulted in very low pod production when it was sown after sorghum.

Seasonal yields indicate that the 1986/87 cowpea at MPFS had a significantly higher grain yield than the other four seasons. Although cowpea grain yield from Rusinga was significantly lower than the yields at MPFS during 1986/87 and 1987, it was not significantly different from the 1987/88 and 1988 MPFS yields. It would have been expected that yields on Rusinga would have been better than those at MPFS as M. testulalis incidence was lower on Rusinga compared with MPFS, but aphid infestations in the early growth stage of cowpea were highly destructive to the plants on Rusinga and in some plots there was very low pod setting. High aphid infestations was followed by an exceptionally dry spell in April/May 1987 which was masked by irrigation at the field station. Field soil condition and flooding in some of the cowpea plots had substantial influence on the productivity of cowpea at both sites in addition to pest incidences and cropping pattern.

The results summarized in Table 7.5 show that although stem borer larval populations were significantly higher in sorghum monocrop than in the three intercrops, damage to sorghum plants was not very variable except in sorghum sown after cowpea where leaf damage was lower than in the other cropping patterns. Sorghum grain yield was significantly lower in sorghum sown after cowpea than in the other three cropping patterns which were statistically similar. The differences in grain yields could be explained by late development of tillers on late planted sorghum. The tillers in the earlier planted sorghum could have produced grain to compensate for the yield of damaged main sorghum stems. Pod borer populations and damage on cowpea pods were low on cowpea sown after and that sown simultaneously with sorghum but the grain yields from the treatments were also lower than in the other two treatments. These low yields appear to have resulted from unrelated environmental conditions such as shade and competition from the taller sorghum plants.

Land productivity under intercropping estimated by the land equivalent ratio (LER) index indicates that all the three intercrop patterns were more productive than the monocrops. This is in agreement with findings reported on cowpea and sorghum intercrops planted simultaneously in Mbita and surrounding areas (Amoako-Atta and Omolo, 1983). Land was more productive when cowpea was sown before sorghum. When land productivity was estimated using land equivalent coefficient (LEC) it appeared that sowing cowpea two weeks after sorghum is not productive under the reported experimental conditions. This demonstrates the advantage of using the LEC as it indicates clearly the interaction between the component crops (Adetiloye et al., 1983) compared with the land equivalent ratio (LER). Widening the inter- and intra-row spacing for sorghum could most likely improve the productivity coefficient when cowpea is sown two weeks after sorghum.

Cowpea is reported to be sensitive to shading (Ezueh and Taylor, 1984), and it was relatively free from sorghum shading when sown before the cereal. At the same time there was enough space for the semi-erect cowpea cultivar to wander freely thereby producing better quality grain due to partial protection of cowpea flowers and pods from pests by the sorghum which was well established at the time of pod setting on the cowpea. The sorghum plants in this cropping pattern could have benefited from nitrogen fixed by the earlier planted cowpea and from moisture conserved in the soil by the ground covering cowpea. This would support two suggestions given by Perrin (1977) that increased crop turnover can be a result of: (1) the more efficient use of solar radiation due to better interception of light by the foliage per unit of space and time and, (2) positive interaction between different plant species with mutual or at least unilateral benefits in crop growth and or reproduction.

The present results therefore, indicate that when cowpea was intercropped with sorghum there were delays in M. testulalis oviposition and larval population build-up (Fig. 6.1-6.4). Larval populations on Rusinga Island were delayed for up to four weeks when cowpea was sown two weeks after sorghum (Fig. 6.3). However, the occurrence of egg and larval population peaks do not seem to have been affected by cropping patterns except on late planted cowpea on Rusinga (Fig. 6.3) where delays were clearly marked. Despite these observations, intercropping cowpea with sorghum simultaneously and sowing cowpea after sorghum significantly reduced M. testulalis populations although grain yields were significantly lower than in both the monocrop and cowpea sown before sorghum. Outstandingly, cowpea sown before sorghum outyielded the other intercropped cowpea patterns, resulting in the highest land productivity. Cowpea sown after sorghum indicated a negative interaction with the already established sorghum although it had fewer larvae and lower pod damage compared with the other cropping patterns. On the basis of the results summarized in Table 7.5, it would appear that if both sorghum and cowpea are to be produced efficiently on a piece of land, then cowpea should be sown before sorghum. Furthermore, widening the inter- and intra-row sorghum spacing is likely to improve the productivity of late planted cowpea because it would reduce the shading effect of sorghum on cowpea, thereby minimizing competition for light between the two crops.

CHAPTER 8

TITLE INFLUENCE OF INTERCROPPING SORGHUM AND COWPEA ON THE STEM AND POD BORER NATURAL ENEMIES AND THEIR RELATIONSHIP TO MICROCLIMATIC FACTORS

8.1 INTRODUCTION

Diversified plant stands are often found to have a richer fauna than monocultures because more insect species find ecological niches there. This in turn results in more food resources for higher populations of mostly unspecialized predacious arthropods which bring about a stronger controlling impact on the build-up of a potential pest (Pimentel, 1961; van Emden and Williams, 1974; Altieri et al., 1978). Among the most carefully documented are those cases of reduced pest incidences due to predators originating from or being attracted to the polycultures (Way, 1953, 1983; Dempster and Coaker, 1974; IRRI, 1974; Kayumbo, 1976; Theunissen and Den Ouden, 1980; Altieri et al., 1985).

Various microclimatic effects have been proposed to explain the causes of differences in insect population trends between mixed and sole crop systems. The degree of canopy shading and the nature of cropping patterns often differ between intercropping and sole crop systems and might have considerable effects on the microclimatic conditions for insects and diseases (Way and Heathcote, 1966; Dempster and Coaker, 1974; Trenbath, 1974; Altieri et al., 1981).

Perrin (1977), and Mumford and Baliddawa (1983) suggested that differences in the canopy structure alter the microclimate in mixed crops from that of the sole crops. A closed canopy with its more humid microclimate is favourable for the growth of fungal diseases but also it enhances entomophagous fungi considerably (Trenbath, 1974). Price (1976) reported that colonization of a soybean field by predators increased rapidly only after canopy closure.

Increased humidity and shade near the soil, caused by ground cover are reported to favour general predators such as spiders, carabids and staphylinids (Dempster, 1969; Dempster and Coaker, 1974; Altieri et al., 1981). Mayse (1978) reported significantly greater abundance of predators, namely predaceous bugs like Orius insideiosus Say and Nabis sp., and syrphid larvae, in high-density soybean stands than in low-density plots. This was attributed partially to a more favourable microclimate due to high humidity in the high-density plots. Kyamanywa and Ampofo (1988) reported that reduced light intensity in a cowpea and maize mixture contributed to a relative scarcity of the legume flower thrips, *Megalurothrips sjostedti* Trybom in the mixture.

In view of the little knowledge about the mechanisms responsible for the regulation of pest populations in cereal and legume intercrops grown around the shores of Lake Victoria in South Western Kenya, this experiment was designed to demonstrate the presence of well-known parasites and general predatory feeders of sorghum and cowpea borers in four cropping patterns. In addition, the influence of these cropping patterns on the field microclimate was assessed by maintaining systematic records of temperature, humidity and light intensity within the crop canopies throughout the cropping season and finally the effect of microclimatic factors on borers and their natural enemies was evaluated.

8.2 MATERIALS AND METHODS

Field studies on borer mortality were carried out in the various crop mixtures described in Chapter 3 namely: cowpea monocrop, sorghum monocrop, cowpea and sorghum sown simultaneously, cowpea sown before and cowpea sown after sorghum. During 1986-88 short rainy season *Chilo partellus* Swinhoe and *Maruca testulalis* Geyer egg counts were made at 4 and 3 days interval respectively. All natural enemies associated with the eggs were also recorded. Five sorghum plants per cell were selected at random in each cropping pattern plot and uprooted. Uprooting was only done before stem elongation (5WAE), thereafter the main stem in a sampling hill was cut at soil surface level. The leaves from each plant were removed while noting all borer larvae and other arthropods found on the plant. The stem was later split open and all borer larvae, pupae and any other arthropod on the stem were recorded. All borer larvae, pupae and other arthropods recovered from the plants were carefully collected in labelled rearing dishes and maintained in the laboratory for identification. Borer larvae and pupae were also reared in the laboratory for the recovery of parasites. All dead larvae and pupae were collected separately and the causes of mortality were established with the help of the pathologist.

Evidence of aerial predatory arthropods at Mbita was mostly on Chrysopa eggs on cowpea leaves. Egg counts were made at the same time with those of *M. testulalis* on cowpea plants. Different ant species were also common but it was decided to include them in the soil arthropod group where trapping could easily be done. Soil arthropods were sampled by using plastic disposable cup pitfall traps (bottom diameter 4.2cm, height 9.5cm, top diameter 6.5cm; and filled with 120ml of water). These traps were each securely installed in the ground in the middle of one cell in each plot. The traps were set for 24 hours and samples were taken weekly, from the 6WAE to the 16WAE. Setting the traps for a longer period than 24 hours caused high arthropod decomposition and sorting them out was difficult. Early trapping was disrupted by floods in parts of the experimental field.

Temperature and relative humidity records were obtained by maintaining two dry- and wet-bulb thermometers permanently in a wooden screen in one plot per cropping pattern from the 4WAE through harvest. The screens were securely anchored to the ground at the centre of one of the inner plot cells. The thermometers were placed in the screen at 30cm and 120cm from the soil surface and daily readings were taken at 0900 hours. The relative humidity figures were obtained from the appropriate tables.

The incident light at ground level was measured twice a week at 0900 hours using a quantum radio meter (LI-1905) which had a meter long sensor. The sensor was placed on the ground across two rows of sorghum with a cowpea row in the middle in the intercrop plots, and across two rows in the cowpea and sorghum monocrops. Light intensity, temperatures and relative humidity readings were taken from the same cell.

All data collected was subjected to analysis of variance to compare: dead larvae, dead pupae, mortality factors, canopy temperature and relative humidity differences, and light intensity between the four cropping patterns.

8.3 RESULTS

The quantification of borer egg mortality and the contribution of mortality factors was not fully achieved in this study because observations made on *C. partellus* eggs during 1987/88 season revealed only 1.4% parasitism by *Trichogramma* sp. at the field station. However, general predators including earwigs, different ant species and chrysopid eggs were frequently observed on most plants. Chrysopid eggs were used as an index of chrysopid activity.

The main observation made on the borer larval mortality in the four cropping patterns during 1986-1988 planting seasons was that dead larvae were observed from 4WAE but more constant deaths occurred from 5WAE through harvest. High mortalities were observed from the middle of the season (7WAE) through harvest. The main mortality factor at the beginning of the season (before 7WAE) was diseases which included physiological disturbances while in the remaining part of the season predators and parasites also accounted for the deaths. Sorghum and cowpea sown simultaneously had a significantly (P=0.05) higher mean percentage larval mortality than the other three cropping patterns which were in turn not significantly different from each other in the four planting seasons. There were significantly (P=0.05) lower larval mortalities during 1987 long rainy season at the field station than in the other three seasons which were statistically similar. The contributions of predators and parasites to borer larval mortality were not significantly different from each other but diseases (mainly bacteria and physiological disturbances) had a significantly (P=0.05) higher contribution to larval mortality than both predators and parasites.

Pupal mortality occured spontaneously from 8WAE through harvest in the four cropping patterns. There were no significant differences in the mean percentage dead pupae observed in the four cropping patterns during the four seasons. However, percentage pupal mortality differed in the four seasons with 1986/87 short rainy season having a significantly (P=0.05) lower mortality compared with the other three seasons. Diseases (chiefly bacteria and physiological disturbances) caused a significantly (P=0.05) higher pupal mortality than both parasites and predators which were in turn similar. Birds were also frequently observed picking out larvae and pupae from the stems particularly towards and after harvest but their impact was not assessed.

Temperature differences within the canopies of the five cropping patterns were high at the beginning of the season but their gaps tended to narrow down towards harvest. Relative humidity differences were generally wide and showed no definite trend. Sorghum treatments showed a close resemblance in their ability to allow light to pass through their canopies but towards harvest sorghum monocrop allowed more light through its canopy than the intercrops. Cowpea monocrop allowed more light to pass through its canopy throughout the cropping season compared with the other cropping patterns.

Soil arthropods were dominated by different predatory ant species which accounted for 54.68% of all arthropods collected for the season. The second largest group were the Coleoptera (24.5%, mainly Carabids, Coccinnelids) and Dermaptera (Earwigs). Significantly more arthropods were trapped in cowpea monocrop than sorghum monocrop and the three intercrops were not significantly different from either of the monocrops.

8.3.1 Sorghum stem borer larval mortality in four cropping patterns during 1986-1988.

Weekly mean percentage dead stem borer larvae during 1986-1988 planting seasons in the four cropping patterns are shown in Figures 7.1-7.4. The mean figures were obtained by taking total dead larvae as a percentage of the total replicate larvae collected. The mean for three replicates was used in plotting the graphs.

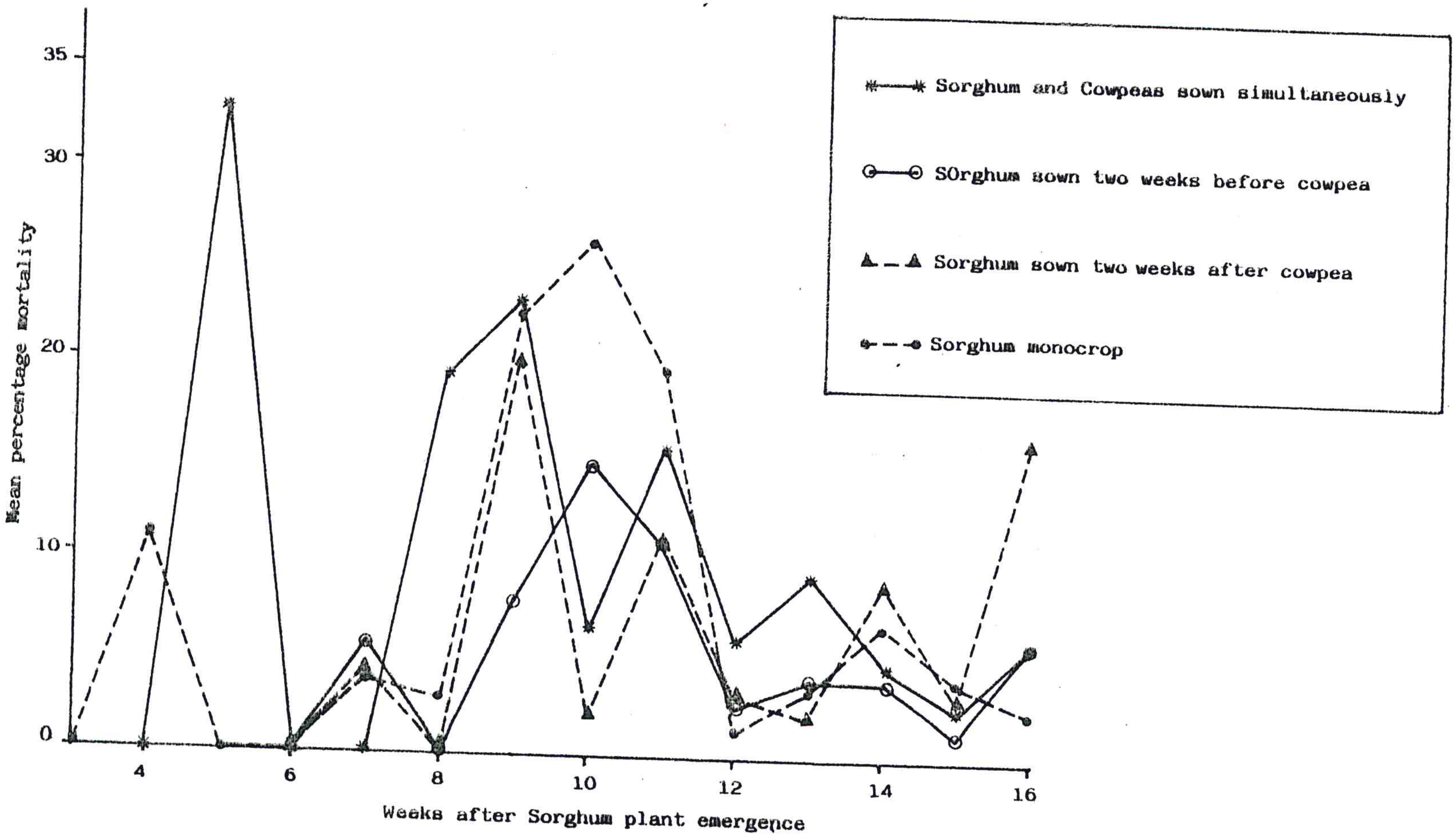
During 1986/87 short rainy season all four cropping patterns had some mortality at the beginning of the season (between 4-7WAE) but this was followed by sharp drops to zero at 5, 6 and 8WAE in different cropping patterns (Fig. 7.1). Towards the end of the season the four cropping patterns maintained a low but constantly fluctuating mean mortality of between 1-10 percent. At harvest the sorghum sown after cowpea had the highest mean percentage mortality of about 16% while sorghum monocrop had the lowest mean of 2.5%. There were no significant differences between the cropping patterns although numerically the intercrop patterns had slightly higher mean percentage mortalities than the monocrop.

Mortality factors observed for the season were parasitism (mainly Apanteles sp. on Busseola fusca Fuller, Euvipio sp. on both B. fusca and C. partellus), predation (particularly different ant species -Pheidole sp., Camponotus sp., Dorylus sp. and Crematogaster sp.; and beetles- Carabids) and disease incidences (unidentified bacteria, and physiological disorders). Parasites and predators accounted for 6.3% (Apanteles sp., 83.3%; Euvipio sp., 16.7%) and 6.4% larval mortality respectively, while diseases accounted for 88.3% of dead larvae. Diseases caused a significantly (P=0.05) higher larval mortality than either parasites or predators during 1986/87 season.

