INFESTATION OF PHASEOLUS VULGARIS (L) BY THE BEANFLY OPHIOMYIA SPP. (DIPTERA: AGROMYZIDAE) AND ITS MANAGEMENT BY CULTURAL PRACTICES.

BY

JOSEPH SIBOMANA KAYITARE

INFESTATION OF *PHASEOLUS VULGARIS* (L) BY THE BEANFLY *OPHIOMYIA* SPP. (DIPTERA: AGROMYZIDAE) AND ITS MANAGEMENT BY CULTURAL PRACTICES.

A THESIS

SUBMITTED TO THE DEPARTMENT OF CROP SCIENCE OF THE FACULTY OF AGRICULTURE, UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (ENTOMOLOGY)

CROP SCIENCE

BY

JOSEPH SIBOMANA KAYITARE

CROP SCIENCE DEPARTMENT,
FACULTY OF AGRICULTURE,
UNIVERSITY OF GHANA.
LEGON.

APRIL, 1993.

DECLARATION

I hereby declare that the work contained in this thesis for the Doctor of Philosophy degree in Crop Science is the result of my own investigations and has not been submitted for a similar degree in any other university.

JOSEPH SIBOMANA KAYITARE

Dr.Kwesi Ampong-Nyarko
ICIPE Supervisor.

Professor J.N. Ayertey
University Supervisor.

ABSTRACT

Cultural practices as management strategy for beanfly control were examined over four cropping seasons in 1991 and 1992 under farmer's developed field conditions at Oyugis, in Homa Bay District of Western Kenya. In many parts of East and Central Africa, the beanfly is a major constraint to the production of the bean crop (Phaseolus vulgaris). Its incidence causes yield losses averaging 47-87%. Control methods used against the pest are mostly insecticides based. Cultural control as a pest management strategy is a less considered area of research which needs to be studied, since it is the first line of defence against pest populations and results in little or no added cost For this reason studies on five cultural practices (soil fertility, intercropping, weeding regimes, plant spacing and planting time) on beanfly infestation were undertaken as possible control methods.

Increase in nitrogen levels increased beanfly infestation by 12-66%. Phosphorus served as catalyst for nitrogen assimilation. The fertilized plants were more succulent, tender and had more nutrients and therefore offered better conditions for beanfly penetration into bean stems, fecundity and development. However, the infested plants in fertilized soils were able to compensate for the damage caused to them and grew quickly to pass the critical stages. Thus the beanfly infestation had little effect on grain yield. The effect of beanfly infestation on yield when no nitrogen and phosphorus were applied, was a 48% reduction in yield. Therefore, the use of nitrogen and phosphorus fertilizers reduced the effect of beanfly damage and increased grain yield.

Intercropping increased beanfly infestation compared to pure stands of beans. The microclimatic conditions (light intensity, temperature and relative humidity) created by intercropping of beans with maize increased beanfly infestation compared to that in the bean monocrop.

Weeding regimes had no effect on beanfly infestation. However weed-free, and weeding three weeks after plant emergence, provided better grain yield.

Plant spacing studies showed an increase of beanfly infestation in wider spacings. The optimal plant density of 222,222/ha (30x15 cm) seemed to give the least beanfly infestation and a high grain yield.

Early planting with the first rains reduced beanfly infestation and gave better grain yield.

Two species of beanfly, *Ophiomyia phaseoli* Tryon and *O. spencerella* Greathead, were identified in Oyugis, where *O. spencerella* was more predominant.

Parasitoids regulated beanfly population in nature. Six species of parasitoids were identified, with *Opius phaseoli* being the dominant species. They were host density-dependent and reduced beanfly population by 14-24%.

The experimental results indicate that the use of nitrogen and phosphorus fertilizers, monocropping system, optimal plant density of 222,222 plants/ha and early planting time were good cultural practices that can form a part of an integrated pest management (IPM) strategy to reduce beanfly infestation with consequent increase in bean production.

ACKNOWLEDGEMENT

I am grateful to Dr. Kwesi Ampong-Nyarko, my ICIPE supervisor, Dr. A.M. Alghali who was my initial supervisor until his departure from ICIPE and Professor J.N. Ayertey, my university supervisor for their contribution on experimental methodology, encouragement and guidance in the course of the research work and their constructive comments in the write-up of this thesis.

I wish to thank Professor Thomas R. Odhiambo, Director, ICIPE for his creation of ARPPIS and the opportunity given me for this training. The study was possible with generous funding from UNDP through PESTNET, ICIPE and USAID. My thanks are due to Dr. Z.M. Nyiira who encouraged me to join ARPPIS and to Dr. E.O. Omolo who, as the PESTNET Coordinator, made possible my stay in Oyugis for the research work. My sincere gratitude to Professor Z.T. Dabrowski and Dr.V.O. Musewe, ARPPIS Academic Coordinators at various stages of my studies for their support. I am also grateful to Mr. Elisha Ouma for providing experimental plots and assistance during my field work. Many thanks to Dr. A. Odulaja, Mrs. J. Omwa and D. Munyinyi both statisticians, my classmates and all ICIPE staff for their contribution to the success of this study.

I am very grateful to the family of Dr. N.K. Maniania for their hospitality in Mbita, source of a new strength when morale was low.

Special recognition to the late unforgettable Mr. J.B. Ndwanyi for his continuous encouragement and support for further studies, may God rest his Soul in Eternal Peace.

Finally, my most sincere thanks are expressed to my wife, T. Akayezu for her patience and encouragement; to my children, R.K. Maniragaba and M.K. Tuyishime for their encouraging letters; may this work serve as an example of perseverance to them; to my parents, all members of my family and friends for their encouragement and support in the course of this study.

COPYRIGHT

TABLE OF CONTENTS

LIST OF TABLES.

LIST OF FIGURES.

LIST OF PLATES

LIST OF ABBREVIATION

ARPPIS: African Regional Postgraduate Programme in Insect Science.

AVRDC : Asian Vegetable Research and Development Center.

BNR : Banque Nationale du Rwanda.

CIAT : Centro Internacional de Agricultura Tropical.

FAO : Food and Agriculture Organization.

ICIPE : International Centre of Insect Physiology and Ecology.

ICRISAT :International Crops Research Institute for the Semi-Arid Tropics.

IITA : International Institute of Tropical Agriculture.

ISAR : Institut des Sciences Agronomiques du Rwanda.

KARI : Kenya Agricultural Research Institute.

MINAGRI :Ministère de l’Agriculture et de l’Elevage.

NAL : National Agricultural Laboratories.

NAS : National Academy of Science.

PESTNET: African Regional Pest Management Research and Development Network.

PRP : Population Reference Bureau.

UNDP: United Nations Development Programme.

USAID: United States Agency for International Development.