Larval mortality during 1987/88 season was observed from the 5WAE through harvest with the highest peak of about 30% in sorghum sown after cowpea which occurred in the 5WAE (Fig. 7.2). The second highest peak of 23.5% was from the same cropping pattern at the 9WAE. All other mortality observations during 1987/88 ranged between zero and 20.3%. The mortalities in the intercrop patterns were slightly higher but not significantly

FIGURE 7.1

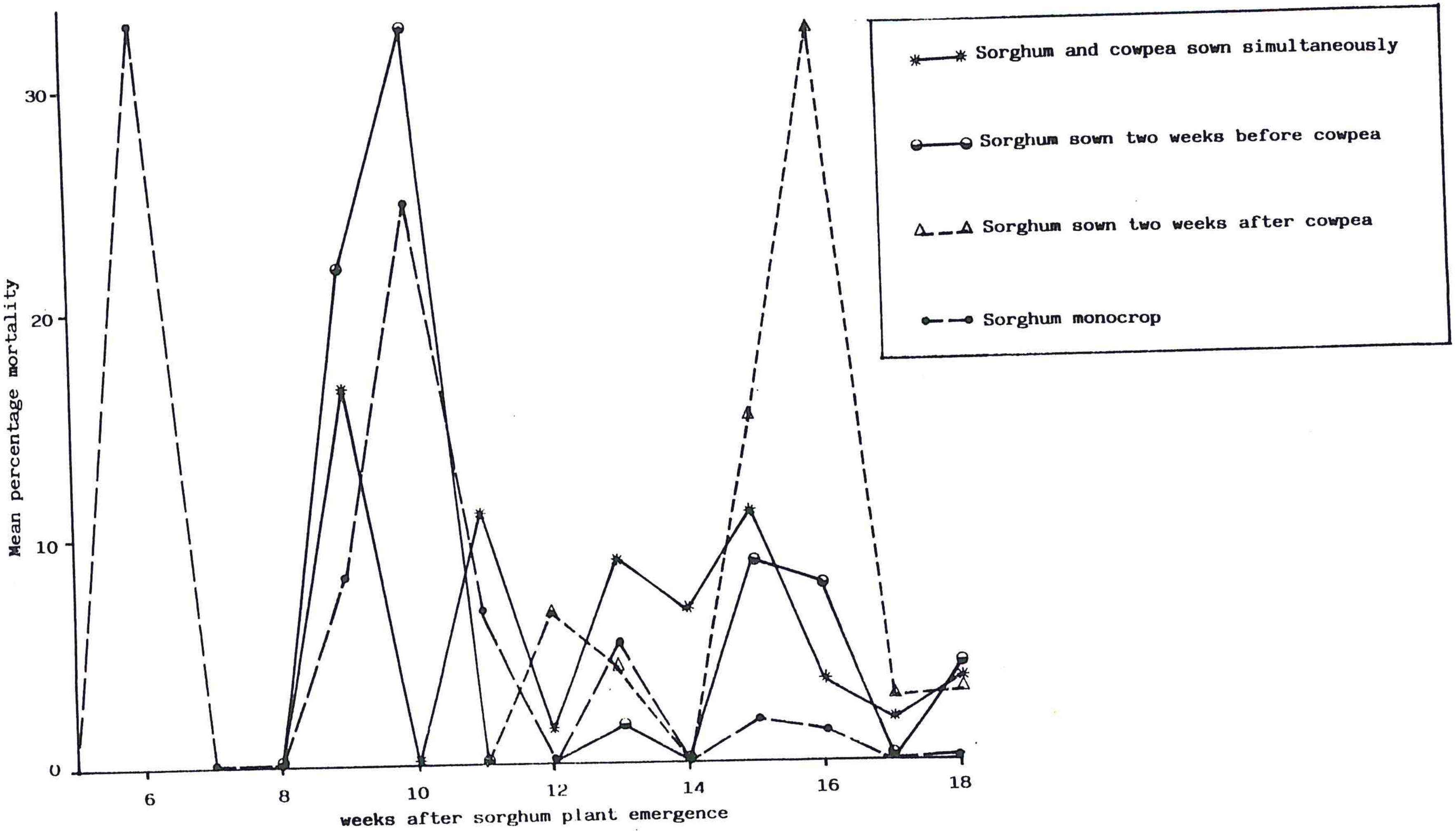
Weekly mean percentage dead stem borer larvae in four sorghum cropping patterns at MPFS during 1986/87 short rainy season



Sorghum and Cowpeas sown simultaneously
SOrghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Sorghum monocrop
Mean percentage mortality
0
10
20
30
35
4
6
8
10
12
14
16
Weeks after Sorghum plant emergence

FIGURE 7.2

Weekly mean percentage dead stem borer larvae in four sorghum cropping patterns at MPFS during 1987 long rainy season


Mean percentage mortality
30
20
10
0
6
8
10
12
14
16
18
weeks after sorghum plant emergence
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Sorghum monocrop

different from those in the sorghum monocrop.

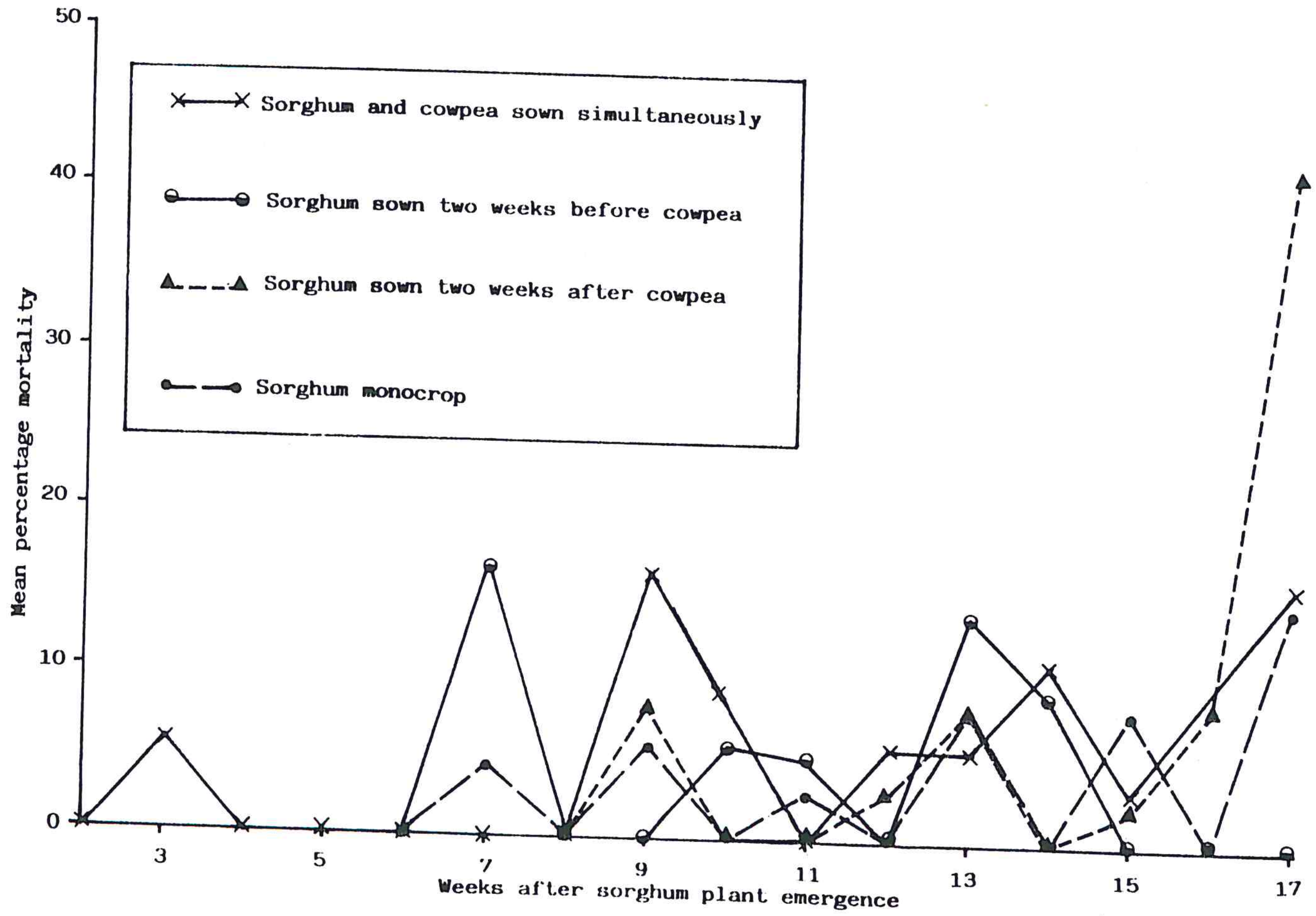
The contribution of mortality factors to dead stem borer larvae for 1987/88 was: predators (7.3%), parasites- 18.3% (Apanteles sp., 83.3%; Euvipio sp., 16.7%), and diseases (74.4%). Dead larvae collected before the 10WAE were predominantly killed by diseases while in the remaining part of the season parasites and predators were also observed.

Weekly mean percentage dead stem borer larval mortality at MPFS in the four cropping patterns during 1987 long rainy season are shown in Fig. 7.3. Dead larvae were observed from the 6WAE to the end of season. Three prominent high peak mortalities of about 33% were observed at the 6, 10 and 16WAE respectively for the sorghum monocrop, sorghum sown before cowpea and sorghum sown after cowpea. There were no significant differences in the larval mortalities between the four cropping patterns although numerically sorghum monocrop had the lowest mean percentage larval mortality for that season.

The main larval mortality factors during 1987 were: predators (9.5%), parasites- 14.3%, (-Apanteles sp., 66.7%; -Euvipio sp., 33.3%), and diseases (76.2%). The parasites were observed from the middle (9WAE) of the

FIGURE 7.3

Weekly mean percentage dead stem borer larvae in four sorghum cropping patterns on Rusinga Island during 1987 long rainy season


Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Sorghum monocrop
Mean percentage mortality
Weeks after sorghum plant emergence
50
40
30
20
10
0
3
5
7
9
11
13
15
17

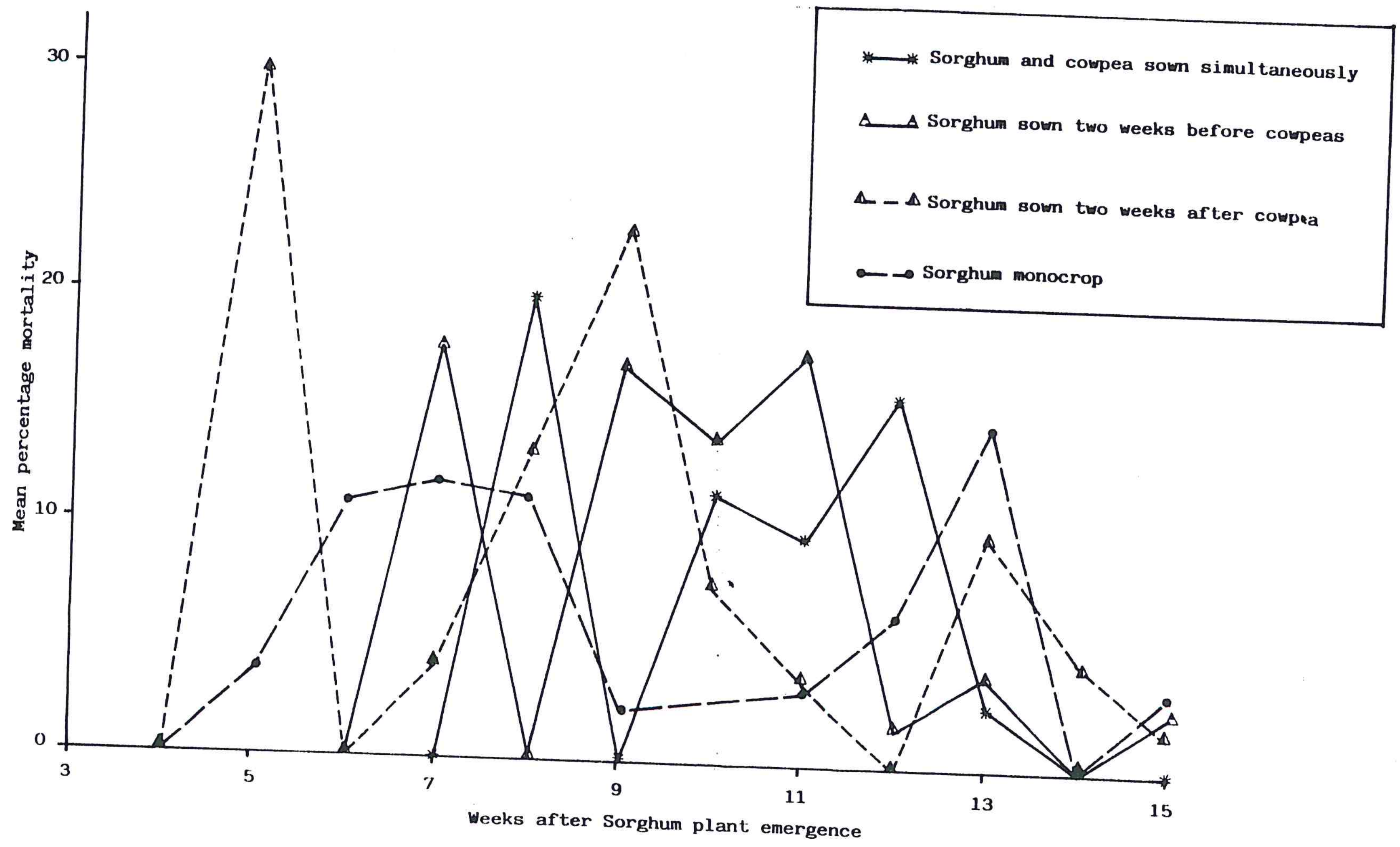
season as was the case during 1986/87 season while predators increased with the age of the crop. Diseased larvae were common at the beginning of the season although they were observed through harvest.

Weekly mean stem borer larval mortality on Rusinga Island in the four cropping patterns during 1987 long rainy season are shown in Fig. 7.4. There was only one prominent high mortality peak in sorghum sown after cowpea (42.2%) which was observed on the last sampling date (17WAE). All other mean mortalities observed in the four cropping patterns ranged between zero and 16.6% showing some erratic occurrence from the beginning of the season to the 9WAE. There were significantly (P=0.05) more dead larvae in 17WAE than at any other time in that season. There were no significant differences between the cropping patterns. However, the intercrops had slightly more dead larvae compared with the sorghum monocrop.

Contribution of the different mortality factors to dead larval count was: predators (10.3%), parasites (12.8%, all by *Apanteles* sp.), diseases (76.9%) (mainly bacteria and physiological disorders). Parasites were observed towards the end of the season while predators and diseases were present almost throughout the season.

FIGURE 7.4

Weekly mean percentage dead stem borer larvae in four sorghum cropping patterns at MPFS during 1987/88 short rainy season


Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpeas
Sorghum sown two weeks after cowpea
Sorghum monocrop
Mean percentage mortality
0
10
20
30
3
5
7
9
11
13
15
Weeks after Sorghum plant emergence

The mean percentage dead stem borer larvae in the four cropping patterns during 1986-88 planting seasons are shown in Table 8.1. Significantly (P=0.05) more larval mortality occurred in sorghum sown simultaneously with cowpea than in the other three cropping patterns which were in turn statistically similar.

The mean percentage stem borer larval mortality in the four planting seasons is shown in Table 8.2. The 1987 long rainy season at MPFS had a significantly (P=0.05) lower mean percentage larval mortality compared with the other three planting seasons which were in turn not significantly different from each other.

Percentage contribution of mortality factors to dead larval count in the four cropping patterns during 1986-88 planting seasons is shown in Table 8.3. There were no significant differences in the percentage mortality caused by diseases and parasites in the four cropping patterns. However, a significantly (P=0.05) higher percentage of predation occurred in sorghum sown simultaneously and sorghum sown after cowpea than in the other two cropping patterns. Diseases accounted for a significantly (P=0.05) higher stem borer larval mortality than either the predators or parasites. The parasites and predators had similar contributions to the stem borer

Table 8.1 Effect of sorghum cropping pattern on stem borer larval mortality during 1986-88 cropping seasons (Mean ± S.E.).

Cropping pattern	Percentage mortality
Sorghum monocrop	3.9 ± 0.6^{b}
Sorghum and cowpea sown simultaneously	5.9 ± 0.7^{a}
Sorghum sown two weeks before cowpea	4.7 ± 0.4^{b}
Sorghum sown two weeks after cowpea	4.8 ± 0.6^{b}

Means followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Table 8.2 Percentage sorghum stem borer larval mortality in four planting seasons during 1986-88 (Mean $\pm$ S.E.)

Planting season	Percentage mortality
1986/87 short rain season at MPFS	5.5 ± 0.4^{a}
1987/88 short rain season at MPFS	5.3 ± 0.3^{a}
1987 long rain season at MPFS	3.3 ± 0.4^{b}
1987 long rain season on Rusinga	5.3 ± 0.7^{a}

Means followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test.

Table 8.3 Percentage mortality factor contribution of different factors to stem borer larval mortalityin four sorghum cropping patterns in 1986-88 period (Mean$\pm$S.E.).

Cropping pattern	Diseases	Parasites	Predators
Sorghum monocrop	83.5 ± 3.0^{a}	11.8 ± 3.6^{a}	4.7 ± 2.8^{b}
Sorghum and cowpea sown simultaneously	76.0 ± 9.1^{a}	11.2 ± 6.6^{a}	12.8 ± 3.5^{a}
Sorghum sown two weeks before cowpea	79.8 ± 6.0^{a}	15.2 ± 4.5^{a}	5.0 ± 3.3^{b}
Sorghum sown two weeks after cowpea	76.0 ± 8.5^{a}	13.3 ± 6.2^{a}	10.7 ± 4.1^{a}
Mean	78.9 ± 3.2^{a}	12.7 ± 2.7^{b}	8.4 ± 0.9^{b}

Cropping pattern means within a column and mortality factor means within the bottom row followed by the same letter are not significantly (P=0.05; Duncan's [1955] multiple range test).

larval mortality for that period.

8.3.2 Effect of sorghum cropping pattern on stem borer pupal mortality during 1986-88 planting seasons

The mean percentage mortality in stem borer pupae for the two year period was almost five times higher than the larval mortality in the four cropping patterns. Seasonal mean percentage dead pupae were also higher than the seasonal mean dead larvae, being twice or more in different planting seasons. The factors causing pupal mortality had different magnitudes of contribution compared with the larvae in that unlike the larvae where diseases caused the majority of mortality, significantly more pupae died of parasitism than either of diseases or predators.

The mean percentage stem borer pupal mortality in the four cropping patterns during 1986-88 period is shown in Table 8.4. Both sorghum sown simultaneously with cowpea and sorghum sown after cowpea had slightly higher (but not significantly) mean percentage pupal mortalities than the other two cropping patterns.

Seasonal mean percentage dead pupae during 1986-88 period is shown in Table 8.5. There was a significantly

(P=0.05) higher mean percentage dead pupae at MPFS during 1987 long rainy season than in the other three planting seasons. Parasites accounted for 50.9% of the total pupal mortality during 1987 and the individual parasite contribution was: Dentichasmias busseolae Heinrich (92.3%) and Pediobus furvus Gah. (7.7%). The second highest mean pupal mortality was also at MPFS during 1987/88 short rainy season when parasites caused 75.9% of the mortality in which D. busseolae accounted for 70.0%; P. furvus, 20.0% and Hyperchalcidia soudanensis Stef. 5%. Pupal mortality during 1987/88 short rainy was significantly (P=0.05) higher than that of 1986/87 short rainy season at MPFS (parasites accounted for 2.24% of the mortality in which D. busseolae caused 85.7% and P. furvus 16.3%). The mean percentage pupal mortality on Rusinga during 1987 long rainy season (where parasitism from D. busseolae alone accounted for 66.7% of the total mortality) was not significantly different from that at MPFS during 1986/87 or 1987/88 short rainy seasons.

Mortality factor contribution to dead stem borer pupae in the four cropping patterns for 1986-88 period is shown in Table 8.6. Parasitism was significantly (P=0.05) higher in sorghum sown simultaneously and sorghum sown after cowpea than in the other two cropping patterns which were in turn similar. Disease factors

Table 8.4 Effect of sorghum cropping pattern on stem borer pupal mortality during 1986-88 planting seasons (Mean* ± S.E.)

Cropping pattern	Percentage mortality
Sorghum monocrop	25.2 ± 7.8[a]
Sorghum and cowpea sown simultaneously	29.8 ± 8.7[a]
Sorghum sown two weeks before cowpea	22.9 ± 11.0[a]
Sorghum sown two weeks after cowpea	28.6 ± 10.4[a]

* Data subjected to Arcsine transformation for analysis
Means followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Table 8.5 Percentage sorghum stem borer pupal mortality during 1986-88 planting seasons (Mean* ± S.E.)

Planting season	Percentage mortality
1986/87 short rain season at MPFS	9.5 ± 0.9[c]
1987/88 short rain season at MPFS	26.2 ± 2.2[b]
1987 long rain season at MPFS	52.2 ± 2.7[a]
1987 long rain season on Rusinga	18.7 ± 5.2[bc]

*Data subjected to Arcsine transformation for analysis
Means followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

were significantly higher in sorghum monocrop and sorghum sown before cowpea than in the other two intercrops. Furthermore, pupae from sorghum sown simultaneously with cowpea had more disease infections than pupae from sorghum sown after cowpea. There was a significantly (P=0.05) higher incidence of predation on pupae in the sorghum monocrop than in the intercrops. Parasites accounted for a significantly (P=0.05) higher percentage of pupal mortality than either diseases and predators in the two year period. Diseases and predators accounted for similar pupal mortalities in that period.

The main pupal parasites were Dentichasmias busseolae Heinrich (contributed 60-83% of the mortality) observed as a solitary pupal endoparasite of C. partellus, and Pediobius furvus Gah. (7-20%) observed as a gregarious pupal endoparasite on C. partellus and B. fusca. Hyperchalcidia soudanensis caused 4% C. partellus pupal mortality in 1987/88 season. Diseases were mainly bacterial infections although many pupae were found with fully developed dead moths within the pupal cuticles, a condition regarded as been a result of physiological disturbances. Predation was chiefly from different ant species (Pheidole sp., Camponotus sp. and Dorylus sp.) and the pupae were found partly eaten or being carried away by the ants.

Table 8.6 Mortality factor contribution to stem borer pupae in four sorghum cropping patterns during 1986-88 period

Cropping pattern	Parasites	Diseases	Predators
Sorghum monocrop	54.9 ± 21.5^{b}	27.8 ± 24.2^{a}	17.3 ± 10.8^{a}
Sorghum and cowpea sown simultaneously	70.8 ± 11.0^{a}	20.8 ± 7.5^{b}	8.3 ± 8.3^{b}
Sorghum sown two weeks before cowpea	58.8 ± 5.1^{b}	32.4 ± 2.8^{a}	8.1 ± 9.1^{b}
Sorghum sown two weeks after cowpea	88.1 ± 9.1^{a}	6.1 ± 3.7^{c}	5.8 ± 5.8^{b}
Mean	68.4 ± 6.5^{a}	18.9 ± 6.2^{b}	12.7 ± 7.6^{b}

Cropping pattern means within a column and mortality factor means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

8.3.3 Mortality in *M. testulalis* larvae and pupae in four cowpea cropping patterns during 1988 long rainy season.

The mean percentage dead *M. testulalis* larvae and pupae in the four cropping patterns are shown in Table 8.7. The cowpea sown simultaneously with sorghum had a slightly higher (but not significantly) mean percentage dead larvae than the other three cropping patterns, while cowpea sown after sorghum had the lowest mean percentage dead larvae. The main factors which contributed to larval mortality were predators (3.8%, notably ants and carabid larvae), parasites (30.8%, particularly *Macrocentrus* sp.) and diseases (65.4%, mainly by caused bacteria).

Mortality in pupae was very low in the four cropping patterns. This would most likely correspond to the low pupal population observed throughout that season. In cowpea sown after sorghum only one dead pupa was collected for the whole season. A total of eight pupae were collected in cowpea sown simultaneously with sorghum and one of them was dead. Twenty three pupae were collected from cowpea monocrop and six of them were dead. No pupae were collected from cowpea sown before sorghum. Predators (mainly ants) accounted for 25% of

Table 8.7 Effect of cowpea cropping pattern on *M. testulalis* larval and pupal mortality in 1988 long rainy season (Mean ± S.E.)

Cropping pattern	Larvae*	Pupae**
Cowpea monocrop	6.5 ± 2.4[a]	25.4
Cowpea and sorghum sown simultaneously	6.8 ± 2.5[a]	33.3
Cowpea sown two weeks before sorghum	5.6 ± 2.0[a]	0.3
Cowpea sown two weeks after sorghum	3.4 ± 2.1[a]	33.3

* Data subjected to Arcsine transformation for analysis of variance (Gomez and Gomez, 1984).

**Data subjected to Bartlett's transformation only (Bartlett, 1947; Gomez and Gomez, 1984) total pupal mortality while diseases accounted for 75%.

8.3.4 General predatory arthropod population in cowpea and sorghum cropping patterns

The predatory arthropods which were assessed included chrysopid eggs (Chrysopa sp., [Neuroptera: Chrysopidae]) on cowpea leaves used here as an index of chrysopid activity, and soil arthropods which were apparently dominated by different species of ants, both larvae and adults of Coleoptera, spiders, earwigs and some bugs.

The mean number of chrysopid eggs observed on cowpea leaves in the four cropping patterns is shown in Table 8.8. There were significantly (P=0.05) less eggs on cowpea sown after sorghum than on the other three cropping patterns which were in turn not significantly different from each other. Numerically however, the cowpea monocrop had a slightly higher mean number of eggs compared with the two intercrops.

The mean number of arthropods collected from the traps is shown in Table 8.8. Significantly (P=0.05) more arthropods were trapped in cowpea monocrop than in sorghum monocrop. The three intercrops were neither significantly different from each other nor from the two monocrops. There was a significantly (P=0.05) lower number of ants in sorghum monocrop than cowpea monocrop, sorghum sown simultaneously with and sorghum sown before cowpea but, sorghum sown after cowpea was statistically similar to the sorghum monocrop and the other two intercrops. Cowpea monocrop had a statistically higher number of beetles than the other cropping patterns. The number of spiders observed in sorghum sown before cowpea was significantly (P=0.05) lower than in the other cropping patterns which were similar. In addition, sorghum sown before cowpea had a significantly (P=0.05) higher number of earwigs than the other cropping patterns which were in turn similar. The composition of arthropods collected was:

Ants	(54.68%)	-mainly Pheidole sp., Camponotus sp. and Dorylus sp.
Coleoptera	(24.50%)	- e.g. Gonocephalus simplex F. and Cheilomenes sp.
Orthoptera	(5.18%)	- mainly crickets
Spiders	(4.39%)	
Earwigs	(3.72%)	- mainly Forficula sp.
Hemiptera	(3.34%)	
Diptera	(1.30%)	
Centipedes	(1.09%)	
Isoptera	(0.58%)	
Lepidoptera	(0.54%)	
Unidentified	(0.68%)	

Table 8.8 Effect of sorghum and cowpea cropping patterns on the number of chrysopid eggs and soil arthropods during 1988 long rainy season (Mean $\pm$ S.E.)

Cropping monocrop	Chrysopid eggs	Soil arthropods:				
		All	Ants	Beetles (carabids)	Spiders	Earwigs
Cowpea monocrop	1.5 ± 0.3^{a}	18.1 ± 2.2^{a}	8.5 ± 1.1^{a}	7.1 ± 2.0^{a}	0.6 ± 0.2^{a}	0.3 ± 0.2^{b}
Sorghum monocrop		12.3 ± 1.4^{b}	6.6 ± 0.9^{b}	2.5 ± 0.6^{bc}	0.7 ± 0.3^{a}	0.3 ± 0.1^{b}
Sorghum and cowpea sown simultaneously	0.9 ± 0.2^{a}	14.4 ± 1.4^{ab}	8.2 ± 1.2^{a}	3.0 ± 0.7^{b}	0.8 ± 0.2^{a}	0.4 ± 0.2^{b}
Sorghum sown two weeks before cowpea	0.3 ± 0.1^{b}	13.7 ± 1.9^{ab}	8.8 ± 1.7^{a}	1.9 ± 0.5^{c}	0.3 ± 0.1^{b}	1.1 ± 0.6^{a}
Sorghum sown two weeks after cowpea	1.1 ± 0.6^{a}	14.0 ± 1.2^{ab}	7.5 ± 0.8^{ab}	3.2 ± 0.6^{b}	0.8 ± 0.2^{a}	0.5 ± 0.3^{b}

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

8.3.5 Light intensity at ground level in five cowpea and sorghum cropping patterns

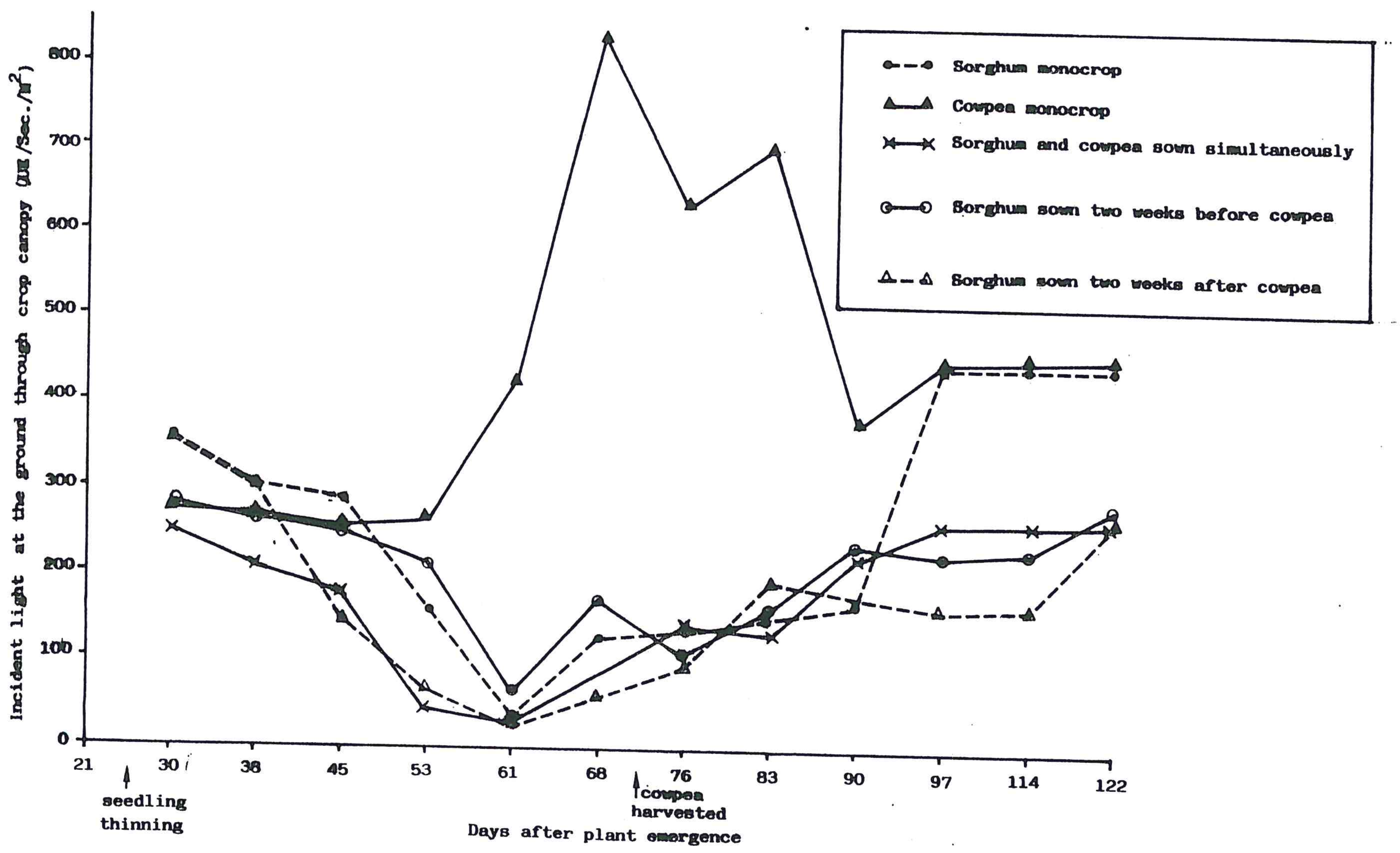
Sorghum cropping patterns showed a close resemblance in their ability to allow light through their canopies throughout the cropping season except towards harvest when sorghum monocrop allowed more light than the other treatments. Cowpea monocrop on the other hand, showed a very high capacity in allowing light through its canopy for a long period in the middle of the season.

The amount of light reaching the ground in the five cropping patterns is shown in Fig. 7.5. All patterns started with a light intensity of between 250 to 350 $\mu E/sec/m^2$ at 30 days after plant emergence (DAE) and maintained a gradual drop until 45DAE. Cowpea monocrop maintained a rising trend for most of the season but towards harvest there was a gradual drop. In the other cropping patterns there was a falling trend (lowest at 61DAE) before a gradual rise towards harvest.

The mean incident light at the ground in the five cropping patterns at three plant growth stages is shown in Table 8.9. Significantly (P=0.05) more light reached the ground in the cowpea monocrop than in all the other cropping patterns which were in turn not significantly

FIGURE 7.5

Effect of sorghum and cowpea cropping patterns on the total amount of incident light reaching the ground through their canopies during 1987/88 short rainy season


Sorghum monocrop
Cowpea monocrop
Sorghum and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Incident light at the ground through crop canopy (μE/Sec./M²)
800
700
600
500
400
300
200
100
0
21
30
38
45
53
61
68
76
83
90
97
114
122
seedling thinning
cowpea harvested
Days after plant emergence

different from each other. At the beginning of the season (26-38DAE) sorghum monocrop and that sown before cowpea both allowed a significantly (P=0.05) higher amount of light through their canopies than sorghum sown simultaneously with cowpea. The other two cropping patterns were statistically similar to sorghum monocrop and that sown simultaneously with cowpea. At closed canopy (57-65DAE) stage cowpea monocrop allowed a significantly (P=0.05) higher amount of light through the canopy than all the other cropping patterns. Later in the season (90-100DAE) cowpea monocrop allowed a significantly (P=0.05) higher amount of light through its canopy than the other three intercropping patterns. Sorghum monocrop had the second highest amount of light through its canopy but it was not significantly different from the cowpea monocrop and two of the intercrops, i.e. sorghum sown simultaneously with cowpea and sorghum sown after cowpea. Sorghum sown before cowpea allowed the least amount of light through its canopy but it was not significantly different from the other intercrops. The bottom row in Table 8.9 indicates that significantly more light passed through the crop canopy at 26-38DAE and 90-100DAE than at 57-65DAE.

Table 8.9 Effect of sorghum and cowpea cropping patterns on the amount of incident light at ground level during 1987/88 short rainy season (Mean* ± S.E.)

Cropping pattern	Incident light at: Open canopy (26-38DAE)	Closed canopy (57-65DAE)	Open canopy (90-100DAE)	Seasonal mean
Cowpea monocrop	275.0 ± 2.9^{ab}	516.3 ± 61.6^{a}	421.0 ± 21.5^{a}	404.1 ± 39.8^{a}
Sorghum monocrop	335.0 ± 15.3^{a}	30.7 ± 4.4^{b}	280.0 ± 85.8^{ab}	215.2 ± 53.2^{b}
Sorghum and cowpea sown simultaneously	236.7 ± 13.3^{b}	42.0 ± 3.5^{b}	231.7 ± 17.6^{bc}	170.1 ± 32.7^{b}
Sorghum sown two weeks before cowpea	332.7 ± 14.9^{a}	39.7 ± 9.8^{b}	168.3 ± 5.4^{c}	180.2 ± 42.7^{b}
Sorghum sown two weeks after cowpea	274.3 ± 4.7^{ab}	66.3 ± 4.4^{b}	231.7 ± 4.4^{bc}	190.8 ± 31.8^{b}
Mean	290.0 ± 11.0^{a}	139.0 ± 51.6^{b}	266.5 ± 27.4^{a}	

Means within a column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test.

8.3.6 Temperature and relative humidity differences within canopies of five sorghum and cowpea cropping patterns

Temperature differences within the crop canopies in the five cropping patterns were all high at the beginning of the season but tended to follow a falling trend towards harvest. The trends in the five cropping patterns are shown in Appendix 2. The temperature differences which were observed on the same days as light intensity, ranged between 0.5 and 5.5 in the five cropping patterns. Wide temperature gaps were observed in the middle of the season (between 61 and 83DAE). The humidity differences observed on the same days as light intensity, ranged from zero to 14 and each cropping pattern had its highest and lowest humidity difference at different dates during the cropping season. After 53DAE there were frequent occasions without relative humidity differences in all the cropping patterns.

The mean temperature and relative humidity differences for the five cropping patterns are shown in Tables 8.10 and 8.11 respectively. Temperature differences were significantly (P=0.05) higher in sorghum monocrop than in three of the cropping patterns, i.e. cowpea monocrop, cowpea and sorghum sown simultaneously, and cowpea sown before sorghum. The second highest difference was in cowpea sown after sorghum, which was not significantly different from sorghum monocrop or cowpea sown simultaneously with sorghum. The third highest temperature difference was in cowpea and sorghum sown simultaneously which was also not significantly different from either cowpea sown before sorghum or that sown after sorghum.

At 26-38 DAE the four cropping patterns had similar temperature differences within their canopies but at 57-65DAE cowpea sown after sorghum had a significantly (P=0.05) lower temperature difference than the other cropping patterns. At 90-100DAE there were no significant differences between the cropping patterns. The temperature differences at 26-38DAE were significantly (P=0.05) higher than at 90-100DAE. Temperature differences at 57-65DAE were not significantly different from those at 26-38 or 90-100DAE.

The relative humidity differences were statistically similar in the two monocrops and also in cowpea sown after sorghum, and the three were significantly (P=0.05) higher than both cowpea sown simultaneously with sorghum and cowpea sown before sorghum which were in turn similar. The humidities of the latter two intercrops were also higher than those in the former three cropping patterns.

The five cropping patterns had similar canopy humidity differences at 26-38DAE but at 57-65DAE cowpea and sorghum sown simultaneously had a significantly (P=0.05) higher difference than cowpea sown after sorghum. However, the other three cropping patterns were not significantly different from the cowpea sown simultaneously with and that sown after sorghum. Cowpea monocrop and that sown after sorghum had significantly (P=0.05) higher humidity differences than sorghum monocrop and cowpea sown before sorghum at 90-100DAE. Cowpea sown simultaneously with sorghum was not significantly different from either cowpea or sorghum monocrops. The mean humidity differences between the three dates were statistically similar.

8.4 DISCUSSION

The present studies quantified very little *C. partellus* egg mortality due to parasitism (only 1.4% from *Trichogramma* sp.). This could suggest that the occurrence of the parasites was very low in the study area during that period. Similar observations have been made at Mbita and on Rusinga by Lu Quing Guang (personal

Table 8.10 Effect of sorghum and cowpea cropping patterns on canopy temperature differences during 1987/88 short rainy season (Mean ± S.E.)

Cropping pattern	Differences at:			Seasonal mean
	Open canopy (26-38DAE)	Closed canopy (57-65DAE)	Open canopy (90-100DAE)	
Cowpea monocrop	4.5 ± 0.2^{a}	3.1 ± 0.3^{a}	2.4 ± 0.2^{a}	2.55 ± 0.1^{d}
Sorghum monocrop	4.6 ± 0.1^{a}	3.5 ± 1.3^{a}	1.8 ± 0.1^{a}	3.17 ± 0.1^{a}
Cowpea and sorghum sown simultaneously	3.9 ± 0.1^{a}	3.7 ± 0.3^{a}	1.5 ± 0.2^{ab}	2.87 ± 0.1^{bc}
Cowpea sown two weeks before sorghum	4.8 ± 0.2^{a}	3.3 ± 0.4^{a}	1.6 ± 0.2^{a}	2.76 ± 0.1^{cd}
Cowpea sown two weeks after sorghum	4.3 ± 0.2^{a}	1.7 ± 0.3^{b}	1.7 ± 0.1^{a}	3.06 ± 0.2^{ab}
Mean	4.4 ± 0.1^{a}	3.0 ± 0.2^{ab}	1.8 ± 0.1^{b}	

Cropping pattern means within a column and canopy means in the bottom row followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

Table 8.11 Effect of sorghum and cowpea cropping patterns on canopy relative humidity differences during 1987/88 short rainy season (Mean $\pm$ S.E.).