CHAPTER 1: GENERAL INTRODUCTION

1.1. Bean production and use.

The word"bean" is applied to several leguminous plants and their seeds. Originally, the name was applied to the seed of Vicia faba (Lamb, 1978; Crossekey, 1980). However, the word is now used in a much wider sense, without specific scientific delimitations. Phaseolus vulgaris (L), common bean (french bean), is a wide- spread leguminous crop grown in the tropics, particularly in Latin America, Africa, Asia, Australia and Oceania (Lamb, 1978; Crossekey, 1980). It is an annual crop which grows either erect and bushy or twining. The seeds are brown, white, reddish black to black or variegated. Beans do not grow well below 600 m because high temperatures cause poor fruit set (Acland, 1985). Beans are best suited to the medium altitude areas from 900-2100m. Beans are not drought-tolerant, so they need moist soil throughout the growing period. They require free draining soils with reasonably high nutrient content (Acland, 1985).

Over the past 10 years, bean production in Africa has averaged between 11.3 and 12.9% of world production, which in 1990 was 16.3 million metric tons (FAO, 1991). The East African countries (Kenya, Tanzania, Uganda, Rwanda and Burundi) account for 61% of the total African bean production.

Latin America produces 3.6 million metric tons annually (45% of the world total) with Brazil and Mexico being the major producers (Oree and Hallman, 1989). Grain yield potential averages 1.4t/ha in the developed countries (USA, Japan, Canada, Western Europe), but actual yields on farmers' fields in the developing countries (Africa, Latin America and Asia) are usually low, averaging 0.5-0.6t/ha African farm yields (665 kg/ha) are not really different from the world average (617kg/ha) (FAO, 1991).

The importance of beans, cropping system and uses vary among countries. For instance, in Rwanda, bean is the most important legume, followed by soybeans, green peas and groundnut. It is cultivated both as a monocrop and as intercrop with either maize, bananas, sweet potato or cassava. In 1990 an area of 300,000 ha provided 200,000 tons of the grain yield (667 kg/ha) (FAO, 1991). In 1983, the average production was 841 kg/ha and the cultivated area for beans represented 27.5% of the whole cultivated area for food crops (MINAGRI, 1983). The annual bean consumption in Rwanda and Burundi per capita has been estimated to be 47.50kg (Huignard, 1985). In Rwanda, beans are cultivated by all farmers, usually on small holdings averaging 0.5-1 ha with varying levels of yield. Beans are consumed as green leaves, green pods, green grains or dried grains (pulses) and constitute an important source of protein and carbohydrates to the rural and urban poor. Rwanda has been an exporter of green beans to

France since 1988 (BNR, 1988, 1989, 1990, 1991). In Rwanda, the haulm is used as fodder for feeding livestock, incorporated in compost to make organic manure and is also used as mulch in coffee and banana plantations.

1.2. Bean production constraints.

There are several constraints limiting bean production and yield in Africa. The major ones include declining soil fertility, heavy biotic pressure from insects and diseases and unfavourable weather conditions.

1.2.1. Soil fertility.

A major constraint responsible for low bean yield is declining soil fertility. As a result of high population pressure, shorter fallow periods are maintained, which lead to over exploitation of the soil (Trutman, 1987). The situation is continuously worsening because of minimal or non-existent use of organic and inorganic fertilizer. Furthermore, bean production is being extended to marginal areas (CIAT, 1976). Although the intensification of bean production in adapted soils could be part of the solution, the lack of knowledge and material input is a limitation to the small-scale farmer.

Nodulation in bean roots is very variable (Acland, 1985). Little is known about the factors which affect nodulation in

East Africa, although it is known that the common strains of Rhizobium spp. belong to the cowpea group and these are ineffective on Phaseolus spp. The root knot nematodes are also often present on the roots and can be confused with the nodules until they are critically examined (Acland, 1985).

1.2.2. Diseases.

Another important constraint to bean production is heavy biotic pressure from insects and diseases. The bean crop has been cultivated for several years in Africa and insect pests and diseases have co-evolved with it and have become major limiting factors. Bean was probably introduced to East Africa by the Spanish and Portuguese between 1576 and 1609, at the same time as maize, during the expedition in Kigezi (Uganda) under the reign of King Kigeri II Nyamuheshera (ISAR, 1982).

Beans produced in Africa mostly suffer yield losses due to a combination of diseases such as anthracnose, (Colletotrichum lindemuthianum (Sacc.& Magn.) ; ascochytose, (Ascochyta phaseolorum (Saccardo); angular leaf spot,(Isariopsis griseola (Sacc.); rust, (Uromyces phaseoli (Reben) Wint; bean common mosaic virus (BCMV); root rots (Rhizoctonia solani (Kuhn); common blight (Xanthomonas phaseoli (E.F.S.M) Dows and halo blights (Pseudomonas phaseolicola (Burk) Dows (Howard and Guillermo, 1980).

1.2.3. Insects.

Many insect pests that attack the bean crop in the field and in storage are major constraints to bean production in Africa and elsewhere. Such pests include the agromyzid beanfly (Ophiomyia spp.), aphids (Aphis fabae) ; thrips (Megalurothrips sjostedti (Trybom); maruca pod borer (Maruca testulalis (Geyer); cutworms (Agrotis spp. and armyworm Spodoptera spp.); corn earworm (Helicoverpa complex) among others. The storage insects are mainly bruchids, Acanthoscelides obtectus Say which starts infestation in the field; Zabrotes subfasciatus Boheman which occurs in warmer areas. These storage insects pose a serious economic problem because they often force producers to sell their beans immediately after harvest when the market is saturated and prices are low (Howard and Guillermo, 1980).

The agromyzid beanfly (Ophiomyia spp) is one of the most important key insect pests attacking beans in the field (Chiang and Talekar, 1980). O. phaseoli Tryon is generally cited to be a severe pest of common beans, (Phaseolus vulgaris). Other species of Ophiomyia important on bean crops in Africa are: O. spencerella (Greathead) and O. centrosematis (de Meijere).

The beanfly attacks the crop within a week of germination by laying its eggs on the leaves (in the case of O.phaseoli), on the stems (O.spencerella) and on the hypocotyl and stem

(*O.centrosematis*) (Spencer, 1959; Talekar, 1987; Oree and Hallman, 1989). Larvae feed within the stems and infested plants become yellowish, stunted and in severe cases the pest may cause complete loss of the bean crop. The symptoms of beanfly attack look like the result of severing of food supply or root rot diseases before the confirmation of the presence of beanfly. The beanfly is distributed in many parts of the tropics and sub-tropics of Africa, Asia, Australia and Oceania. The host plants belong to different orders such as Leguminosae, Solanaceae and Fabaceae (Santokh, 1982; Oree and Hallman, 1989).