Cropping pattern	Differences at: Open canopy (26-38DAE)	Closed canopy (57-65DAE)	Open canopy (90-100DAE)	Seasonal mean
Cowpea monocrop	8.7 ± 0.7^{a}	3.5 ± 1.3^{ab}	7.5 ± 0.7^{a}	6.0 ± 0.4^{a}
Sorghum monocrop	8.3 ± 0.3^{a}	4.0 ± 1.1^{ab}	1.5 ± 0.8^{b}	6.6 ± 0.3^{a}
Cowpea and sorghum sown simultaneously	6.4 ± 0.4^{ab}	8.1 ± 1.3^{a}	4.8 ± 1.0^{ab}	4.3 ± 0.4^{b}
Cowpea sown two weeks before sorghum	7.9 ± 0.4^{a}	3.3 ± 1.0^{ab}	1.4 ± 0.8^{b}	4.0 ± 0.4^{b}
Cowpea sown two weeks after sorghum	7.1 ± 0.3^{a}	2.4 ± 1.1^{b}	6.9 ± 1.0^{a}	5.7 ± 0.4^{a}
Mean	7.7 ± 0.2^{a}	4.3 ± 0.6^{ab}	4.4 ± 0.5^{ab}	

Cropping pattern means within a column and canopy means in the bottom row followed by the same letter are not significnatly different (P=0.05; Duncan's [1955] multiple range test).

communication). Previous reports from the site (Seshu Reddy, 1983) indicated that predators such as earwigs (*Diaperasticus erythrocephala* Oliver), ladybird beetles (*Cheilomenes* sp.) and black ants (*Camponotus* sp.) destroy a large proportion of all four common stem borer species eggs (*C. partellus*, *B. fusca*, *E. saccharina*, and *S. calamistis*). These predators were frequently observed on plants in the present study but they were not found feeding specifically on borer eggs.

Mohyuddin and Greathead (1970) also reported that *Pheidole* sp. and other formicids were responsible for destroying 90% of the eggs of stem borers at Kawanda in Uganda. Mathez (1972) reported from the Coast Province of Kenya that predator activity on stem borer eggs in the field appeared to be nil although in the laboratory some unidentified ants were found feeding on the eggs. He further reported that parasitism played a vital role in egg mortality where it accounted for up to 90% kill (mainly from *Telenomus* sp. and *Trichogramma* sp. on *Chilo* eggs and *Platytelenamus busseolae* Gah. and *Trichogramma* sp. on *S. calamistis* eggs).

Girling (1978) reported two species of ants *Tetramorium bicarinatum* (Nylander) and *Camponotus sericeus* (F.) taking *E. saccharina* eggs from maize plants while several other species of ants were present on the plants. Furthermore he reported a gradual decline in egg numbers over the 7-8 days between oviposition and hatching, and 91.6% of the eggs were taken away during that period. In an experiment with insecticide and grease banded maize and sorghum stems to prevent ants from climbing up, Girling (1978) found that only 5.8% of the eggs disappeared. It would therefore appear that the stem borer egg parasites could be more predominant at the coast than they have been found on the mainland while ant predators play an equally important role on the mainland.

Sorghum sown simultaneously with cowpea had significantly more dead stem borer larvae than the other cropping patterns. This could probably be a result of the slightly shaded, cooler canopy whose relative humidity differences did not fluctuate much over the study period compared with the other cropping patterns. Such conditions were also relatively better for larval mortality in the other two intercrops than in sorghum monocrop. Seasonal mean percentage larval mortality was significantly lower during 1987 long rainy season at the field station than in the other three planting seasons.

It would have been expected that the long rainy season could have a higher larval mortality from diseases which seemed to have the highest contribution of all mortality factors. This did not happen due probably to an unusually erratic rainfall pattern towards the middle of the 1987 season. Diseases caused a significantly higher larval mortality than parasites and predators. Disease infections were predominant at the beginning of the season (up to 53DAE) most probably because the relative humidity, shade and temperatures within the canopies were more constant compared with the rest of the season, and the plants were either constantly irrigated or were receiving the first rains of the season. These conditions could have enhanced disease multiplication.

The principal larval parasite in the present study was *Apanteles sesamiae* Cam. which was mostly recovered from *B. fusca*. There were only a few parasites recovered from *C. partellus* and none from *S. calamistis* or *E. saccharina*. Ingram (1958) reported *A. sesamiae* as the principal larval parasite of *S. calamistis* larvae but it had also been collected from *B. fusca* and *C. partellus*. The results from the present study indicate that diseases accounted for a higher percentage in larval mortality than parasites and predators. Mathez (1972) reported that unidentified bacteria, viral and fungal diseases were the most important factors limiting larval populations. Incidences of ant predators were negligible in the Coast Province. However, in the present study ant predation played a very important role, which is in line with the findings observed at Kawanda by Girling (1978) that at least 90% of the larvae were taken away by ants.

Higher larval mortalities were observed at the field station during 1986/87 short rainy season compared with 1987 long rainy season. This could be related to the higher stem borer larval populations observed in the short rainy season compared with the long rainy season. Similarly Mathez (1972) reported that diseases and parasites killed a total of 10% of the larvae on maize planted in the long rains and 15% on maize planted during the short rains.

The mean percentage pupal mortality during 1986-88 was not significantly different in the four cropping patterns. It was however, significantly higher at the field station during 1987 long rainy season than in the other three planting seasons. Stem borer pupal mortalities ranged between 22.9-29.8% for each of the four cropping patterns, except during 1986/87 short rainy season when a low mean percentage pupal mortality of 9.5% was observed. Mathez (1972) reported that less than 10% of pupae failed to reach the adult stage. These observations may lead one to suggest that pupal mortality is higher around Mbita area appear to be higher than at the Coast Province.

Parasitism accounted for a significantly higher pupal mortality than either predators or diseases. The majority of the pupae were parasitised by D. busseolae (particularly on C. partellus) and to a lesser extent by Pediobus furvus on both C. partellus and B. fusca. Girling (1978) reported that 18.9% of field-collected E. saccharina pupae failed to produce adults and dissection showed that in the majority of the pupae adults had developed inside the pupal cuticle but they failed to emerge. Furthermore, Mathez (1972) found that 10% of the pupae were prevented from reaching adult stage by diseases and physiological disturbances and a few were found partly eaten by ants as observed in the present study, while parasites (particularly P. furvus Gah.) accounted for up to 100% parasitism when the pest populations were very low at the end of the season.

M. testulalis larval mortality was numerically higher in cowpea sown simultaneously with sorghum than in the other cropping patterns. The least mortality was observed in cowpea sown after sorghum. It would appear that the present cropping patterns also affected this borer's mortality trend although the results are inconclusive because they were observed for only one season. The pupal mortality was rather spontaneous and seemed to have occurred mostly in cowpea monocrop where the pupal population was also higher than in the other cropping patterns, suggesting a kind of density-dependent mortality relationship.

The number of chrysopid eggs was significantly lower in cowpea sown after sorghum than in the other three cropping patterns. This could have been due to the fact that the dense and taller sorghum may have acted as a physical barrier to the egg laying adult chrysopids.

There were fewer soil arthropods in sorghum monocrop than in cowpea monocrop. The three intercrops were statistically similar to each other and to the two monocrops. The slightly higher arthropod numbers (which included most of the predators) observed in intercrops compared with the sorghum monocrop could partly explain the higher stem borer larval and pupal mortalities observed in some of the intercrops. In addition, the relatively high and constant humidity and temperatures in the intercrops could have enhanced the incidence of disease infections while the lower light intensity and slightly lower temperatures could have provided favourable conditions for the predators to hide under the cowpea canopy. Shading in the intercrops appears to favour parasites in sorghum sown before and after cowpea, while predators appear to be have been favoured in sorghum sown simultaneously with cowpea and that sown after cowpea. However, overriding factors like weather, interspecific plant competition and shade seem to have barred the yield effects which would have been realised from predator and parasite activity on borer populations. This is evident from the low grain yields in cowpea sown after sorghum where the pest population was low (Chapter 7) and natural enemies and pod borer mortality were high (Table 8.3 and 8.7 respectively).

Light intensity was higher in cowpea monocrop than in the intercrops but this was only in some plots while in others there was near total darkness due to the thick growth and consequent closure of the canopy of the plants as a result of favourable soil conditions. Many of the arthropods (particularly the beetles and earwigs) would hide under the leaf trash directly below the cowpea plants and come out only when disturbed. The situation could have been different if an erect cowpea cultivar was used. The above results showed insignificant soil arthropod population differences between cowpea monocrop and the intercrops except in the case of earwigs where sorghum sown before cowpea had a significantly higher number than the other cropping patterns (Table 8.8). However, there was a higher number of ants in the intercrops than in monocrop sorghum, and more earwigs in sorghum sown before cowpea than in sorghum monocrop. Thus, the present results contradict those reported by Kayumbo (1976) that more predators were attracted into maize and cowpea mixture than in the sole cropped cowpea. These differences could be justified by the fact that cowpea and sorghum could have a different crop environment from that of maize and cowpea and the growing conditions could also be different.

Field observations during the growth of the crops had shown that the diversity of the arthropods collected and their total numbers were less at the beginning of the season but increased with crop age and cowpea ground cover until about 65DAE when most of the ground was covered in the intercrops. Towards the end of the season (after 100DAE) however, arthropod species were fewer and only ants and beetles dominated the samples. This would support the findings reported by Price (1976) that colonisation of a soybean field by predators increased rapidly with canopy closure. Dempster (1969), Dempster and Coaker (1974) and Altieri *et al*. (1981, 1985) reported that ground cover provided shade near the soil and this increased humidity which in turn favoured general predators such as spiders and carabids. The more humid environment in some of the intercrops could have enhanced disease infections as stipulated by Trenbath (1974) and the slightly higher light intensity in sorghum monocrop could have contributed to the lower number of arthropods compared with the intercrops. While light intensity would discourage pests like the legume flower thrips, M. sjostedti (Kyamanywa and Ampofo, 1988) it would have little direct effect on the borers which feed within the stems and pods. Its importance could only be indirectly through their natural enemies.

The intercropping patterns used in the present study demonstrated their ability to favour stem and pod borer larval and pupal mortalities by attracting more parasites and predators but overriding factors such as weather, shade and interspecific plant competition appear to have barred the beneficial impacts of natural enemies. Sorghum sown simultaneously with cowpea showed the highest (though not always significant) larval and pupal mortalities during 1986-88 period. It also had high numbers of soil predators (particularly ants, beetles and spiders). Although the other two intercrops showed less defined trends in larval and pupal mortalities compared with simultaneous planting, they had a substantial influence on borer populations and the general field crop environment.

SECTION D

CHAPTER 9

GENERAL DISCUSSION AND CONCLUSIONS.

Under the conditions prevailing at Mbita and on Rusinga Island, the studies on *C. partellus* oviposition showed that eggs were laid on sorghum plants throughout the cropping season which is an indication of adaptability of this pest to the plant. Mathez (1972) reported similar findings on the Coast Province of Kenya. Oviposition also occurred on other plants within vicinity and this is a clear reflection of the pest's non-specificity in oviposition behaviour as was observed by Roome *et al*. (1977). Fewer egg batches and eggs were found on farmer's field crop compared with the field station. This observation could be explained by the fact there is continuous cropping of sorghum at the field station often under irrigation thus, providing good quality food supply for the pest.

Generally there were higher numbers (though not always significant) of egg batches and eggs on sorghum monocrop than intercrops. High egg peak counts were observed earlier in sorghum monocrop than intercrops.

This is an indication of early recognition and preference of plants in the monocrop for oviposition by the pest. Similar observations were made on *O. furnacalis* in maize intercropped with peanuts (Raros, 1973; Hasse, 1981), on *P. xylostella* in tomato and cabbage intercrop (Buranday and Raros, 1975) and on Brussels sprouts and tomato intercrop (Perrin and Phillips, 1978).

When *C. partellus* moths were confined to sorghum and cowpea plants in cages, they laid a statistically similar number of egg batches and eggs on sorghum and cowpea intercrops. However, the percentage egg batches was higher on sorghum monocrop than the three intercrops and was significantly different from both sorghum sown simultaneously with cowpea and that sown after cowpea. The number of eggs was significantly higher in sorghum monocrop than the three intercrops. These findings reveal the degree of *C. partellus* oviposition on the non-host cowpea plants although under natural conditions it was observed at a much smaller scale than in the cages. Oviposition on host and non-host plants when the two are grown together would directly lead to fewer larvae on the host sorghum plants and could be one of the factors being utilized unknowingly by traditional farmers in their intercropping practice for the control of pests like *C. partellus*. Oviposition preference for monocrop plants in intercropping experiments have also been reported for M. brassicae in Brussels sprouts and spurry intercrops (Theunissen and Den Ouden, 1980) and for P. xylostella also in Brussels sprouts (Perrin and Phillips, 1978).

The outstanding observations made on the stem borer larval populations at the two experimental sites were that the population was 42-57% higher at the field station than on Rusinga Island and the stem borer species composition and proportions were different. On Rusinga only C. partellus and B. fusca were recorded at almost equal proportions of 49.7% and 50.3% respectively, while at the field station there were four stem borer species (C. partellus accounting for 63-67%, B. fusca 20-27%, E. saccharina 4-6% and S. calamistis 2-4%). Furthermore, a significantly higher stem borer larval population was recorded in the short rain seasons than in the long rain seasons and in general the larval population showed an increasing trend from the beginning of the cropping seasons (at less than 1 larva per plant) towards harvest (about 2-3 larvae per plant at harvest).

Sorghum monocrop had a significantly higher mean number of stem borer larvae than intercrops in four planting seasons but in some individual seasons (e.g. on

Rusinga during 1987) there were no significant differences between monocrop sorghum and the intercrops. Sorghum sown simultaneously with cowpea showed the lowest mean larval population throughout the study period.

Higher stem borer larval populations at the field station compared with the farmers' fields around Mbita could be explained by the continuous cropping at the field station. Stem borer composition and proportion differences between the field station and farmers' fields around Mbita could be due to the presence of some sugarcane plants and the frequent artificial releases of borers at the field station. In this regard E. saccharina which prefer sugarcane was observed at the field station (Chapter 5). Higher stem borer larval populations and different borer compositions at the field station compared with the surrounding farmers' fields were also observed by Ogwaro (1983) and he related this to the frequency of sorghum cropping and the presence of sugarcane plants at the field station compared with the farmers' fields.

Seasonal differences in stem borer larval populations had been reported earlier in East Africa (Coaker, 1956; Ingram, 1958; Amoako-Atta et al., 1983). Coaker (1956) had concluded that crops grown under adequate rainfall were apparently unaffected by stem borer attacks. Ingram (1958) reported that short rain season crops were exposed to a population of borers that had built up considerably in the previous rain season, while Mathez (1972) suggested that lower stem borer larval populations in the long rain season were an outcome of high mortalities which were associated with fungal and bacterial diseases. This point has been substantiated in the present study e.g. Table 8.3, although detailed studies on individual factors were not carried out.

The most interesting finding about the four stem borer species larvae is that all four were found in the same host plant stem particularly towards the end of the season. C. partellus was present on sorghum from two weeks after plant emergence (2WAE) through harvest. Later some of them would be found in a state of aestivation-diapause in the dry stems (Scheltes, 1978). B. fusca was found on the crop from the end of the 5WAE and would diapause in the dry stems, while E. saccharina was found active from the 8WAE through harvest. Similar observations on C. partellus and E. saccharina larval activities at Mbita have been reported on maize cultivars by Ampofo (1986). S. calamistis was observed at the beginning of the long rainy season as mature larvae and towards harvest in the same season as well as in the succeeding short rainy season as first instar larvae, showing evidence of possible population carry-over through volunteer tillers. According to Girling (1978) the four stem borer species occupied different ecological niches in that *B. fusca* and *S. calamistis* preferred sorghum and maize of medium age (after 5WAE) and *S. calamistis* population peaked when *B. fusca* numbers were declining, whereas *C. partellus* was on sorghum at all stages of growth although it preferred mature plants. *E. saccharina* preferred mature sugarcane, sorghum or maize.

Planting sorghum after cowpea did not show significant stem borer larval population differences from simultaneous planting as reported for maize and beans (Altieri *et al.*, 1978) athough there was significant delay in *C. partellus* colonisation and establishment in early sorghum growth stage. The probable explanation is that as the nearby earlier planted sorghum matured there was a tendency for borer moths to oviposit on the late planted sorghum. Thus, more eggs and early instar larvae were observed on these plants towards harvest. This was therefore a form of temporal diversity where nutritional differences related to host plant maturity could have played its role (Perrin, 1980). Late planted sorghum was healthier, stronger and it retained its green leaves for a slightly longer period, which could be a reflection of mutual benefits (in terms of soil nutrient availability particularly nitrogen and soil moisture conservation) from the already established cowpea. It is important however, for late plantings to be done within reach of the first seasonal rains otherwise the plants' vigour becomes very poor if planting is extended for long periods.

The studies on *C. partellus* newly hatched larval establishment showed high larval losses (average range of 27-70% in different planting patterns) between the 4 and 8WAE. The slightly wider sorghum row spacing used in the present study could have enhanced the higher larval loss observed at the 4WAE compared with the 6 and 8WAE (Chapter 6). Sorghum sown after cowpea had significantly higher larval losses than the other cropping patterns in the three infestation dates. This could be due to the wide spacing and fewer tillers on sorghum sown after cowpea as a result of cowpea shading. Roome (1980) reported 40% *C. partellus* larval mortality within 24 hours after hatching and he associated the loss with dispersal. Mathez (1972) also reported that up to 100% of the larvae may disappear during dispersal phase. Girling (1978) demonstrated an estimated mortality of at least 93% in *E. saccharina*.

C. partellus larval establishment on infested plants was significantly higher in sorghum monocrop than the three intercrops. The average percentage establishment for the cropping patterns ranged between 26-60%, with sorghum sown after cowpea having the lowest (26.6%) and sorghum monocrop the highest (60.0%). Larval establishment was higher in the 6 and 8WAE than in the 4WAE. The reason for better establishment at a later plant growth stage could be due to increased leaf area for contact by larvae dropping on their silk threads. The lower larval establishment in intercropped sorghum could have been due to some of the larvae wasting their time on the cowpea plants where they could not feed and therefore could have died, while on the clean rows in monocrop plots some larvae could have managed to reach other sorghum plants in the vicinity as was observed in Chapter 6. Girling (1978) reported that only 3.8% of introduced *E. saccharina* larvae settled on infested maize plants in the field. The wider and random plantings commonly used by the traditional farmers could be enhancing such larval losses in pests of their crops.

Establishment on neighbouring sorghum plants was significantly lower in both sorghum sown simultaneously with cowpea and that sown after cowpea than in the other two cropping patterns. The low establishment in the two intercrops could have been due to larvae being trapped in the cowpea plants thereby failing to reach nearby sorghum plants. Van Hamburg (1980) reported that 100% of field sorghum plants became infested with C. partellus larvae although eggs were laid on only 18%. He also observed that infestations made before the 4WAE resulted into fewer larval survival while higher mean larval survival occurred when the plants were infested at the 7WAE. Girling (1978) reported that 3.2% of E. saccharina larvae established on surrounding maize plants.