1.3. Attempts at beanfly control.

Despite extensive entomological research over the years, complete control, without the use of chemicals, has not been obtained for the beanfly (Jackai and Sing, 1987). Beanfly control options are insecticides, resistant varieties, biological and cultural control.

The insecticide is applied to give protection during the first four weeks after germination (Talekar, 1987). However insecticide treatment may have side effects, such as pest resistance and effects on nontarget organisms (Smit, 1970). Moreover the use of insecticides has economic constraints. Also the better control of beanfly with insecticides does not necessarily increase grain yield (Anonymous, 1976).

Sources of resistance to beanfly have been identified in wild soybeans. However a close linkage between resistance and undesirable agronomic characters such as small, too woody and too narrow stems has not yet allowed the transfer of the resistance into agronomic cultivars (AVRDC, 1984; 1986).

Beanfly is parasitised by a large number of Hymenopteran species. Their incidence makes natural control of beanfly potentially feasible. Despite an extensive parasitism of beanfly however, sufficient flies survive to cause substantial damage.

Cultural methods may be of benefit in reducing losses due to beanfly through delaying its outbreaks (Glass, 1975). Such practices are the first line of defense against pest populations and have been shown to be effective for several insects and are simple and easy to adopt (Coaker, 1987). The application of cultural practices by a small scale farmer would be easy compared to the other control options. Therefore the objective of this study was to examine the effects of various cultural practices involved in bean production on beanfly infestation. The effect of nitrogen and phosphorus was studied to assess the attractiveness of the beanflies to the bean plants, their feeding, growth, fecundity and progeny. Studies conducted at the Asian Vegetable Research and Development Center (AVRDC, 1979) showed that the intercropping of beans (soybean, mungbean) with some crops (pearl millet, watermelon etc..) in Asia reduced beanfly infestation. The effect of intercropping of beans and maize, the most grown stapple food in Kenya was tested to assess if it can reduce beanfly infestation. Plant diversity which reduces insect pests incidence because of the increase of natural enemies has not been studied as a management strategy for beanfly control. Weeding regimes may also suggest the interval of weeding which should favour natural enemies development and hence reduce beanfly population. Variations of beanfly infestation were studied in close and wide spacings, in order to determine the optimum bean density that will reduce beanfly infestation and increase bean production. Ambient climatic conditions, such as rainfall were related to beanfly infestation in five successive planting dates in order to predict critical climatic conditions necessary to minimize beanfly infestation.

CHAPTER 2: LITERATURE REVIEW.

2.1. Beanfly biology.

In view of its relative importance, most of the work on beanfly biology has concentrated on O.phaseoli. Its biology was studied on green gram (Vigna radiata) and black gram (V.mungo) (Otanes, 1918; Spencer, 1973; Rejesus, 1978; Saxena, 1978). Although notable differences exist between them, the biology of different species of Ophiomyia attacking beans is similar. Consequently there has been considerable taxonomic confusion in the literature which has led to inaccuracies in the species record (Santokh, 1982).

2.1.1. Morphological distinctive characters of main beanfly species.

Three main species of beanfly have been identified in East Africa, distinguishable by pupal colour, genitalia and abdominal spiracles. These species are O.phaseoli (Tryon), O.spencerella (Greathead) and O.centrosematis (de Meijere) (Allen and Smithson, 1986). Pupal colour of both O.phaseoli and O.centrosematis is translucent yellowish brown and darker towards the tip. O.spencerella is black, tending to be paler on its ventral surface close to the stem. The aedeagus of O.phaseoli is less heavily chitinised, whereas that of

O.spencerella is solidly chitinised throughout. The aedeagus of O.centrosematis has two tiny spiracles at its tip, with small "teeth" behind them. The pattern and position of the posterior spiracle of 3rd instar larvae and pupae are distinctive. In both O.phaseoli and O.spencerella there are 8-9 spiracular openings with rather large spiracles, whereas in O.centrosematis the spiracles are smaller and three-lobed (Allen and Smithson, 1986).

2.1.2. O.phaseoli (Tryon).

O.phaseoli is extensively distributed in Africa, Asia, Australia and Oceania. It is known to be a severe pest of common beans (Phaseolus vulgaris), soybean (Glycine soya), mungbean (Vigna mungo) and cowpea (Vigna unguiculata). The non-leguminous host plants include Carthamus tintorius and Solanum nigrum. The beanfly O.phaseoli was described by Tryon in 1895. Spencer (1959) put it in the genus Melanagromyza and later in Ophiomyia, where it remains at present (Spencer, 1973). The adult beanfly is shiny with often bluish tinge and measures 1.5-2 mm in length with a wingspan of nearly 3.0 mm (Plate 1). The adult female begins to oviposit 2-3 days after copulation which takes place three days after emergence. The fly selects a suitable host plant and examines it with its labellum. It uses the ovipositor to make minute slit-like

Plate 1. Adult beanfly: *Ophiomyia* spp.

punctures in the epidermis. Only about one out of every 10 punctures contains eggs; the remaining being pseudopunctures for feeding (Manohor and Balasubramanian, 1980; Santokh, 1982). The female feeds on the exudate from the wound and a male feeds on the remains after the female leaves the plant (Oree and Hallman, 1989).

Oviposition occurs on both upper and lower surfaces of young leaves during daylight hours (Ali, 1957; Greathead, 1968). Oviposition on the lower surface of the leaf epidermis of beans occurs mainly during rainy weather (Davis, 1969). Beanfly prefers shady to sunny areas for biological activities, so the incidence of infestation in shady places is higher (36.0%) than in those exposed to the sun (12.8%) (Santokh, 1982). Because the flies probably are susceptible to rapid dehydration in direct sunlight, they tend to avoid exposed areas in the field (Santokh, 1982). A single female lays between 100 and 300 eggs within 2 weeks (Otanes, 1918; Raros, 1975).

The biology of O.phaseoli has been investigated by several workers (Spencer, 1959; Ho, 1967; Swaine, 1968; Manohor and Balasubramanian, 1980; Santokh, 1982; Talekar, 1983).

Incubation period of the eggs is 2-4 days. The larvae of Agromyzidae, as in other cyclorrhaphous Diptera, have three instars. The first instar larva mines into the nearest leaf vein through which it reaches the midrid and then passes into the petiole. At the junction between the leaf blade and the petiole, the larva moults to the second instar. The average duration of the first instar is 1.5 days in the laboratory. The second instar larva mines down toward the stem and it moults again in a cavity it makes at the base of the petiole. The duration of the second instar is 2.5 days. The freshly emerged third instar mines into the main stem just beneath the cuticle and epidermis and terminates in a pupal blister at a node but it may pupate just above the soil surface in the stem. The average duration of the third instar is 4 days. The larval stage lasts for 8-10 days and the pupal stage lasts an additional 9-10 days. The periods are shorter under higher temperatures and longer under lower temperatures. The life cycle lasts three weeks in hot weather or 12 weeks in cool weather (Caldwell, 1945; Greathead, 1968; Davis, 1969).

The adult emerges in the morning hours and is initially light-brown before it turns black (Santokh, 1982). The adult has a premating period of three days (Greathead, 1968; Babu, 1978). Mating takes place in the morning in fields of the host plant and the duration of copulation is highly variable, lasting from 40 minutes to almost 3 hours (Lall, 1959; Santokh, 1982).

2.1.3. *O. spencerella* (Greathead).

O. spencerella was described in 1968 by Greathead who recorded it on *P. vulgaris* in East Africa. In East Africa *O. spencerella* may be more important on beans than *O. phaseoli* in some circumstances in this region (Greathead, 1968). *O. spencerella* is indigenous to Africa and is abundant in Kenya (Spencer, 1973). This species is superficially identical to *O. phaseoli* (Tryon) but may be separated by the different shape in the male aedeagus glans and by the colour of the puparia, which is black (usually pale-brown in *O. phaseoli*) (Plate 2) (Harris, 1992). *O. spencerella* has been found in small numbers on *Vigna umbellata*, *Phaseolus lunatus*, *Vigna mungo*, and *Vigna unguiculata* (Greathead, 1968). In East Africa, *O. spencerella* attacks Fabaceae.

The eggs of *O. spencerella* are usually laid into the hypocotyl at ground level when the seedling is two to three days old. A few eggs are deposited in young stems above the cotyledon, and rarely in leaves. The larvae feed near ground or in the taproot, moving back to ground to pupate (Harris, 1992). With *O. spencerella*, a thin, transparent "window" is made in the epidermis which facilitates the emergence of the adult.

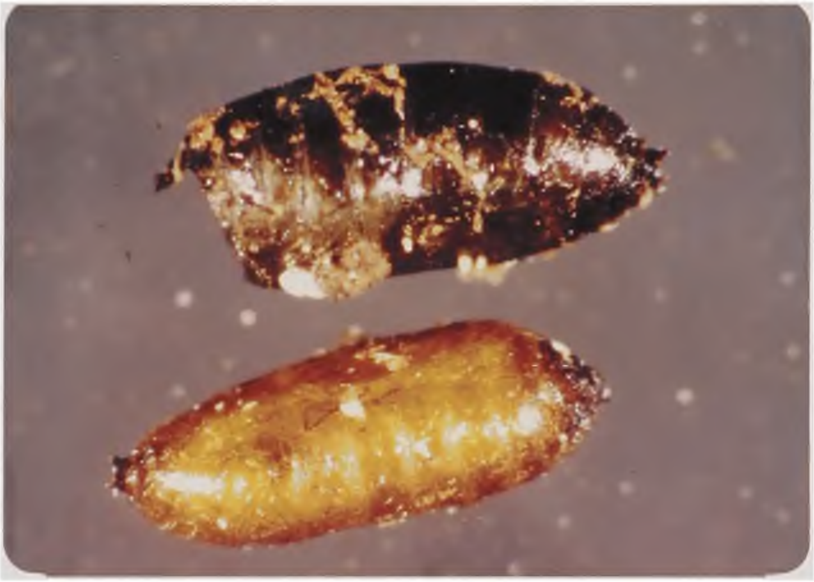

Plate 2. Puparium of beanfly: *O. spencerella* (black), *O. phaseoli* (yellowish brown)

2.1.4. O. centrosematis (de Meijere).

O. centrosematis has been found distributed throughout East Africa, Australia and tropical Asia (Spencer, 1973). The host plants of this species of beanfly are *Crotalaria striata* Dc.(mucronata), *Calopogonium mucunoides* Desv., *Centrosema pubescens* Benth., *G. max*, *P. lunatus*, *P. vulgaris*, *Tephrosia candida* (Roxb.) A.Dc. and *V. unguiculata* (Greathead, 1968).

Greathead (1968), working in East Africa, showed that oviposition takes place not in the leaves, but in the hypocotyl and tender stem. The larvae feed just beneath the epidermis of the stem and in part of the tap root. No larvae were found feeding within the pith of the main stem or roots (Lee, 1976). The larva pupates just beneath the epidermis. Pupation is generally close to the soil surface where the pupa, which is translucent red to yellow brown, is lodged beneath the epidermis (Greathead, 1968). In most cases, the anterior spiracles of the pupae pierce the dry epidermis and form a semi-transparent "window" to facilitate adult emergence. In the laboratory on potted plants, development time from egg to adult was 30 days at a mean temperature of 21°C (Greathead, 1968).

2.2. Beanfly population seasonality.

The infestation by _O_. _phaseoli_ increases as long as host plants are available in the field. An average minimum temperature of 16.7℃, with a maximum of 32.5℃ and 65-75% R.H are ideal conditions for beanfly growth. High precipitation seems to inhibit the development of _O_. _phaseoli_ in the field but high temperature increases the incidence of beanfly on the host plants (Santokh, 1982).

Optimum conditions for beanfly population establishment would thus appear to be low rainfall with temperatures ranging from 15℃ to 30℃. Diapause in beanfly is not thought to be very important and survival in the dry season occurs on wild hosts and on small irrigated crops (Subasinghe _et al_., 1978). Under these circumstances, the well defined bimodal rainfall pattern can be expected to determine pest phenology. Thus _O_. _phaseoli_ population tends to increase during the dry period after rain (Subasinghe and Amarasena, 1983). Talekar and Chen (1983) observed that the agromyzid flies, _O_. _phaseoli_ and _O_. _centrosematis_ infest soybean practically throughout the year, but that infestation was most severe during the dry season where almost all plants were damaged. Also, Van der Goot (1930) reported greater infestation of _O_. _phaseoli_ in the dry season than in the wet season. The most likely explanation is that rainfall prevents feeding and oviposition. In Taiwan, during the dry season, insect infestation is considerably reduced probably because of relatively cool temperatures. Morgan (1938) in Australia; Abul-Nasr and Assem (1968) in Egypt reported a reduction in beanfly infestation on crops planted during the winter months. They suggested that the reduction in population was due to the cooler weather when most of the larvae entered the pupal stage and became inactive. They also found reduced larval populations in May and June, a phenomenon which was attributed to extremely hot, dry weather, when eggs failed to hatch. The beanfly incidence varies considerably in time and space. Hence, knowledge of seasonal incidence or low incidence periods and peak activity periods of this stem miner would be useful in timing control operations (Gain and Kundu, 1986). One of the most important features of rainfed agriculture is ensuring the best use of available rainfall. If farmers plant their crop after the first rains, the crop could escape damage from the beanfly (Subasinghe and Amarasena, 1983).