The studies on M. testulalis oviposition indicated that more moths were attracted to cowpea monocrop where they laid a significantly higher number of eggs than in one or more of the intercrops in different seasons. This could be due to sorghum acting as physical barrier to the ovipositing moths in that the alternate row cropping could have interfered with their orientation to intercropped cowpea as postulated by Ezueh and Taylor (1984).

There were significantly more M. testulalis larvae on cowpea in monocrop than in one or more of the intercrops in different seasons. This could be related to the higher number of eggs observed on cowpea monocrop. Lower larval incidences in intercropped cowpea compared with monocrop cowpea have also been reported from northern Nigeria (Raheja, 1973), and here in Kenya at Mbita and the surrounding areas (Amoako-Atta and Omolo, 1983; Omolo and Seshu Reddy, 1985). Other findings on *M. testulalis* population reduction have been reported from maize and cowpea intercropping experiments (Karel, *et al*., 1982; Ezueh and Taylor, 1984). There were significantly (63.9% of the total) more *Maruca* pupae on cowpea monocrop than intercrops (36.1%). However, pupal population was generally smaller than larval population. The explanation for small pupal population could have been the high incidences of ant predation on pre-pupal stage.

The method and time of planting the intercrops have also been found to affect this pest's population, for example, Taylor (1977) showed that intra-row mixing of sorghum and cowpea resulted in less *Maruca* incidence than either monocrop or inter-row association. Furthermore, Ezueh and Taylor (1984) reported that planting cowpea 12 weeks after maize establishment resulted in significantly low incidences of *Maruca* than simultaneous planting.

There was an increase in percentage infested sorghum plants with the age of the crop and almost all plants were infested from the 10WAE. A higher (but not significant) number of infested plants was observed in sorghum monocrop than in intercrops at the field station. On Rusinga monocrop sorghum had a significantly higher number of infested plants than intercrops. The increased infestation with plant age could be related to increases in stem borer larval population observed in Chapter 5. Amoako-Atta et al. (1983) and Dissemond and Weltzien (1986) reported similar findings in Mbita area. Higher plant infestation in monocrops hava also been reported in corn, cucumber and broccoli (Bach, 1980); and in Brussels sprouts and spurry intercrops (Theunissen and Den Ouden, 1980).

Percentage tunnelled stem length was lower (though not significantly) in sorghum sown after cowpea than the other three cropping patterns at the 11 and 16WAE. This could have been due to late borer colonisation and establishment observed in Chapters 4 and 5 respectively. Lambert et al. (1987) reported similar results on maize and clover in that when clover was intercropped with maize 10 and 25 days after maize establishment, there was significantly less European Corn Borer (*Ostrinia nubilalis* Hubner) damage to maize plants at 10 day clover sowing for two seasons and for only one season in 25 day clover sowing. In addition, the mean tunnel lengths per plant in infested maize were not significantly different between intercropped and monocropped maize. This point was substantiated in the present study e.g. Table 6.5. There were insignificant differences in stem tunnelled length in the four cropping patterns although it appeared higher (but not significantly) in the short rainy season than long rainy season. This is most likely due to the higher stem borer larval population observed in the short rainy season, an observation which supports the findings reported by Coaker (1956), that crops grown under inadequate rainfall suffered more from stem borer attacks than those grown under adequate rainfall.

Percentage cowpea pod damage was significantly higher on cowpea monocrop than on both cowpea sown before and that sown after sorghum. This could be related to borer populations in the three cropping patterns. Simultaneous planting of cowpea and sorghum however, did not show significant differences in pod damage from the monocrop although the intercrop had a comparatively less percentage damage. Similar results have been reported for sorghum and cowpea intercrops in Nigeria (Raheja, 1973; Taylor, 1977), Kenya (Amoako-Atta and Omolo, 1983) and for maize and cowpea intercrops in Tanzania (Karel et al., 1982) and Nigeria (Ezueh and Taylor, 1984).

Sorghum grain yields in the four cropping patterns showed slight variations which could be associated with the cultivar (Serena) used. This cultivar has a high tillering capability which seem to have compensated for any damaged main stems. The late planted sorghum however, had very few tillers due to cowpea shading in the early stages of sorghum growth. Seasonal yield variations were as a result of adverse weather conditions but could also be due to pest severity. Higher stem borer larval populations in the short rainy seasons could have reduced the yielding capability of the plants as was observed by Ingram (1958). Similar lower short rainy season yields compared with the long rainy seasons in Mbita area were reported by Amoako-Atta and Omolo (1983). They related the differences to borer larval population trends.

Late planted sorghum on Rusinga Island in 1987 long rainy season was severely affected by a dry spell at germination. This was followed by heavy rains which flooded some of the plots, affecting plants' vigour and hence their yielding capability. The 1988 long rainy season crop at MPFS suffered flooding in parts of the field at the establishment stage, followed by a heavy aphid infestation as the rains subsided. Consequently, some of the sorghum plants were very weak and mostly developed chaffy heads.

Mean cowpea grain yields during 1986-88 were statistically similar in both monocrop and that sown before sorghum, and the two were significantly higher than the yields from the other two intercrops. Cowpea sown simultaneously with sorghum had a significantly higher yield than that sown after sorghum. Grain yield in cowpea sown before sorghum was as high as in monocrop because the semi-erect local cultivar (Ex-Luanda) had ample space as an added crop and therefore its branches spread as far as possible producing healthy pods. The late planted sorghum did not have tillers to shade the cowpea as was the case in cowpea sown after sorghum. Similar higher cowpea grain yields in monocrop compared with that sown simultaneously with sorghum were reported by Taylor (1977) and Amoako-Atta and Omolo (1983) who related the findings to competition between the two plant species. These observations support the findings reported by Ezueh and Taylor (1984) that cowpea is sensitive to shading in intercropped patterns. Evans (1960) also reported reduced groundnut yields when groundnuts were intercropped with maize and he associated this to maize shading. Seasonal yield differences in cowpea grain yields at Mbita and its surroundings were also reported by Amoako-Atta and Omolo (1983).

Intercropping sorghum and cowpea simultaneously resulted in average sorghum grain yield increase of 2.3% over the monocrop while cowpea yields were reduced by 24.4%. Sorghum sown before cowpea had an average grain yield increase of 5.1% and cowpea had a reduction of 4.5% compared with their monocrops. Sorghum sown after cowpea had a yield depression of 23.8% whereas cowpea sown after sorghum had an average of 41.8% less grain yield compared with their monocrops (Table 7.5).

Land productivity under intercropping estimated by the land equivalent ratio (LER) index indicated that the three intercrop patterns were more productive than the monocrops. Total yield increases were: sorghum sown before cowpea 18%, sorghum and cowpea sown simultaneously 35%, and sorghum sown after cowpea 71%. The increases could be accounted for by plant mutual benefits and reduced plant competition for some resources. These observations are in line with the findings reported on simultaneous planted intercrops of maize, sorghum and groundnuts (Evans, 1960); castor-bean with groundnuts or soya-bean (Evans and Sreedharan, 1962); and on cowpea and sorghum at Mbita and its surrounding areas (Amoako-Atta and Omolo, 1983). Enyi (1973) found that intercropping maize or sorghum with pigeon peas, cowpeas or beans in Tanzania led to reductions in leaf area indices, fresh weight yield at anthesis, straw and grain yield of cereal crops at harvest, but total grain yield per hectare was increased in the sorghum and pigeon pea mixtures. In addition, Dissemond (1987) reported that in some seasons there were higher absolute grain yields in pure stands than intercrops in cowpea, maize and sorghum but using LER as a relative and therefore comparable basis the cowpea intercrops were found to outyield their cereal monocultures by 30%. This value is comparable to that of simultaneously planted sorghum and cowpea in the present study. However, land equivalent coefficiency (LEC) showed that sowing cowpea two weeks after sorghum did not appear productive under the present experimental conditions beacuse it seems there were signs of interspecific competition.

Studies on C. partellus egg mortality factors could not clearly show the contribution of each factor except that of the parasite Trichogramma sp. whose occurrence was very scanty (it caused only 1.4% egg mortality in one season). Frequently however, several predators which have been reported (Seshu Reddy, 1983) to destroy a large proportion of stem borer eggs in Mbita area were found on sorghum plants but were not observed feeding on the eggs. They included earwigs (particularly Diaperasticus erythrocephala Oliver), ladybird beetles (Cheilomenes sp.) and ants (Camponotus sp., Pheidole sp., Dorylus sp.).

Mohyuddin and Greathead (1970) also reported that *Pheidole* sp. and other formicids were responsible for destroying 90% of stem borer eggs at Kawanda. In contrast however, Mathez (1972) reported that the activity of ants in the field appeared to be nil but that some unidentified ants were found feeding on the eggs in the laboratory. He further reported that parasitism played a vital role in egg mortality where it accounted for up to 90% kill. Common parasites were *Telenomus* sp. and *Trichogramma* sp. on *Chilo* eggs, *Platytelenamus busseolae* Gah. and *Trichogramma* sp. on *S. calamistis* eggs. Girling (1978) reported two species of ants *Tetramorium bicarinatum* Nylander and *Camponotus sericeus* F. taking *E. saccharina* eggs from maize while several other species of ants were present on the plants. It would therefore appear from this account that stem borer egg parasites could be the main mortality factor at the coast while predators account for the bulk of egg mortality on the mainland .

High larval mortalities were recorded from the middle of the season (7WAE) through harvest. Diseases were the main mortality factor at the beginning of the cropping season but predators and parasites were also present in the remaining part of the season. Frequent irrigation and the seasons' early rains could have accounted for the prevalence of diseased larvae observed at the beginning of the season. Mathez (1972) observed that high rainfall caused high larval mortality which he associated with fungal and bacterial diseases.

Sorghum sown simultaneously with cowpea had a significantly higher stem borer larval mortality than the other three cropping patterns. Lower light intensity in this cropping pattern coupled with the slightly high but less fluctuating temperatures and relative humidity could have favoured the activity of predators found in the soil arthropod group as well as enhancing disease multiplication which contributed substantially to larval mortality. Such conditions were also slightly better for larval mortality in the other two intercrops than in sorghum monocrop (Table 8.9-8.11).

Larval mortality from diseases was significantly higher than from parasites and predators. Unidentified bacteria caused most of the mortality in the larvae. Mathez (1972) reported that unidentified bacteria, viral and fungal diseases were the most important factors which limited stem borer larval population. The principal larval parasite in the present study was Apanteles sesamiae Cam. mostly on B. fusca but also on C. partellus. An average of 8% larval mortality was observed in the field populations. Ingram (1958) reported _A. sesamiae_ as the principal larval parasite of _S. calamistis_ although it had also been collected from _B. fusca_ and _C. partellus_. Mathez (1972) reported negligible ant predation while Girling (1980) reported that at least 90% of the larvae of _E. saccharina_ were taken away by ants. A higher percentage (5.5%) larval mortality was observed at MPFS during 1986/87 short rainy season compared with 1987 long rainy season (3.3%). This difference could perhaps be due to the high larval population observed in the short rainy season. These observations would support the findings reported by Mathez (1972) that stem borer larval mortality on maize planted in the long rainy season was 10% while that on maize planted during the short rainy season was 15%.

Stem borer pupal mortality was higher (though not significantly) in sorghum sown simultaneously with cowpea than in the other three cropping patterns. This could be a result of better microclimatic conditions for the activity of parasites which accounted for 68.4% of pupal mortality. An average mean pupal mortality of between 22.9-29.9 was observed in the four cropping patterns, which is higher than that (10%) reported by Mathez (1972).

A significantly higher number of pupae died of parasitism (68.4%) than of either predators (12.7%) or diseases (18.9%). The majority of pupae were parasitised by D. busseolae (especially on C. partellus) and a few by Pediobus furvus Gah. (on both B. fusca and C. partellus). Pupae were found partly eaten or being carried away by ants and most of the dead ones contained fully developed adults which were frequently dry. Mathez (1972) reported that 10% of pupae were affected by diseases and physiological disturbances while a few were half eaten by ants. He further reported that parasites (in particular P. furvus) accounted for up to 100% pupal mortality when the pest population was very low at the end of the season. Girling (1978) found that 18.9% of field collected E. saccharina pupae failed to produce adults. Further investigations showed that adults had developed inside the pupal cuticle but they failed to emerge.

The studies on M. teslulalis populations did not show any natural enemies on the eggs. However, there were significantly more chrysopid eggs (laboratory tests showed that their larvae feed on borer eggs) on cowpea monocrop, cowpea sown before sorghum and cowpea sown simultaneously with sorghum than on cowpea sown after sorghum. The numerically higher (though not significant) larval mortality observed on cowpea sown simultaneously with sorghum compared with the other cropping patterns and the low mortality observed on cowpea sown after sorghum could probably be due to the favourable microclimate for natural enemies found in the former case and to the low larval population in the latter case. Although pupal mortality was spontaneous and no conclusive remarks could be made on this stage, it would appear that the cropping patterns used had some effects on pod borer mortality.

The higher (though not significant) number of soil arthropods observed in sorghum and cowpea intercrops compared with sorghum monocrop could partly explain the higher stem borer larval population in the monocrop as well as the higher stem borer larval and pupal mortalities observed in some of the intercrops. The lower light intensity and slightly lower temperature fluctuations in intercrops could have favoured soil arthropod activity while the relatively constant high temperatures and relative humidity could have enhanced disease infections in the intercrops (Tables 8.9-8.11). Dissemond (1987) reported an average of 5-10% higher relative humidity in sorghum and cowpea intercrop than in sorghum monocrop. Cropping patterns had shown slight insignificant differences in air temperature.

Soil arthropod species increased with cowpea cover and after cowpea harvest the number of species decreased gradually to only beetles and ants at sorghum harvest. These findings support those reported by Price (1976) that colonisation of a soybean field by predators increased with canopy closure. Ground cover has also been reported (Dempster, 1969; Dempster and Coaker, 1974; Altieri et al., 1981, 1985) to provide shade near the soil and this in turn increased humidity that favoured general predators such as spiders and carabids. The slightly higher light intensity in the sorghum monocrop compared with the intercrops could have discouraged some of the soil arthropods. While high light intensity would discourage pests like M. sjostedti (Kyamanywa and Ampofo, 1988) it would have little direct effect on the stem and pod borers which spend most of their time inside the stems and pods respectively, but its importance to these borers would be indirectly through their natural enemies.

The intercrop patterns used in the present study seemed to demonstrated their ability in interfering with the oviposition of C. partellus and M. testulalis as well as delaying their larval population build-ups. Late planting in sorghum and cowpea appeared to be the best patterns in delaying borer colonization and establishment when the crops were most susceptible to damage. Despite the steady rise in borer larval populations with the age of the crops, the intercrops had lower populations than the monocrops, and they remained better in terms of stem borer infestations and land productivity. Although stem borer larval populations in intercrops were similar to those in monocrops towards crop harvest, the plants' reproductive stage had already advanced to such an extent that pest infestations would not adversely affect grain yield in which the subsistence farmer is mostly interested.

The success of initial pest attack within an agroecosystem is dependent on the level of success of the gravid female settling on a favourable host to oviposit before death (Amoako-Atta et al., 1983). Any delay or interference in this phase reduces the colonization effeciency or survival of the borers since it is the ephemeral females from the carry-over season which will oviposit to start a new cycle of infestation in the agroecosystem which will later be self generating. Southwood and Way (1970) observed that for most annual crops, the numbers of exogenous insects invading at the beginning of the growing season, either from adjacent uncultivated areas or from great distances is a vital factor in determining pest abundance. An initial delay in pest colonization therefore sets in subsequent delays in the pest build-ups which seemed to be substantiated in the present studies.

Depending on the interest of the farmer and under similar growing conditions as those used in this study there are three alternatives:

a) if one is interested in getting some cowpea and a good crop of sorghum, then simultaneous planting could be adopted

b) if interest is on a good sorghum crop and just a little cowpea, then cowpea could be sown after sorghum, but,

c) if interest is more on a good cowpea crop and a reasonable sorghum crop, then cowpea could be sown before sorghum. This cropping pattern appeared to be the most efficient method of producing the two crops on a piece of land.

The ecological benefits of mixed cropping are yet to be fully quantified and documented, but there is hardly any doubt that it forms a basis for a coordinated strategy for pest and disease control in tropical agricultural practice (Taylor, 1977). Herrera (1975) pointed out that traditional farmers in most of the tropics seem to realise the existence of some form of ecological balance in this practice, hence its use in various forms. He, however, advocated considerable planning and wise use of insecticides and management to maintain and improve the beneficial effects of intercropping. The findings reported in this study and the work reported by various workers in this field point out clearly the need to intensify work on the design and evaluation of pest management systems based on mixed cropping practices so that in replacing the traditional practices of the tropical farmer, we can offer practices that are acceptable, ecologically sound and capable of maximising the benefits of agricultural enterprise in a tropical environment.

RECOMMENDATIONS AND AREAS FOR FUTURE WORK

Intercropping sorghum and cowpea was demonstrated to have positive effects in reducing stem and pod borer population build-up in the early stages of plant growth. Planting the sorghum and cowpea simultaneously, or planting the cereal or legume 14 days earlier, were found to be more effective in suppressing the population of the borers resulting in higher land productivity than their monocrops. Borer populations were lowest when sorghum and cowpea were sown simultaneously and land productivity was highest when cowpea was sown before sorghum.

In these studies only two dates of planting were tested (14 days before or after) but more information could be obtained from a wider range of time intervals for example, 10, 20, 25, and 30 days before and after. Obviously longer intervals would be more practical in areas where the rainy season is sufficiently long and rainfall distribution is more even compared with Mbita, otherwise planting too late in a season in an area with erratic rainfall pattern like that of Mbita may affect the vigour of the plants.

In the present work sorghum was the main crop, so that most attention was paid to the stem borers which are a major threat to its production while only some time was devoted to cowpea pest complex. It is therefore recommended that future work should pay more attention to the major cowpea pests, for example, the legume flower thrips, aphids, leaf beetles, flower beetles, pod bugs, and bean fly depending on the importance and the locality where the pests are found. Furthermore, studies on the legume pod borer should be designed to concentrate efforts on moth oviposition, larval establishment, and natural enemies under different cropping systems.

Simultaneous cereal and legume sowing is a common practice with most farmers and in the case of maize, legumes are commonly sown after the first weeding about 3 weeks after emergence. However, relay planting (planting legumes when maize cobs are about to mature) is also common in some areas. These practices are geared at reducing plant competition. It is not a common practice however, for local farmers to sow the legumes before the cereals because the main crop has always been the cereal and therefore it is given priority. In the present experiments it was demonstrated that planting cowpea before sorghum gave the highest land productivity compared with the other cropping patterns. If the farmer could be convinced to plant cowpea before sorghum to form a ground cover which would preserve moisture, reduce soil erosion, provide shade for soil arthropods, protect the sorghum from early stem borer colonization and establishment, and enrich the soil with nitrogen; he would realise better returns from his land and would appreciate this cropping pattern. The extra legume grain would earn him some extra income.

Since various natural enemies caused borer larval and pupal mortalities, further investigations should be carried out to identify them and quantify their individual role in population regulation. Furthermore, diseases accounted for an average of over 70% of larval mortality and therefore identification of such disease agents could throw some light on whether to augment them or introduce new ones in future pest management programmes.

Oviposition and larval establishment studies were carried out for C. partellus. However, B. fusca, E. saccharina and S. calamistis infested the crop relatively late compared with C. partellus. Investigations on the colonisation and establishment of these borers would help in the manipulation of crop planting and other control strategies which could reduce their populations.