2.3. Beanfly damage.

Beanfly infestation begins as soon as the plants emerge above ground. The female fly, with the help of its ovipositor, punctures newly emerged leaves. Soon after the holes are made, the adult feeds on the sap from the plant. Feeding on the sap that bleeds from ovipositional punctures is incidental to oviposition. The punctures create small, yellow, translucent and sunken windows in the leaf epidermis. This injury, however does not significantly damage the plant (Talekar and Chen, 1983).

The importance of beanflies in the tropics lies in the fact that all species, especially those that feed in the main stem, prefer young plants. O. phaseoli and O. centrosematis favour plants from the cotyledon stage up to the early trifoliate leaf stage (Talekar and Chen, 1983; Talekar, 1987). As a result of infestation during the cotyledon stage, the plants succumb to the injury within a month after germination. The stronger plants can form new roots above the damaged parts, especially during the rainy season, while slightly damaged ones usually grow through the infestation without noticeable reduction in growth. The loss of seedlings in this way was estimated to be almost 28% in Phaseolus mungo. This implies that heavy infestation above 90% may cause complete crop failure. In this case resowing may not be possible due to the delay in sowing time (Santokh, 1982). In some production areas, seedling mortality as high as 80-100% has been recorded where the pest had not been controlled. Van der Goot (1930) also observed up to 100% plant mortality. If infestation starts in the late seedling stage, yield losses in excess of 50% can be expected (Sepswasdi, 1976). But beanfly infestation 4 weeks after emergence, which is quite common, does not reduce yield (Talekar, 1987). Mining by O. phaseoli in terminal portions of a plant bearing pods, may lead to 50%

loss in pods which are unable to reach maturity. The plants that survive an attack produce few pods, many of which are empty or contain small seeds (Abul-Nasr and Assem, 1968; Greathead, 1968; Swaine, 1968). For instance in P. mungo, the number of grains per pod was reduced in infested plants, and a reduction in grain size and weight were also recorded. If a plant survives an attack, it may recover by forming adventitious roots above the affected place, in which case yield would largely not be affected. Thus, the primary reduction in yield caused by beanflies is through the death of the plant (Plate 3), rather than a reduction in plant vigour (Tengecho et al., 1988).

2.4. Beanfly control.

The beanfly may be controlled successfully through an integrated approach. This could include plant resistance, cultural practices, biological and chemical control.

2.4.1. Host plant resistance.

A plant's ability to withstand attacks and recover from injury is associated with the concept of host-plant resistance. Thus, a plant's resistance to insect attack is its heritable quality that enables it to prevent the growth of insect populations or to recover from injury arising from

Plate 3. Withered bean plants due to beanfly damage.

their attack. Inhibition of insect population growth may be caused by biochemical and morphological characteristics of a plant. They can affect the behaviour or the metabolism of the insects and reduce their damage (Kogan, 1982). Certain morphological characteristics of host plants such as toughness of tissues and trichome may act as barriers to normal feeding or oviposition. Also the chemical compounds exuded from the outer layers of tissues generate olfactory stimuli that mediate host finding and recognition. For the insect, some may have nutritional value while others may act as feeding excitants, inhibitants or toxicants (Auclair, 1957).

2.4.1.1. Morphological and physiological parameters of host plant resistance against the beanfly.

The use of resistant bean varieties can provide economic solution for the suppression of beanfly incidence (Chiang and Talekar, 1980). Evidence of this comes indirectly from work so far done on beanfly in soybean. In the determination of soybean-resistant varieties some morphological and physiological plant parameters which are correlated with resistance to beanfly were identified (Chiang and Norris, 1983). During the early plant growth stage beanfly infestation seems to be influenced especially by the trichome density of the lower (abaxial) surface of leaves, leaf area, leaf moisture content and stem diameter (Fehr and Caviness, 1977; Chiang and Talekar, 1980). Beanflies spend their larval and pupal life inside the stem of the host plant (Spencer, 1973; Lee, 1976). The plant's physiology and anatomy especially in the bean stem would be critical to their survival and fitness. In general, the mechanical effects of trichomes on herbivorous insects depend on density, erectness, shape and/or length (Norris and Kogan, 1980). It has been found that density, as well as length, of trichomes on the abaxial surface of the soybean leaf may serve critical roles in the plant′s resistance to the agromyzid beanflies. The trifoliate leaves of resistant varieties have more trichomes and lower moisture content than those of susceptible ones. The differentiation of the primary and secondary phloem fibers and the accumulation of polyphenols (tannins) throughout the cortex are both highly associated with resistance in wild soybeans (_Glycine soya_) to _O.centrosematis_ (Chiang and Norris, 1985).

2.4.1.2. Role of length of internodes in beanfly resistance.

The length of internodes in bean plants has been shown to be significantly different between beanfly resistant and susceptible varieties. Beanfly-susceptible varieties have longer internodes (Chiang and Norris, 1983a). The shorter internodes in the resistant varieties during the early growth stages would indicate an earlier suspension of internodal elongation and apparently earlier differentiation of sclerenchyma. Sclerenchyma cells are characterized by thick, often lignified secondary wall; they occur in portions of a plant which has ceased elongation (Esau, 1976). Such developments may increase the toughness of plant tissues and thus make them more resistant to the tearing or chewing action of insect mandibles and more difficult to digest (Howe, 1949; Agarwal, 1969; Wellace *et al*., 1973).

The cross-sectional area of the stem occupied by the pith cavity seems to be 1.5 to 2 times larger in beanfly-susceptible than in beanfly-resistant soybean varieties. It is logical that such a pith would be correlated with resistance because larvae of the beanfly mine exclusively through the pith cavity. Moreover, the greater number of parenchyma cells in the larger pith cavity of the susceptible varieties may provide critical nutrient to the larvae. It was found that when beanfly larvae reach the third instar, the pith cavity of beanfly-resistant varieties was too narrow and tightly enclosed by lignified gelatinous xylem fibers for the larva to pass through, or to turn around and continue feeding until it pupates (Lee, 1976). Therefore, the combination of nutrient reduction due to a smaller amount of parenchyma tissue in the pith and a greater mechanical hindrance caused by the relatively small pith cavity surrounded by gelatinous lignified xylem fibers would appear to contribute to the resistance of such soybean varieties to beanfly attack (Lee, 1976; Gangrade and Kogan, 1980).

In the overall view, the stem-resistance of bean varieties to O. phaseoli seems to be caused largely by the earlier differentiation of primary and secondary phloem fibers and the thinner cortical layer in the stem. Also the disruption of the primary phloem fibers in the lower stem may give larvae of O. centrosematis a good opportunity to destroy the phloem and cause serious damage to the plant. The earlier differentiation of the periderm in the lower portion of the stem and/or root seems to contribute significantly to the resistance of stems to the larva of O. centrosematis (Lee, 1976).

2.4.1.3. Biochemical basis of resistance.

The concentration of phenolic compounds, in some cases, has been found to be almost ten times greater in highly resistant soybean varieties than in susceptible ones (AVRDC, 1982). The high concentration of phenolic compounds in highly resistant varieties relates to fewer insects in damaged stems and indicates that antibiosis is a possible mechanism of resistance. The reported biological actions of tannins and other polyphenols include especially repellency or deterrency, which may affect palatability, growth inhibition through altered protein availability and enzyme inhibition, and as direct toxicants. These may jointly contribute to the protection of plants against many herbivores and pathogens (Feeny, 1970; Bernays et al.,1981). Lee (1976) suggested that cortex-feeding larvae of O. centrosematis and O. phaseoli should be largely able to avoid such chemicals which are localized specifically in the epidermis and outermost cortex in susceptible varieties and still obtain adequate food from the underlying cortex. Such avoidance however, is not possible in resistant varieties because all cortical cells contain tannins and other phenols.

The expression of some bean and soybean resistance parameters to beanfly has been attributed to a combination of genes (Singh et al., 1971) while others attribute it to a single gene (Junyi et al.,1991).

2.4.1.4. Purple stem indicator of resistance.

In the field, resistant wild soybeans develop a prominent purple stem; the highly susceptible varieties do not. Purple stem was positively correlated with high resistance to the beanfly O. centrosematis (Chiang and Norris, 1984). Moreover, the identification of the anthocyanidin malvidin as the purple pigment in the epidermis of beanfly-resistant soybeans further demonstrates the biosynthetic interrelationships among certain flavonoids and the lignins and polyphenols now known to contribute to such insect resistance (Chiang and Norris, 1983 b, c).

Sources of resistance to beanflies have been identified in wild soybeans with small stem which is too woody for feeding, and a pith tissue which is too narrow for penetration. But due to a close linkage between undesirable agronomic characters and resistance, it has not yet been possible to transfer the resistance into agronomic cultivars (AVRDC, 1984, 1986).

2.4.2. Cultural practices.

The principle of cultural control is to manipulate management practices so that the environment is less favourable for pest invasion, reproduction, survival and dispersal, and to achieve reductions in pest numbers either below economic injury levels or to allow sufficient biological control factors to take effect (Takashi, 1964; Ashdown, 1977). Cultural methods may not by themselves reduce pest populations below acceptable levels but may be of benefit in reducing losses due to pests through delaying pest outbreaks or reducing the magnitude or frequency of such outbreaks (Glass, 1975). Such practices are the first line of defence against pest populations (Coaker, 1987). Many cultural methods are associated with ordinary farm management practices. These are simple and often do not require added production cost because they can be incorporated into agronomic practices with only slight modifications. These manipulations alter the within-crop environment and thus influence the agroecosystem to have effect on pest population dynamics and their natural enemies (Metcalf et al., 1962; Barfield and Gerber, 1979; Arkin and Taylor, 1981; Hatfield and Thomason, 1982). Cultural control practices are usually compatible, both among themselves and with other pest control tactics and strategies, and therefore are highly desirable for the management of pests. Cultural control practices which have been shown to be effective include manuring and fertilizing, intercropping, plant densities, timing of planting, sanitation, land preparation methods, undersowing or weed cover management and cropping patterns (Van Emden, 1965; Altieri et al., 1977a; Pimentel, 1986).

2.4.2.1. Soil fertility and beanfly infestation.

Insect population growth can be dramatically affected by host vigour (Mattson and Addy, 1975). Thus, fertilisation can alter host plants in ways that make them more or less susceptible to herbivore insect attack (Rodriguez, 1951, 1972; Mattson and Addy, 1975; Jones, 1976; Slansky and Feeny, 1977; McNeill and Southwood, 1978; Mattson, 1980; McClure, 1980; Tingey and Singh, 1980; Scriber, 1982). It has been observed that proper use of fertilizers can help to keep bean plants growing vigorously in dry weather and under poor soil conditions and thus suffer less damage due to beanfly attack (AVRDC, 1980). Nitrogen, a key element in plant nutrition, is usually the most deficient in soils of all the essential major elements (Salam and Subramanian, 1989). Bean crop, being a legume, is capable of symbiotic nitrogen fixation with appropriate Rhizobium strains (Gates, 1945; Gomez and Schoonhoven, 1977). However, soil, bean variety or inoculation difficulties can limit fixation (Leonard, 1931; Dupree, 1965; CIAT 1976). In such cases the bean plant is forced to rely on soil or fertilizer nitrogen. Nitrogen deficiency is most common in soils with low organic matter. Nitrogen fixation may also be ineffective in the absence of adequate amounts of phosphorus (Lathrop and Keirstead, 1946; Dupree, 1965; CIAT, 1976), since Rhizobium spp. are sensitive to low phosphorus levels. Nitrogen level of host plants has been identified among the factors influencing the survival of phytophagous homopterous insects (Maltais, 1951; Auclair, 1976; McClure, 1980; Archer et al., 1982; Prestige, 1982; Jansson and Smilowitz, 1986). Several studies have been carried out on the effect of fertilizers on insect pests of various plant crops e.g. (Katiyar, 1972) on wheat borers (Narayanasamy et al.,1976; Vaithilingam et al.,1978) on pests of rice and (El-Saadany et al.,1977) on potato aphids and leaf hoppers. The studies conluded that high level of potassium reduced insect pest incidence. Ralph et al., 1989 reported that the increase of European corn borer (Ostrinia nubilalis) (Lepidoptera: Pyralidae) infestation in corn intercropped with soybean in 60 to 120 kg N/ha may be related to more soft leaf tissue at the higher nitrogen rate. Also, Shri and Gupta (1988) reported that an increasing concentration of nitrogen consistently increased the population of grubs, whereas an increasing concentration of phosphorus and potassium alone and in combination reduced the population of grubs. Again, using total plant nitrogen as an indicator of plant quality, female potato leaf-hoppers laid more eggs on high nitrogen plants (William and Gage, 1990). The best control was obtained with the lowest dose of nitrogen and the highest dose of phosphorus and potassium. A similar increase in the population of cotton aphids was observed by Beckhan (1970) and of the lucerne aphid, Aphis craccivora, by Waghary and Singh (1965). Higher phosphorus and potassium concentration also reduced the incidence of Haplothrips sp. and Hadena sp. on cereal crops (Persin, 1971), of Sitobion avenae on wheat (Baron, 1972) and of leaf-rollers on rice paddy (Vaithilingam et al., 1978). Increased nitrogen, phosphorus and potassium in the presence of insects results in yield increase. The higher yield obtained with increased levels of phosphorus and potassium might be due to reduced insect attacks, whereas the higher yield resulting from increased nitrogen might be due to increased plant vigour, which enables the plants to tolerate a higher pest population without loss in yield (Shri and Gupta, 1988). Information on the effect of nitrogen on beanfly infestation is lacking, hence the need for studies in this area.