Farmers plant their cereal and legume crops in several patterns. It would be of great value to study borer population trends in those patterns to evaluate them and perhaps suggest ways of improving or incorporating them in pest management packages.

Stem and pod borer resistant cultivars could be combined with time of planting and intercropping to investigate the effect of the combination on the borer population build-up.

REFERENCES CITED

ABASA, R. O. 1983. Current and future pest management strategies in polycultural systems in East Africa. Insect Science and its Application Vol. 4, No. 1/2, pp.167-171.

ACLAND, J. D. 1971. East African Crops. Cowpea pp. 112-113, Sorghum pp. 186-191. Essex, England, FAO/Longman 252pp.

ADETILOYE, P. O.; EZEDINMA, F. O. C. and OKIGBO, B. N. 1983. A land equivalent coefficiency (LEC) concept for the evaluation of competitive and productive interactions in simple to complex crop mixtures. Ecological Modelling 19: 27-39.

AINA, P. O.; LAL, R. and TATLOR, G. S. 1977. Soil and crop management in relation to soil erosion in the rainforest region of Western Nigeria. In: Proceedings of the National Soil Erosion Conference, May 1976. Purdue University, Lafayette, IN, USA, pp. 75-84.

AIYER, A. K. Y. N. 1949. Mixed cropping in India. Indian Journal of Agricultural Sciences 19: 439-543

ALGHALI, A. M. 1987. Effect of time of Chilo partellus Swinhoe (Lepidoptera: Pyralidae) infestation on yield loss and compensatory ability in sorghum cultivars. Tropical Agriculture (Trinidad) 64 (2): 144-148.

ALGHALI, A. M. 1988. Oviposition on sorghum by the stem borer, Chilo partellus (Swinhoe) (Lepidoptera: Pyralidae). Journal of Plant Protection in the Tropics 5(1): 45-50.

ALTIERI, M. A.; VAN SCHOONHOVEN, A.; and DOLL, J. D. 1977. The ecological role of weeds in insect pest management systems: A review illustrated by bean (Phaseolus vulgaris L.) cropping systems. PANS 23:195-205.

ALTIERI, M. A.; FRANCIS, C. A.; VAN SCHOONHOVEN, A. and DOLL, J. D. 1978. A review of insect prevalence in maize (Zea mays L.) and bean (Phaseolus vulgaris L.) polycultural systems. Field Crops Research (Netherlands) Vol. 1 (1) pp. 33-49.

ALTIERI, M. A. and TODD, J. W. 1981. Some influences of vegetational diversity on insect communities of Georgian soybean fields. Protection Ecology 3, 333-338.

ALTIERI, M. A.; TODD, J. W.; HAUSER, E. W.; PATTERSON, M.; BUCHANAN, G. A. AND WALKER, R. H. 1981. Some effects of weed management and row spacing on insect abundance in soybean fields. Protection Ecology 3, 339-343.

ALTIERI, M. A. AND LETOURNEAU, D. K. 1982. Vegetational management and biological control in agroecosystems Crop Protection Vol. 1, No. 4, 405-430.

ALTIERI, M. A.; WILSON, R. C. and SCHMIDT, L. L. 1985. The effects of living mulches and weed cover on the dynamics of foliage- and soil-arthropod communities in three crop systems. Crop Protection Vol.4 (2), 201-213.

AMPOFO, J. K. O. 1986. Effect of resistant maize cultivars on larval dispersal and establishment of Chilo partellus (Lepidoptera: Pyralidae). Insect Science and its Application Vol.7(1) pp. 103-106.

AMOAKO-ATTA, B. and OMOLO, E. O. 1983. Yield losses caused by the stem-/pod-borer complex within maize-cowpea-sorghum intercropping systems in Kenya. Insect Science and its Application Vol. 4, No. 1/2, pp. 39-46.

AMOAKO-ATTA, B.; OMOLO, E. O. and KIDEGA, E. K., 1983. Influence of maize, cowpea and sorghum intercropping systems on stem-/pod-borer infestations. Insect Science and its Application Vol. 4, No. 1/2, pp. 47-57.

ANDERSON, T. J. 1926. Insect pests of the maize crop. Bulletin of the Department of Agriculture, Kenya, No.5, 8pp.

ANDREWS, D. J. 1974. Responses of sorghum varieties to intercropping. Experimental Agriculture 10, 57-63.

ANDREWS, D. J. and KASSAM, A. K. 1976. The importance of multiple cropping in increasing world food supplies. In: Papendick, R. I., P. A. Sanchez, and G.B. Triplett (Eds.), 1976: Multiple Cropping. ASA Special Publication No. 27. Madison pp. 1-10.

ANON 1978. Farming Systems Research at the International Agricultural Research Centres. World Bank, Washington DC, 66pp.

BACH, C. E. 1980a. Effect of plant diversity and time of colonization on an herbivore-plant interaction. Oecologia 44, 319-326.

BACH, C. E. 1980b. Effects of plant density and diversity on the population dynamics of a specialist herbivore: the striped cucumber beetle Acalymma vittata (Coleoptera: Chrysomelidae). Ecology 61: 1515-1530.

BACH, C. E. 1981. Host plant growth form and diversity: Effects on abundance and feeding preference of a specialist herbivore, Acalymma vittata (Coleoptera: Chrysomelidae). Ibid. 50, 370-375.

BALIDDAWA, C. W. 1984. Movement and feeding activity of adult pea leaf weevil, Sitona lineatus L. in an oat-broad bean diculture. Insect Science and its Application Vol. 5. No. 1, 33-39.

BALIDDAWA, C. W. 1985. Plant species diversity and crop pest control- An analytical review. Insect Science and its Application Vol. 6(4), pp. 479-487.

BARTLETT, M. S. 1947. The use of transformations. Biometrics 3: 39-52.

BERNAYS, E. A.; CHAPMAN, R. F. and WOODHEAD, S. 1983. Behaviour of newly hatched larvae of Chilo partellus (Swinhoe) (Lepidoptera: Pyralidae) associated with their establishment in the host-plant, sorghum. Bulletin of Entomological Research 73: 75-83.

BERNAYS, E. A.; WOODHEAD, S. and HAINES, L. 1985. Climbing by newly hatched larvae of the spotted stalk borer Chilo partellus to the top of sorghum plants. Entomologia Experimentalis et Applicata 39(1): 73-79.

BLESZYNSKI, S. 1970. A revision of the world species of Chilo Zincken (Lepidoptera: Pyralidae). Bulletin of the British Museum (Natural History) (Entomology) 25: 99-195.

BOCK, K. R. and CONTI, M. 1974. Cowpea aphid-borne mosaic virus. Kew, U. K., CMI (Commonwealth Mycological Institute), CMI/AAB Descrptions of plant viruses,134

BOHLEN, E. 1978. Crop pests in Tanzania and their control. Second Revised Edition, Berlin und Hamburg: Parey 1978.

BURANDAY, R. P. and RAROS, R. S. 1975. Effects of cabbage-tomato intercropping on the incidence and oviposition of the diamondback moth, Plutella xylostella (L.). Philippine Entomologist, 2 (5), 369-374.

CAPINERA, J. L.; WEISSLING, T. J. and SCHWEIZER, E. E. 1985. Compatibility of intercropping with mechanized agriculture: Effects of strip intercropping of Pinto Beans and Sweet Corn on insect abundance in Colorado. Journal of Economic Entomology 78: 354-357.

CHADHA, G. and ROOME, R. E. 1980. Oviposition behaviour and the sensilla of the ovipositor of Chilo partellus (Lepidoptera: Pyralidae) and Spodoptera littoralis (Lepidoptera: Noctuidae). Journal of Zoology 192: 169-178.

CHAPMAN, R. F.; WOODHEAD, S. and BERNAYS, E. A. 1983. Survival and dispersal of young larvae of Chilo partellus (Swinhoe) (Lepidoptera: Pyralidae) in two cultivars of sorghum. Bulletin of Entomological Research 73(1): 65-74.

COAKER, T. H. 1956. An experiment on stem borer control on maize. East African Agricultural and Forestry Journal 21, 220-221.

CROMARTIE, W. J. 1975. The effect of stand size and vegetational background on the colonization of cruciferous foodplants by herbivorous insects. Journal of Applied Ecology 12, 517-533.

CROMARTIE, W. J. 1981. The environmental control of insects using diversity. In: Pest management, CRC Handbook, Series in Agriculture Vol. 1, pp. 223-252. Boca Raton, Florida.

DEMPSTER, J. P. 1969. Some effects of weed control on the numbers of the small cabbage white butterfly (*Pieris rapae* L.) on brussels sprouts. Journal of Applied Ecology 6, 339-346.

DEMPSTER, J. P. and COAKER, T. H. 1974. Diversification of crop ecosystems as a means of controlling pests. In: Prceedings of the 13th Symposium of the British Ecological Society 13: 106-114.

DICK, J. 1945. Some data on the biology of the sugarcane borer (Eldana saccharina, Wlk.). In: Proceedings of the South African Sugarcane Technologists Association 19, 75-79.

DISSEMOND A. and WELTZIEN, H. C. 1986. Influence of sorghum and cowpea intercropping on plant pests in a semi-arid area of Kenya. Med. Fac. Landbouww. Rijksuniv. Gent. 51/3a: 1147-1155.

DISSEMOND, A. 1987. Der eifluss von mischkulturen aus sorghum, mais und vigna auf den befall durch schadlinge krankheiten und unkrauter in Kenia. (English summary). Ph. D. Thesis Landwirtschaftlichen Fakultat der Rheinischen Friedrich-Wilhelms-Universitat zu Bonn.

DOUWES, P. 1968. Host selection and host-finding in egg-laying female Cidaria albulata L. (Lepidoptera: Geometridae). Opuscula Entomologia 33: 233-279.

DUERDEN, J. C. 1953. Stem borers of cereal crops at Kongwa, Tanganyika 1950-1952. The East African Agricultural Journal, October, 1953 pp. 105-119.

DUNCAN, D. B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-41.

EDJE, O. T. 1981. Response of sorghum and beans in monoculture and in association. LUSO: Journal of Science and Technology (Malawi) 2(1), 3-13.

VAN EMDEN, H. F. 1977. Insect-pest management in multiple cropping systems- a strategy. In: Proceedings of Symposium of Cropping Systems Research Development, Asian Rice Farmer. International Rice Research Institute 1977, Los Banos, Philippines

VAN EMDEN, H. F. and WILLIAMS, G. F. 1974. Insect stability and diversity in agroecosystems. Annual Review of Entomology 19: 455-475.

ENYI, B. A. C. 1973. Effects of intercropping maize or sorghum with cowpea, pigeon peas or beans. Experimental Agriculture, 9, 83-90.

EVANS, A. C. 1960. Studies on intercropping, I. Maize or sorghum with groundnuts. East African Agricultural and Forestry Journal 26: 1-10.

EVANS A. C. and SREEDHARAN, A. 1962. Studies on intercropping, II. Castor-beans with groundnuts and soya beans. East African Agricultural and Forestry Journal 28: 7-8.

EZUEH, M. T. and TAYLOR, A. T. 1984. Effects of time of intercropping with maize on cowpea susceptibility to three major pests. Tropical Agriculture (Trinidad) Vol. 61 No. 2: 82-86.

FAO, 1983. 1982 FAO Production Yearbook Vol. 36. Rome, Italy: FAO. 320pp.

FISHER, N. M. 1977. Studies in mixed cropping. Part I. Seasonal differences in relative productivity of crop mixtures and pure stands in the Kenya highlands. Experimental Agriculture 13, pp. 177-184.

FISHER, N. M. 1977. Studies in mixed cropping. Part II. Population pressures in maize-bean mixtures. Experimental Agriculture 13, pp. 185-191.

GEBREKIDAN, B. (ed.) 1982. Sorghum improvement in Eastern Africa: In: Proceedings of the Regional Workshop on Sorghum Improvement in Eastern Africa, 17-21 October 1982, Nazareth and Debre Zeil, Ethiopia, Ethiopian Sorghum Improvement Project 196p

GERARD, B. M. 1976. Measuring plant density effects on insect pests in intercropped maize-cowpea. In: Symposium on Intercropping in Semi-Arid Areas (Proceedings), Morogoro, Tanzania, 10-12 May 1976.

GIRLING, D. J. 1978. The distribution and biology of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) and its relationship to other stem borers in Uganda. Bulletin of Entomological Research 68, 471-488.

GLASS, E. H. and THURSTON, H. D. 1978. Traditional and modern crop protection in perspective. Bio Science 28: 109-115.

GOMEZ, A. A. and GOMEZ, K. A. 1983. Multiple cropping in the humid tropics of Asia. International Development Research Centre, IDRC, Ottawa, Ontario, Canada 1983, 41-62.

GREENE, G. L. and MORRILL, W. L. 1970. Behavioural responses of newly hatched cabbage looper (Trichoplusia ni) and fall armyworm (Spodoptera frugiperda) larva to light and gravity (Lepidoptera: Noctuidae). Journal of Economic Entomology 63: 1984-1986.

GUTHRIE, W. D.; DICKIE, F. F. and NEISWANDER, C. R. 1960. Leaf and sheath feeding resistance to the European corn borer in eight inbred lines of dent corn. Ohio Agricultural Experimental Station, Wooster, Ohio Research Bulletin 860.

HARRIS, K. M. 1962. Lepidopterous stem-borers of cereals in Nigeria. Bulletin of Entomological Research 3:139-171.

HARRIS, K. M. 1985. Lepidopterous stem borers of sorghum. In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A & M University. College Station, Tx. USA. ICRISAT, Patancheru, A. P. 502 324, India.

HARWOOD, R. R. 1979. Small farm development. Understanding and improving farming systems in the humid tropics. Westview Press, Bouder, Co., USA, 160pp.

HASSE, V. 1981. The influence of vegetational diversity on host-finding and larval survival of the Asian corn borer, *Ostrinia furnacalis* Guenee (Lepidoptera: Pyralidae). *Ph. D. Thesis, Justus-Liebig-Universitat, Giessen.*

HERRERA, W. T. 1975. Corn-Legume combinations: Recent International Rice Research Institute (IRRI) Multiple Cropping Results. *Paper presented to 6th Ams. Conf. Intensified Corn Production Programme, University of the Philippines.*

INGRAM, W. R. 1958. The Lepidopteran stalk borers associated with Graminae in Uganda. *Bulletin of Entomological Research 49:* 367-383.

IRRI, 1973. International Rice Research Institute. IRRI annual report for 1972, pp. 30-31. *International Rice Research Institute, Los Banos, Philippines*

IRRI, 1974. International Rice Research Institute. IRRI annual report for 1973, pp. 22-24. *International Rice Research Institute, Los Banos, Philippines*

JACK, R. W. 1917. The maize stalk borer (Calamistis fusca, Fuller). Bulletin of the Department of Agriculture South Africa, No. 3, 111pp.

JACKAI, L. E. N. 1981a. Relationship between cowpea crop phenology and field infestation of the legume pod borer, Maruca testulalis. Annals of the Entomological Society of America 74(4), 402-408.

JACKAI, L. E. N. 1981b. Use of an oil-soluble dye to determine the oviposition sites of the legume pod-borer Maruca testulalis (Geyer) (Lepidoptera: Pyralidae). Insect Science and its Application 2(4), 205-207.

JEPSON, W. F. 1954. A critical review of the world literature on the lepidopterous stalk borers of tropical graminaceous crops. Commonwealth Institute of Entomology, London, 127pp.

KAREL. A. K. and MUEKE, J. M. 1978. Management of insect pests in mixed cropping systems in Kiambu District, Kenya. Plant Protection Progress, 1, 48-61.

KAREL. A. K., LAKHANI, D. A. and NDUNGURU, B. J. 1982. Intercropping of maize and cowpea: Effects of plant population on insect pests and seed yield. In: Symposium on Intercropping in Semi-Arid Areas (Proceedings), Morogoro, Tanzania, 4-7 August 1980. Ottawa, Ontario, IDRC 186e.

KASS, D. C. L. 1978. Polyculture cropping systems: review and analysis. Cornell International Agricultural Bulletin No. 32. Ithaca, NY: Cornell University. 69pp.

KATO, D.; KAREL, A. K. and NDUNGURU, B.J. 1982. Effect of insecticide spray on insect pests and yield of sorghum and simsim in pure stand and in intercropping. Summary. In: Proceedings of the Symposium on Intercropping in Semi-Arid Areas, Morogoro, Tanzania, 4-7 August 1980. Ottawa, Ontario, IDRC 186e. pp. 117-118.

KAYUMBO. H. Y. 1975. Ecological background to pest control in mixed-crop ecosystems in East Africa. Paper presented at AAAS/Ford Foundation.

KAYUMBO. H. Y. 1976. Pest control in mixed cropping system. In: Symposium on Intercropping in Semi-Arid Areas (Proceedings), Morogoro, Tanzania, 10-12th May 1976.

KAYUMBO, H. Y. 1977. Ecological background to pest control in mixed cropping systems. In: Proceedings of the Workshop on Cropping Systems in Africa. Morogoro, Tanzania, 1-6 December, 1975, 51-53.

KENNEDY, J. S. 1977. Host-plant finding by flying aphids. Imperial College Field Station, Silwood Park, Ascot, Berkshire, SL 5 7 PY, United Kingdom.

KYAMANYWA, S. and AMPOFO, J. K. O. 1988. Effect of cowpea and maize mixed cropping on the incident light at the canopy and flower thrips (Thysanoptera: Thripidae) population density. Crop Protection Vol. 7, pp. 186-189.

LAMBERT, J. D. H.; ARNASON, J. T.; SERRATOS, A.; PHILOGENE, B. J. R. and FARIS, M. A. 1987. Role of intercropped red clover in inhibiting European corn borer (Lepidoptera: Pyralidae) damage to corn in Eastern Ontario. Journal of Economic Entomology 80(6): 1192-1196.

LATHEEF, M. A. and ORTIZ, J. H. 1983. The influence of companion herbs on egg distribution of the imported cabbageworm, Pieris rapae (Lepidoptera: Pieridae), on collard plants. Canadian Entomologist 115: 1031-1038.

LE PELLEY, R. H. 1959. Agricultural insects of East Africa. East African High Commission, Nairobi, Kenya. 307pp.

LITSINGER, J. A. and MOODY, K. 1976. Integrated pest management in multiple cropping systems. In: Multiple Cropping (Edited by Sanchez, P. A.), American Society of Agronomy. Special Publication No. 27. Madison, W S. USA. pp. 293-316.

MADGE, D. S. 1964. The light reactions and feeding activity of larvae of the cutworm Tryphaena pronuba L. (Lepidoptera: Noctuidae). Part I. Laboratory investigations. Entomologia Experimentalis et Applicata 7: 47-61.

MANGUM, C. L. and RIGDEWAY, W. O. 1968. Phototactic response of first-instar larvae of the pink bollworm to light of different wavelengths. Journal of Economic Entomology 61: 396-398.

MATHEZ, F. C. 1972. Chilo partellus Swinh., C. orichalcociliellus Strand. (Lepidoptera: Pyralidae) and Sesamia calamistis Hmps. (Lepidoptera: Noctuidae) on maize in the Coast Province, Kenya. Mitteillungen der Schweizerischen entomologischen Gesellschaft 45: 267-289.

MATTESON, P. C. 1982. The effect of intercropping with cereals and minimal Permethrin applications on insect pests of cowpea and their natural enemies in Nigeria. Tropical Pest Management 28(4):372-380

MATTESON, P. C., ALTIERI, M. A. and GAGNE, W. C. 1984. Modification of small farmer practices for better pest managememt. Annual Review of Entomology 29: 383-402.

MAY, K. W. and MISANGU, R. 1980. Some observations on the effect of plant arrangement for intercropping. In: Proceedings of the Second Symposium on Intercropping in Semi-Arid Areas, Morogoro, Tanzania 4-7 August 1980, Ottawa, Ontario, Canada. IDRC-186e 168pp.

MAYSE, M. A. 1978. Effect of spacing between rows on soybean arthropod populations. Journal of Applied Ecology 15: 439-450.

MOHYUDDIN, A. I. and GREATHEAD, D. J. 1970. An annotated list of the parasites of graminaceous stem-borers in East Africa, with a discussion of their potential in biological control. Entomophaga 15, 241-274.

MUMFORD, J. D. and BALIDDAWA, C. W. 1983. Factors affecting insect pest occurrence in various cropping systems. Insect Science and its Application 4, 59-64.

NEUPANE, F. P., COPPEL, H. C. and CHAPMAN, R. K. 1985. Bionomics of the maize borer, Chilo partellus (Swinhoe) in Nepal. Insect Science and its Application Vol. 6, No.4 pp. 547-553.

NORTON, G. A. 1976. Multiple cropping and pest control: an economic perspective. Meded. Fac. Land-bouww. Rijks. Univ. Gent. 40, 219-226.

OCHIENG, R. S. 1977. Studies on the bionomics of two major pests of cowpea (*Vigna unguiculata* [L.] Walp.): *Ootheca mutabilis* Sahlb. (Coleoptera: Chrysomelidae) and *Anoplocnemis curvipes* Fabricius (Hemiptera: Coreidae). **Ph. D. Thesis. Ibadan, Nigeria, University of Ibadan.**

ODEBIYI, J. B. 1981. Studies on the biology of the cowpea pod-borer, *Maruca testulalis* in Kenya- I Determination of the larval instars. *Insect Science and its Application Vol. 1 No. 4,* pp. 339-341.

O'DONNELL, M. S. and COAKER, T. H. 1975. Potential of intercrop diversity for the control of *Brassica* pests. In: *Proceedings of the 8th British Insecticidal Fungicide Conference 1:* 101.

OGWARO, K. 1983. Intensity levels of stem-borers in maize and sorghum and the effect on yield under different intercropping patterns. *Insect Science and its Application Vol. 4 No. 1/2,* pp. 33-37.

OMOLO, E. O. and SESHU REDDY, K. V. 1985. Effects of different sorghum-based cropping systems on insect pests in Kenya. In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A & M. University, College station, Texas USA. ICRISAT, A. P. 502 324, Patancheru, India pp. 395-401.

PERRIN, R. M. 1977. Pest management in multiple cropping systems. Agro-Ecosystems 3: 98-118.

PERRIN, R. M. 1977. Some effects of mixed cropping on the population dynamics of insect pests. Entomologia Experimentalis et Applicata 24: 386-393

PERRIN, R. M. 1980. The role of environmental diversity in crop protection. Protection Ecology 2, 77-114.

PERRIN, R. M. and PHILLIPS, M. L. 1978. Some effects of mixed cropping on the population dynamics of insect pests. Entomologia Experimentalis et Applicata 24: 585-593.

PIMENTEL, D. 1961a. The influence of plant spatial patterns on insect populations. Annals of the Entomological Society of America 54: 61-69.

PIMENTEL, D. 1961b. Species diversity and insect population outbreaks. Annals of the Entomological Society of America 54: 76-86.

PIMENTEL, D. and GOODMAN, N. 1978. Ecological basis for the management of insect populations. Oikos 30: 422-437.

PRICE, W. 1976. Colonization of crops by arthropods: Non-equilibrium communities in soybean fields. Environmental Entomology 5: 605-611.

PRICE, W. and WALDBAUER, G. P. 1975. Ecological aspects of pest management. In: Introduction to Insect Pest Management (R. L. Metcalf and W. H. Luckman, eds.), pp. 37-73. New York: John Wiley and Sons.

RAHEJA, A. K. 1973. A report on the insect pest complex of grain legumes in Northern Nigeria. In: Proceedings of first IITA GLIP Workshop 295-301.

RAROS, R. S. 1973. Biological stability in multiple cropping. First Multiple Cropping Workshop, 18-20 September 1973, Bogor, Indonesia.

RAROS, R. S. 1975. International Rice Research Institute 1976. IRRI annual report for 1975, Los Banos, Philippines.

REES, D. J. 1986. Crop growth, development and yield in semi-arid conditions in Botswana. 1. The effect of population density and row spacing on *Sorghum bicolor*. Experimental Agriculture Vol. 22, pp. 153-167.

RHEENEN, H. A. VAN; HASSELBACH, O. E. and MUIGAI, S. G. 1982. Bean production in monoculture and in association with maize: The effect of diseases and pest incidence. In: Proceedings of the 2nd Symposium on Intercropping in Semi-Arid Areas, Morogoro, Tanzania, 4-7 August 1980. IDRC Publication (Canada) No. 186e, pp. 115-116.

RISCH, S. J. 1980. Fewer beetle pests on beans and cowpeas interplanted with banana in Costa Rica. Turrialba (IICA) Vol. 30(2) pp. 228-229.

RISCH, S. J. 1980. The population dynamics of several herbivorous beetles in a Tropical Agroecosystem: The effect of intercropping corn, beans and squash in Costa Rica. Journal of Applied Ecology 17: 593-612.

RISCH, S. J. 1981. Insect herbivore abundance in tropical monocultures and polycultures: an experimental test of two hypotheses. Ecology 62, 1325-1340.

RISCH, S. J.; ANDOW, D. and ALTIERI, M. A. 1983. Agroecosystem diversity and pest control: data, tentative conclusions and new research directions. Environmental Entomology 12: 625-629.

ROOME, R. E. 1980. Dispersal of newly hatched *Chilo partellus* (Swinhoe) larvae from sorghum cultivars. Journal of Applied Entomology Vol. 90(2), 174-180.

ROOME, R. E.; CHADHA, G. K. and PADGHAM, D. 1977. Choice of oviposition site by *Chilo*, the sorghum stem borer. Bulletin SROP 1977: 115-131.

ROOT, R. B. 1973. Organization of a plant arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). Ecological Monographs 43, 95-124.

ROOT, R. B. 1975. Some consequences of ecosystem texture. In: Ecosystem Analysis and Prediction (S. Levin, ed.), Philadelphia: Society for industrialand Applied Mathematics, Pennsylivania, USA. pp. 83-97.

SCHELTES, P. 1978. Ecological and physiological aspects of aestivation-diapause in the larvae of two Pyralid stalk borers of maize in Kenya. Ph. D. Thesis, Landbouwhogeschool, Wageningen.

SERVICE, P. 1984. The distribution of aphids in response to variation among individual host plants: Uroleucon rudbeckiae (Homoptera: Aphididae) and Rudbeckia laciniata (Asteraceae). Ecological Entomology Vol. 9, No. 3, 321-328.

SESHU REDDY, K. V. 1982. Pest management in sorghum: Sorghum in the Eighties. In: Proceedings of the International Symposium on Sorghum. 2-7 November 1981, ICRISAT Centre, Patancheru, A. P., India. Vol. 1: 237-246,

SESHU REDDY, K. V. 1983. Studies on the stem borer complex of sorghum in Kenya. Insect Science and its Application Vol. 4 (1/2): 3-10.

SESHU REDDY, K. V. 1985. Sorghum (Serena) yield loss due to Chilo partellus infestations. International Centre of Insect Physiology and Ecology (ICIPE) 13th Annual Report 1985. page 6.

SINGH, S. R. and VAN EMDEN, H. F. 1979. Insect pests of grain legumes. Annual Review of Entomology 24: 255-278.

SINGH, R. S. and ALLEN, D. J. 1980. Pests, diseases, resistance and protection in cowpeas. In: Summerfield, R. J. and Bunting, A. H. (Eds.). Advances in legume science. Kew, Royal Botanic Gardens and London MAFF, pp. 419-443.

SINGH, S. R. and JACKAI, L. E. N. 1985. Insect pests of cowpeas in Africa: their life cycle, economic importance and potential for control. In: Cowpea research, production and utilization (Eds. Singh, S. R. and Rachie, K. O.) John Wiley and Sons Ltd. pp. 217-231.

SINGH, S. R.; VAN EMDEN, H. F. and TAYLOR, T. A. ; Eds., 1978a. Pests of grain legumes: ecology and control. London, U. K., Academic Press.

SINGH, S. R.; VAN EMDEN, H. F. and TAYLOR, T. A. 1978b. The potential for the development of integrated pest management systems in cowpea. In: Singh, S. R.; VAN EMDEN, H. F. and TAYLOR, T. A., eds., Pests of grain legumes: ecology and control. London, U. K., Academic Press, pp. 329-336.

SMITH, J. G. 1976. Influence of crop background on aphids and other phytophagous insects in Brussels sprouts. Annals of Applied Biology 83: 1-13.

SOUTHWOOD, T. R. E. and WAY, M. J. 1970. Ecological background to pest management. In: Concepts of Pest Management (R. L. Rabb and F. E. Guthrie, eds.) Raleigh, North Carolina: North Carolina State University Press 1970. pp. 6-29.

STANTON, M. L. 1983. Spatial patterns in plant community and their effects upon insect search. In: Ahmad, S.(ed.), Herbivorous Insects: Host-seeking Behaviour and Mechanisms. Academic Press, New York: pp. 125-157

STARKS, K. J. 1969. Some cereal crop insects in East Africa. East African Agricultural and Forestry Research Organization, Serere Research Station, Uganda (Mimeo).

STEELE, W. M. and MEHRA, K. L. 1980. Structure, evolution nd adaptation of farming systems and environments of Vigna. In: "Advances in legume science" (Eds. Summerfield, R. J. and Bunting, A. H.) Royal Botanical Gardens, Kew. London.

STEINER, K. G. 1982. Intercropping in tropical smallholder agriculture with special reference to West Africa. Schriftenreihe der GTZ No. 137, Eschborn.

STILING, P. D. 1985. An introduction to insect pests and their control. Macmillan Publishers Ltd., London and Basingstoke 1985, 97pp.

SUNESON, C. A. 1960. Genetic diversity- a protection against diseases and insects. Agronomy Journal 52: 319-321.

SWAINE, G. 1957. The maize and sorghum stalk borer, Busseola fusca (Fuller) in peasant agriculture in Tanganyika Territory. Bulletin of Entomological Research 43: 645-678.

TAHVANAINEN, J. O. and ROOT, R. B. 1972. The influence of vegetational diversity on the population ecology of a specialized herbivore, Phyllotreta cruciferae (Coleoptera: Chrysomelidae). Oecologia 10, 321-346.

TAMS, W. H. T. 1932. New species of African Heterocera. Entomologist 65, 124-129.

TAMS, W. H. T. and BOWDEN, J. 1953. A revision of the African species of Sesamia Guenee and related genera (Agrotidae: Lepidoptera). Bulletin of Entomological Research 43: 645-678.

TAYLOR, T. A. 1967. The bionomics of Maruca testulalis Gey., a major pest of cowpea in Nigeria. Journal of the West African Science Association 12, 112-129

TAYLOR, T. A. 1968. The effect of insecticide applications on insect damage and performance of cowpea in southern Nigeria. Nigerian Agricultural Journal 5: 29-37.

TAYLOR, T. A. 1977. Mixed cropping as an input in the management of crops in Tropical Africa. African Environment 2(4), 111-126.

TAYLOR, T. A. 1978. Maruca testulalis: An important pest of tropical grain legumes. In: Pests of Grain Legumes: Ecology and Control (Eds. Singh, S. R., Taylor, T. A. and van Emden, H. F.) Academic Press, London pp. 193-200.

THEUNISSEN, J. and DEN OUDEN, H. 1980. Effects of intercropping with Spergula arvensis on pests of Brussels sprouts. Entomologia Experimentalis et Applicata 27: 260-268.

TOTHILL, J. D. 1958. Some reflections on the causes of insect outbreaks. In: Proceedings of the Tenth International Congress on Entomology 4, 525-531.

TRENBATH, B. R. 1974. Biomass productivity of mixtures. Advances in Agronomy 26: 177-210.

TRENBATH, B. R. 1976. Plant interactions in mixed crop communities. In: Multiple Cropping, Special Publication No. 27. Papendick, R. I., Sanchez, P. A., and Triplett, G. B., Eds. American Society of Agronomy, Madison, Wis. 129.

USUA, E. J. 1975. Studies in relation to Maruca testulalis. In: Luse, R. A. and Rachie, K. O. (eds.) Proceedings IITA Collaborator's Meeting on Grain Legume Improvement, 9-13 June 1975 Ibadan, Nigeria pp. 52-54.

VAN HAMBURG, H. 1980. The grain stalk-borer Chilo partellus (Swinhoe) (Lepidoptera: Pyralidae): survival and location of larvae at different infestation levels in plants of different ages. Journal of the Entomological Society of South Africa 43(1), 71-76.

WAHUA, T. A. T. and MILLER, D. A. 1978. Relative yield total and yield comparison of intercropped sorghum and soyabean. Agronomy Journal 70: 287-291.

WAIYAKI, J. N. 1968. The biology and control of the principal lepidopterous borers associated with sugarcane at the Tanganyika Planting Company, Arusha-Chini. Unpublished report, Tropical Pesticide Research Institute, Arusha, Tanzania.

WALKER, P. T. 1960. The relation between infestation by stem borer, Busseola fusca, and yield of maize in East Africa. Annals of Applied Biology 48(4), 780-786.

WAY, M. J. 1953. The relationship between certain ant species with particular reference to the control of the coreid Theraptus sp. Bulletin of Entomological Research 44: 669-691.

WAY, M. J. 1971. A prospect of pest control. Inagural lecture, Imperial College of Science and Technology, University of London, 127-162.

WAY, M. J. 1975. Concepts of diversity and stability in relation to tropical pest incidence and control. In: Proceedings of the 9th Annual conference of the Entomological Society of Nigeria, pp. 1-13.

WAY, M. J. 1977. Pests and disease status in mixed stands vs. monocultures; the relevance of ecosystem stability. In: Origins of pest, parasite, disease and weed problems, Cherett, J. M. and Sagar, G. R., Eds., 18th Symposium of the British Ecological Society, Blackwell, Oxford. 127-138.

WAY, M. J. 1979. Significance of diversity in agroecosystems. In: Proceedings Plenary Session Symposium of the 9th International Congress on Plant Protection, Washington, pp. 9-12.

WAY, M. J. 1983. Report on consultant's visit to Tanzania to examine and advise on Pseudotheraptus wayi problem on coconuts. National Coconut Development Programme and GTZ, Tanzania, 82pp.

WAY, M. J. and HEATHCOTE, G. D. 1966. Interactions of crop density of field beans, abundance of Aphis fabae Scop. virus incidence and aphid control of chemicals. Annals of Applied Biology 57: 409-423.

WHITNEY, W. K. 1977. Insect and mite pests and their control. In: Food crops of the lowland tropics, (eds. Leakey, C. L. A. and Wills, J. B.) Oxford Universty Press 1977. pp. 195-235.

WIENER, L. F. and NORRIS, D. M. 1982. Light and other stimuli in the location of feeding sites by lesser peach tree borer larvae. Environmental Entomology 11: 399-402.

WILLEY, R. W. 1979. Intercropping - its importance and its research needs: Part I. Competition and yield advantages. Field Crop Abstracts 32: pp.1-10.

WILLEY, R. W. 1979. Intercropping - its importance and its research needs: Part II. Agronomic relationships. Field Crop Abstarcts 32: pp. 73-85.

YOUNG, W. R. and TEETES, G. L. 1977. Sorghum entomology. Annual Review of Entomology 22: 193-218.

APPENDIX 1

1) Weekly mean number of stem borer larvae in four sorghum cropping patterns at MPFS in 1986/87 short rainy season

a) All stem borer larvae (mean on 5 plants)

WAE	Cropping patterns: Sorghum monocrop	Sorghum and cowpea sown simultaneously	Sorghum sown before cowpea	Sorghum sown after cowpea	Mean
3	5.8[a]	7.3[a]	1.7[ab]	0.5[b]	2.9[d]
4	7.8[a]	3.2[ab]	2.6[ab]	1.4[b]	3.2[d]
5	9.0[a]	4.8[ab]	8.4[a]	1.4[b]	5.3[cd]
6	6.3[a]	5.3[a]	8.4[a]	9.6[a]	7.3[c]
7	9.0[a]	9.0[a]	8.4[a]	4.4[a]	7.3[c]
8	10.2[a]	5.8[ab]	2.3[b]	4.4[ab]	5.3[cd]
9	11.6[a]	6.8[a]	10.2[a]	6.8[a]	8.4[c]
10	6.3[a]	6.3[a]	6.3[a]	14.4[a]	7.8[c]
11	7.8[a]	5.8[a]	7.3[a]	9.0[a]	7.3[c]
12	16.8[a]	16.8[a]	13.0[a]	12.3[a]	14.4[b]
13	13.7[a]	10.9[a]	16.0[a]	19.4[a]	15.2[b]
14	22.1[a]	8.4[b]	16.0[ab]	15.2[ab]	15.2[b]
15	24.0[a]	24.0[a]	31.4[a]	18.5[a]	24.0[a]
16	23.0[a]	13.7[a]	14.4[a]	14.4[a]	16.0[b]
Mean	11.6[a]	8.4[b]	9.0[ab]	7.8[b]	

Cropping pattern means in a row and weekly means in the last column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

b) *C. partellus* larvae (mean on 5 plants)

WAE	Cropping patterns: Sorghum monocrop	Sorghum and cowpea sown simultaneously	Sorghum sown before cowpea	Sorghum sown after cowpea	Mean
3	4.8[ab]	6.8[a]	1.0[c]	2.2[bc]	3.6[c]
4	7.3[a]	2.6[ab]	2.0[b]	2.9[ab]	3.6[c]
5	8.4[a]	4.4[ab]	9.0[a]	2.0[b]	5.8[bc]
6	6.3[a]	4.8[a]	7.8[a]	2.9[a]	5.8[bc]
7	7.3[a]	7.8[a]	5.8[a]	3.2[a]	5.8[bc]
8	9.0[a]	4.4[ab]	1.0[b]	2.2[b]	3.6[c]
9	7.3[a]	5.3[a]	2.9[a]	2.9[a]	4.4[c]
10	2.9[a]	4.4[a]	3.2[a]	9.0[a]	4.4[c]
11	3.2[a]	2.6[a]	2.6[a]	6.3[a]	3.6[c]
12	7.3[a]	8.4[a]	6.8[a]	11.6[a]	8.4[ab]
13	8.4[a]	6.3[a]	11.6[a]	10.9[a]	9.0[ab]
14	17.6[a]	7.8[b]	13.0[ab]	11.6[ab]	12.3[a]
15	13.0[a]	10.9[a]	16.0[a]	12.3[a]	13.0[a]
16	16.0[a]	10.9[a]	12.3[a]	13.0[a]	13.0[a]
Mean	8.4[a]	6.3[b]	6.3[b]	5.3[b]	

Cropping pattern means in a row and weekly means in the last column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

2) Weekly mean number of stem borer larvae in four sorghum and cowpea cropping patterns at MPFS in 1987 long rainy season

a) All stem borer larvae (mean on 5 plants)