Kogan (1977), has postulated that for polyphagous homopterans, such as white flies, the host plant range of immature stages should be determined rather by the presence of allelochemicals than nutritional factors. Nutritional limitations will manifest themselves as slower developmental times and higher mortalities in later instars, and plant fertilization will result in increased survival and developmental rates. Allelochemic limitations will manifest themselves as greater mortality in the earlier instars, developmental times that do not vary across host plants and survival and developmental rates are not affected by plant fertilisation.

2.4.2.2. Effect of plant diversity on insect pests occurrence.

Climatic diversity in diversified plant communities tends to reduce the probabilities of phytophagous pest population explosions (Tahvanainen and Root, 1972; Litsinger, 1975). Associations of crops also provide more diversity of food source for phytophagous insects, predators and parasites (Risch, 1979). Biological complexity has also been reported to affect olfactory responses, altering the dynamics of insects in an agroecosystem (Tahvanainen and Root, 1972). Some workers have reported that chemical repellency, masking, feeding inhibition by odours from non-host plants, prevention of emigration in pests and optimum synchronism between pests and their natural enemies are likely to be important in efficient pest regulation in intercropping systems (Tahvanainen and Root, 1972; Litsinger, 1975). The effect of increasing diversity in cropping systems on pest populations has often been considered in terms of stabilizing parasite and predator populations and/or increasing their activity (Van den Bosch and Stern, 1969; De Loach, 1970; Dempster and Coaker, 1974; Van Emden and Williams, 1974). However, under certain conditions, natural enemy species numbers and activity are higher in the simpler, sole crops than in diversified crops (Pimentel, 1961; Root, 1973). Thus, the impact of insect pests on crop plants may be reduced by constructing architecture within the crop ecosystem that support natural enemies or have direct deterrent effects on the pest population itself. This approach to pest management is, therefore, crop oriented rather than pest oriented (Baliddawa, 1985). Some empirical studies on the effects of plant diversity on arthropods have concluded that specialized crop pests tend to have lower population densities in diversified systems while polyphagous crop pests show no particular response (Andow, 1983a, 1986). This has been explained by the "enemies hypothesis" which states that crop diversification results in lowered pest numbers because of increased natural enemy activity (Sheehan, 1986). It is also reported that the presence of a non-host plant reduces population densities of a specialized herbivore and only rarely increases populations (Andow, 1983a, 1986; Risch _et al_.,1983). A "time-wasting hypotheses" has also been proposed to account for lower herbivore populations in diversified cropping systems. This occurs when herbivores are retained on the non-host plant vegetation, then move, searching for host plants and waste time evaluating these plants. This can increase the time between finding host plants and thus reduce the population densities on the host plants (Risch, 1981; Kareiva, 1983).

There must be factors responsible for the change of insect pest populations in intercrops/pure crop stands which have not yet been explained in detail. Research results are sometimes contradictory and indicate the complicated interactions of the control mechanisms. The outcome would appear to depend on the local conditions, the pest complex, specific crop combination and the season (Dissemond and Hindorf, 1990).

It is, therefore critical to select the correct intercropping systems for a given environment, since a specific diversity in the same system can be beneficial in one region but harmful in another. The ultimate goal of pest management in intercropping systems should however be to reduce loss of crop yield and quality rather than merely reduce pest numbers (ICRISAT, 1976).

2.4.2.2.1. Intercropping and insect populations.

Integrated pest management strategies are based on ecological knowledge that permits an agroecosystem management to maintain pest populations and damage below economic injury levels. Evidence indicates that the principal agricultural problems occur in areas that practise monoculture, characterised by reduced faunistic and floral richness (Altieri et al., 1977b; Anonymous 1974, 1977b). Monocultures, often thought to be often highly productive and efficient, have been criticized for their genetic uniformity and susceptibility to insect pests attack and resultant increased pest problems. Intercropping, which means generally the growing of two or more crops at the same time on the same piece of land, is the most common agricultural method employed by African subsistence farmers, whereas in highly mechanized farms and plantations they are the exceptions (Okigbo and Greenland, 1976). Mixed cropping systems with their abundant variety of different crop combinations have a long tradition in the tropics and subtropics (Okigbo and Greenland, 1976; Steiner, 1982). Several reasons account for the success of this farming method: efficient resource use, stable yield, reduced pest and disease losses, conservation of soil fertility and break of labour peaks (Steiner, 1982). Cropping system management provides a foundation on which to base pest control tactics that will be accessible to small farmers. It has therefore been suggested that attention be paid to intercropping (eg.leguminous and cereals) which is most often effective against monophagous insects (Risch et al.,1983).

Unlike monocultures, the regulation of insect pests in multiple crop systems is realised through several mechanisms such as protection from wind, hiding, shading, alteration of colour or shape of the stand. Also, taller plants may provide a physical barrier for insect pest of the crop in the lower strata (Risch, 1979). Biological interference, such as production of adverse chemical stimuli and presence of predators or parasitoids have been emphasized as some of the effects of intercropping (Pimentel, 1961; Van Emden and Williams, 1974; Litsinger, 1975). William and Gage (1990) reported that potato leafhopper densities and subsequent damage to potato leaves were reduced by bean-potato intercropping. Similarly, in Nigeria, cassava intercropped with maize and sorghum had lower population of Zonocerus variegatus than the monocultures. The effects of intercropping varied with cassava and maize varieties with reduced herbivore levels in some combinations but not others (Clifford et al., 1989). Intercropping of legumes with other crops has been reported as a cultural control method for some insect pests because of the increased species diversity in this type of agro-ecosystem (Kayumbo, 1976). In contrast, there have been reports that this diversity favours some pests on cowpea, such as the foliage-feeding beetles, Ootheca spp., which have no difficulty in spreading through plots of cowpea intercropped with maize (Gerard, 1976; Karel et al., 1980; Anon, 1980). Gethi and Khaemba (1991) also reported that pod-sucking bugs were significantly more on cowpea intercropped with maize than cowpea planted as pure crops. Kyamanywa and Tukahirwa (1988) reported that the practice of mixed cropping beans with cowpeas confers no advantage to either crop with respect to attack by Megalurothrips sjostedi. It was observed by Ralph et al.,1989 that some insects were unaffected by intercropping and even others eg. western corn rootworm, Diabrotia virgifera virgifera Leconte and corn leaf aphid, Rhopalosiphum maidis (Fitch) were favoured by intercropping.