WAE	Cropping patterns:				Mean
	Sorghum monocrop	Sorghum and cowpea sown simultaneously	Sorghum sown before cowpea	Sorghum sown after cowpea	
3	8.4[ab]	9.0[ab]	12.3[a]	2.9[b]	7.8[b-d]
4	5.8[a]	1.4[a]	2.3[a]	1.2[a]	2.6[fg]
5	2.9[a]	1.2[a]	1.7[a]	2.0[a]	2.0[g]
6	4.4[a]	1.4[a]	2.3[a]	4.0[a]	2.9[e-g]
7	6.3[a]	1.2[a]	3.2[a]	2.6[a]	2.9[e-g]
8	3.2[a]	2.3[a]	2.9[a]	2.6[a]	2.6[fg]
9	3.2[a]	4.4[a]	7.3[a]	6.3[a]	5.3[c-f]
10	3.6[ab]	2.3[b]	3.2[ab]	9.0[a]	4.4[e-g]
11	4.0[a]	5.3[a]	7.8[a]	6.8[a]	5.8[c-e]
12	13.0[a]	10.2[a]	8.4[a]	9.0[a]	10.2[ab]
13	9.6[a]	10.2[a]	13.0[a]	11.6[a]	10.9[ab]
14	9.0[a]	6.8[a]	5.8[a]	7.8[a]	7.3[b-d]
15	11.6[ab]	4.0[b]	12.3[a]	9.0[ab]	9.0[a-c]
16	16.8[a]	13.7[a]	13.0[a]	11.6[a]	13.7[a]
17	9.0[a]	10.2[a]	14.4[a]	19.4[a]	13.0[a]
18	14.4[a]	13.7[a]	14.4[a]	9.6[a]	13.0[a]
Mean	7.3[a]	5.3[b]	6.8[ab]	6.3[ab]	

Cropping pattern means in a row and weekly means in the last column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

b) *C. partellus* larvae (mean on 5 plants)

WAE	Cropping patterns: Sorghum monocrop	Sorghum and cowpea sown simultaneously	Sorghum sown before cowpea	Sorghum sown after cowpea	Mean
3	8.4[ab]	9.0[ab]	11.6[a]	2.9[b]	7.8[b-d]
4	5.8[a]	1.4[a]	2.3[a]	1.2[a]	2.6[ef]
5	2.9[a]	1.2[a]	1.4[a]	2.0[a]	2.0[f]
6	4.4[a]	1.4[a]	2.0[a]	2.9[a]	2.6[ef]
7	5.8[a]	1.2[a]	2.9[a]	2.7[a]	2.9[d-f]
8	2.9[a]	2.0[a]	2.6[a]	1.0[a]	2.0[f]
9	2.0[a]	2.9[a]	4.0[a]	3.2[a]	2.6[ef]
10	2.6[a]	2.3[a]	1.7[a]	4.0[a]	2.6[ef]
11	2.9[a]	5.3[a]	4.8[a]	5.3[a]	4.4[c-e]
12	2.6[a]	6.8[a]	5.8[a]	6.8[a]	5.3[b-d]
13	6.3[a]	5.3[a]	10.9[a]	5.3[a]	6.8[a-c]
14	5.3[a]	4.0[a]	4.8[a]	5.3[a]	4.8[c-e]
15	7.8[a]	2.9[a]	7.8[a]	6.3[a]	6.3[a-c]
16	12.3[a]	9.0[a]	9.6[a]	6.8[a]	9.6[a]
17	6.8[a]	6.3[a]	11.6[a]	11.6[a]	9.0[a]
18	9.6[a]	9.6[a]	9.6[a]	6.3[a]	8.4[ab]
Mean	5.3[a]	4.0[a]	5.3[a]	4.4[a]	

Cropping pattern means in a row and weekly means in last column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

3) Weekly mean number of stem borer larvae in four sorghum and cowpea cropping patterns at Rusinga in 1987 long rainy season

a) All stem borer larvae (mean on 5 plants)

WAE	Cropping patterns: Sorghum monocrop	Sorghum and cowpea sown simultaneously	Sorghum sown before cowpea	Sorghum sown after cowpea	Mean
3	1.2[a]	2.3[a]	1.0[a]	1.0[a]	1.4[gh]
4	1.0[a]	1.2[a]	1.0[a]	1.0[a]	1.0[h]
5	1.0[a]	1.0[a]	1.0[a]	2.9[a]	1.4[gh]
6	2.9[a]	2.0[a]	2.6[a]	2.7[a]	2.6[fg]
7	4.4[a]	1.7[a]	2.3[a]	5.3[a]	3.2[ef]
8	7.3[a]	3.2[ab]	4.0[ab]	2.6[b]	4.0[ef]
9	7.3[a]	2.9[a]	4.4[a]	4.4[a]	4.8[c-e]
10	9.6[a]	4.8[ab]	6.3[a]	2.0[b]	5.3[b-d]
11	9.6[a]	6.8[a]	6.8[a]	5.3[a]	7.3[a-c]
12	8.4[a]	6.8[a]	6.3[a]	4.0[a]	6.3[a-d]
13	3.6[a]	7.3[a]	6.3[a]	5.3[a]	5.8[b-d]
14	5.3[a]	4.8[a]	8.4[a]	9.6[a]	6.8[a-c]
15	7.8[b]	6.8[b]	6.8[b]	16.0[a]	9.0[a]
16	6.3[a]	7.8[a]	4.0[a]	4.0[a]	5.3[b-d]
17	10.9[a]	10.2[a]	7.8[a]	4.8[a]	8.4[ab]
Mean	5.3[a]	4.4[a]	4.0[a]	4.4[a]	

Cropping pattern means in a row and weekly means in the last column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

b) *C. partellus* larvae (mean on 5 plants)

WAE	Cropping patterns: Sorghum monocrop	Sorghum and cowpea sown simultaneously	Sorghum sown before cowpea	Sorghum sown after cowpea	Mean
3	1.2^{a}	2.3^{a}	1.0^{a}	1.0^{a}	1.4^{e}
4	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{a}	1.0^{e}
5	1.0^{a}	1.0^{a}	1.0^{a}	2.3^{a}	1.4^{e}
6	2.3^{a}	2.0^{a}	2.3^{a}	1.0^{a}	1.7^{c-e}
7	2.3^{a}	1.2^{a}	1.2^{a}	1.2^{a}	1.4^{de}
8	4.0^{a}	4.0^{a}	3.6^{a}	1.4^{a}	2.7^{b-d}
9	2.9^{a}	1.2^{a}	3.2^{a}	1.0^{a}	2.0^{c-e}
10	4.8^{a}	4.0^{ab}	3.2^{ab}	1.0^{b}	2.9^{a-c}
11	6.3^{a}	3.6^{a}	4.0^{a}	3.2^{a}	4.0^{ab}
12	2.6^{a}	4.0^{a}	2.3^{a}	2.6^{a}	2.9^{b-d}
13	2.3^{a}	4.4^{a}	2.9^{a}	3.2^{a}	3.2^{a-c}
14	2.9^{ab}	2.3^{b}	6.3^{a}	2.4^{ab}	4.0^{ab}
15	4.8^{a}	4.0^{a}	3.6^{a}	8.4^{a}	4.8^{a}
16	4.4^{a}	2.9^{a}	2.6^{a}	3.2^{a}	3.2^{a-c}
17	4.0^{a}	4.4^{a}	4.0^{a}	4.4^{a}	4.4^{ab}
Mean	2.9^{a}	2.7^{a}	2.7^{a}	2.7^{a}	

Cropping pattern means in a row and weekly means in the last column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

4) Weekly mean number of stem borer larvae in four sorghum and cowpea cropping patterns at MPFS in 1987/88 short rainy season

a) ALL stem borer larvae (mean on 5 plants)

WAE	Cropping patterns: Sorghum monocrop	Sorghum and cowpea sown simultaneously	Sorghum sown before cowpea	Sorghum sown after cowpea	Mean
3	7.3[a]	3.6[ab]	5.3[ab]	1.4[b]	4.4[f]
4	8.4[a]	4.0[a]	4.8[a]	2.9[a]	4.8[ef]
5	9.6[a]	9.6[a]	7.3[a]	1.0[b]	6.3[d-f]
6	7.8[a]	1.2[b]	6.3[a]	5.8[ab]	4.8[ef]
7	7.3[a]	1.2[b]	5.3[ab]	2.0[ab]	4.0[f]
8	8.4[a]	9.0[a]	9.6[a]	9.6[a]	9.0[b-d]
9	8.4[a]	9.6[a]	6.3[a]	9.6[a]	8.4[c-e]
10	17.6[a]	6.8[b]	11.6[ab]	13.7[ab]	12.3[a-c]
11	10.2[a]	12.3[a]	9.6[a]	10.9[a]	10.9[bc]
12	13.0[a]	16.0[a]	12.3[a]	12.3[a]	13.7[a-c]
13	14.4[a]	12.3[a]	13.7[a]	10.9[a]	13.0[a-c]
14	14.4[a]	6.8[b]	19.4[a]	8.4[b]	11.6[a-c]
15	12.3[a]	13.7[a]	12.3[a]	19.4[a]	14.4[ab]
16	14.4[b]	9.0[b]	14.4[b]	36.0[a]	16.8[a]
Mean	10.9[a]	9.0[b]	9.6[ab]	9.0[ab]	

Cropping pattern means in a row and weekly means in the last column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

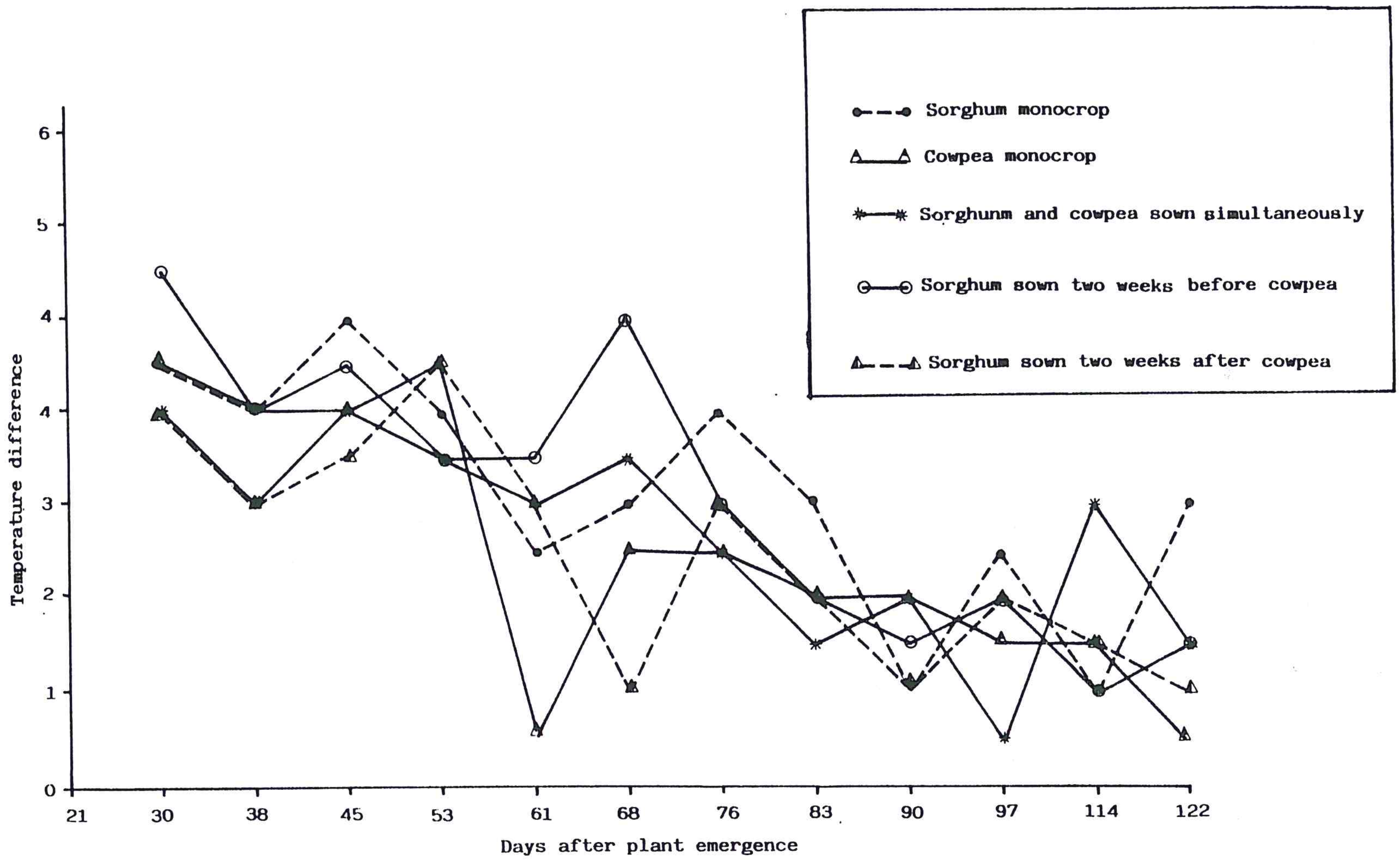
b) C. *partellus* larvae (mean on 5 plants)

WAE	Cropping patterns: Sorghum monocrop	Sorghum and cowpea sown simultaneously	Sorghum sown before cowpea	Sorghum sown after cowpea	Mean
3	7.3^{a}	3.6^{ab}	5.3^{ab}	1.4^{b}	4.0^{de}
4	8.4^{a}	4.0^{a}	4.8^{a}	2.6^{a}	4.8^{c-e}
5	9.6^{a}	8.4^{a}	7.3^{a}	1.0^{b}	5.8^{de}
6	7.3^{a}	1.0^{b}	5.3^{a}	2.3^{ab}	3.6^{de}
7	3.6^{a}	1.2^{a}	4.4^{a}	1.2^{a}	2.6^{e}
8	6.3^{a}	6.8^{a}	6.8^{a}	2.3^{a}	5.3^{cd}
9	4.8^{a}	6.8^{a}	3.6^{a}	4.4^{a}	4.8^{c-e}
10	6.8^{a}	3.6^{a}	6.8^{a}	5.8^{a}	5.8^{cd}
11	6.8^{a}	6.3^{a}	3.2^{a}	9.0^{a}	6.3^{cd}
12	6.8^{a}	10.9^{a}	6.3^{a}	8.4^{a}	7.8^{bc}
13	8.4^{a}	5.8^{a}	7.8^{a}	10.2^{a}	7.8^{bc}
14	8.4^{ab}	4.0^{b}	15.2^{a}	4.8^{b}	7.8^{bc}
15	6.3^{b}	10.2^{ab}	9.6^{ab}	17.6^{a}	10.9^{ab}
16	12.3^{b}	9.0^{b}	10.9^{b}	29.2^{a}	14.4^{a}
Mean	7.3^{a}	5.3^{b}	6.8^{ab}	5.8^{ab}	

Cropping pattern means in a row and weekly means in the last column followed by the same letter are not significantly different (P=0.05; Duncan's [1955] multiple range test).

APPENDIX 2.1

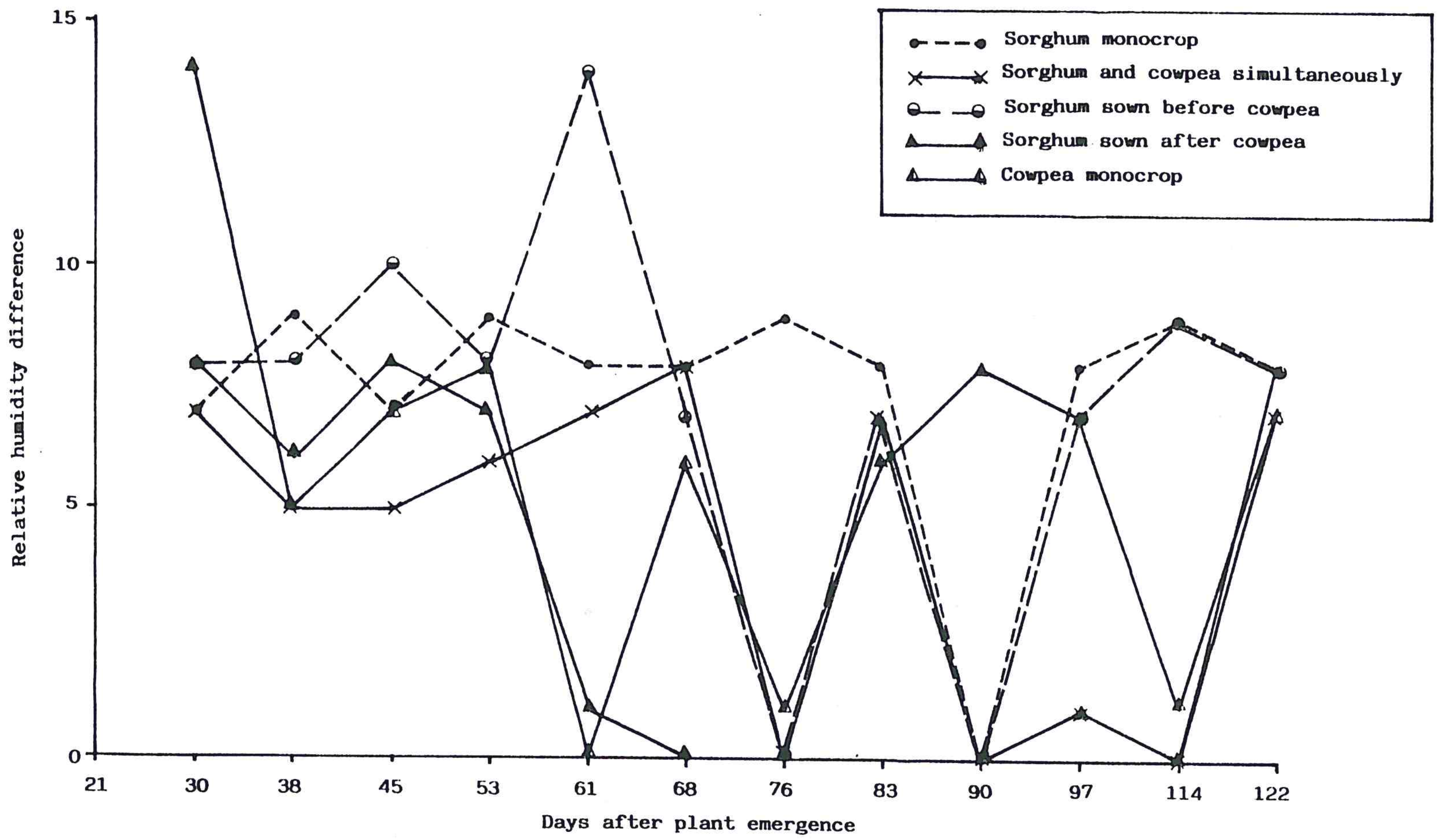
Crop canopy temperature differences in five cowpea and sorghum cropping patterns at MPFS during 1987/88 short rainy season



Sorghum monocrop
Cowpea monocrop
Sorghunm and cowpea sown simultaneously
Sorghum sown two weeks before cowpea
Sorghum sown two weeks after cowpea
Temperature difference
0
1
2
3
4
4
5
6
21
30
38
45
53
61
68
76
83
90
97
114
122
Days after plant emergence

APPENDIX 2.2

Crop canopy relative humidity differences in five cowpea and sorghum cropping patterns at MPFS during 1987/88 short rainy season


Sorghum monocrop
Sorghum and cowpea simultaneously
Sorghum sown before cowpea
Sorghum sown after cowpea
Cowpea monocrop
15
10
5
0
Relative humidity difference
21
30
38
45
53
61
68
76
83
90
97
114
122
Days after plant emergence