The damage caused by a given level of pest incidence is therefore likely to vary considerably from one cropping system to another (ICRISAT, 1976), from one cultivar to another, and in different soil environments (ICRISAT, 1977d). While pest numbers per plant may be much lower in a mixed than in a sole-crop, the physiological stress on plants, such as low-growing annuals intolerant of the shade beneath a taller crop and low plant density may cause greater loss of yield in mixed crops (ICRISAT, 1976, 1977d). However, the lack of knowledge and understanding of traditional cropping systems and their socio-economic context has led to an apparent misapplication of agro-technology into the rural areas of developing countries (Amoako-Atta, 1982). Therefore, increased and more coherent research and development in this area is a priority need.

As pest suppression in intercropping is frequently incomplete, the question that needs to be answered is whether intercropping lowers pest populations below the economic injury level and results in increased crop yield? Studies reported in this respect have shown variable responses resulting from intercroping (Dempster and Coaker, 1974). Ampong-Nyarko *et al*., 1992 showed yield advantages under conditions where intercropping reduced *Chilo partellus* and *Megalurothrips sjostedi* density by intercropping sorghum with cowpea.

2.4.2.2.2. Effect of weeds on the incidence of insects.

Weeds are plants that grow where they are not wanted and directly compete with crop plants for sunlight, water and mineral nutrients. They are sometimes alternate hosts to some crop pests (Way and Cammell, 1981). Weeds, therefore, are in general undesirable. However, non-crop plant species may sometimes be useful components of a crop ecosystem. If properly managed, weeds can affect the biology and population dynamics of beneficial insects and improve the chances of the crop plants escaping pest damage. Outbreaks of certain pests are more likely to occur in weed-free fields than in weedy ones (Van Emden, 1965; Dempster, 1969; Smith, 1976; Altieri et al.,1978). Crop fields with a dense weed cover and high diversity, usually have more predacious arthropods than do weed-free fields (Speight and Lawton, 1976). Smith (1976) showed lower aphid colonisation in Brassicae with weeds than in stands which were weed-free. Similarly, Altieri et al.,(1977a) reported that the potato leafhopper was reduced on host plants in proximity to several grass species. The reduction of beanfly infestation in mungbeans grown among weeds is realised through camouflage (McIntosh, 1975). Root (1973) suggested that weeds could enhance natural enemies by providing alternative hosts or prey, and by providing pollen and nectar food resources. Altieri and Letourneau (1982) showed that weeds can enhance both predators and parasitoids in both annual and perennial cropping systems but were more effective in perennial crops. Finally, predators and parasitoids appear to respond to changes in their food resources and microclimate in much the same way as herbivores respond to theirs. Therefore, weeds sown directly near crops or cover crops, or planting trees and shrubs in field borders should stimulate movement of natural enemies into the crop (Altieri _et al_.,1977a).

Polyphagous host-alternating pests can use weeds to build up large populations that damage crops. But weeds can also be used as trap crops to lure the pests away from the target crop (Marcovitch, 1935). To be successful, the trap crop must occupy a small space compared to the food crop, and it must be highly attractive to the pest, but no examples where weeds have been successfully used as trap crops are known (Altieri _et al_.,1984).

The diversity of chemical stimuli emanating from weed/crop mixtures may reduce herbivore attack on the crop plants. Many herbivores use host plant chemicals to locate their host plants (Ahmad, 1983). Several investigators have suggested that the presence of non-host plant odours can mask host plant stimuli or repel the colonizing herbivore (Tahvanainen and Root, 1972; Raros, 1973; Altieri _et al_., 1978). Also, altered microclimate in weed/crop mixtures can reduce herbivorous insect populations. For example, shade reduced both _Acalymma themei_ in corn, bean, and squash systems at Tabasco, Mexico and Acalymma vittatum populations (Risch, 1981). In addition, weeds can create favourable microenvironments for a pest within or near a crop field.

Clearly, current understanding of the factors that affect herbivore populations in crop/non-host plant mixtures is rudimentary. Andow (1983a) showed that weeds greatly reduced the immigration rates of Epilachna varivestris to a field of beans but only slightly increased emigration rates.

In addition, when weeds are present with the crop plant, weed-crop competition can occur. The effect of competition must be integrated and evaluated with the effects of weeds on the arthropod community. The greatest pest control benefit from weeds would be the case where weeds do not compete strongly with the crop. Even though a general understanding of the effects of weeds on arthropods is poor, under some conditions, weeds can have a beneficial effect. In weeding system, reduced pest control costs and enhanced yields are the only possible benefits. In general, if arthropod damage is severe and the weeds greatly reduce arthropod damage and do not compete strongly with crop, then weeds would enhance crop yield (Altieri et al., 1978; Andow, 1983b).

2.4.2.3. Effect of plant spacing on the incidence of insect pest populations.

The primary objective in spacing crop plants is to maximize yield per unit area without reducing crop quality. Nevertheless, planting density per unit area can affect pest numbers and the damage they cause, possibly by influencing the microenvironment that affects the pest and its natural enemies, the growth and development of the crop and its attractiveness to colonizing insects (Coaker, 1987). However, absolute populations of pests can be greater on high than low plant densities, thereby exposing subsequent crops on neighboring sites to a greater risk of damage (Wheatley, 1972).

Crop density affects insect population dynamics. Plant density may affect rate of development and population build-up, insect behaviour, food search and oviposition sites. Close spacing may also increase the effectiveness of natural enemies and result in more efficient control of pest populations (Ahmed and Rao, 1965). On the other hand, the micro-environment created by close spacing may favour some pest species (Israel and Rao, 1962). Pimentel (1961) reported that widely spaced plants attracted few insects and were less damaged than the same species at greater plant population densities. On the contrary, Way and Heathcote (1966), cited examples where less damage occurred when planting densities were increased. Alghali (1984b), suggested that the rice stem borer Diopsis thoracica causes more damage in widely spaced rice than closely spaced ones. Moreover, Ofuya (1987), stated that close spacing of cowpeas increases the danger of damage by Cydia ptychora. Spacing undoubtedly affects the yield of cowpea, thus wide spacing can lead to a significant reduction in yield (Ezedinma, 1974). Similarly, a high plant population due to close spacing may depress yield (Remison, 1980) or have no yield advantage (Kayode and Odulaja, 1985). Whatever the density at which yield is optimised, it is clearly disadvantageous to increase density still further as this is likely to lead to even greater damage. Some other workers have also observed increased incidence of insect pests and diseases in cowpeas planted at high densities (Nangju, 1976; Remison and Okunariwo, 1979). Cultivars which are strongly vegetative with overlapping foliage suffer greater insect damage than nonvigorous types. In wide spacing, closed canopies are not formed between plant rows, thus offering the least daytime shelter for the insects. Consequently, oviposition here may be lower. Also, Helenius (1990) reported that a low total plant density could affect movement velocity and patterns. Further, Wijeratne Banda and Fernando (1981) reported that the pod borer, M.testulalis, damages pods which are in close contact with each other more than those in wide spacing. According to Kyamanywa and Tukahirwa (1988) on the infestation of the flower thrips, Megalurothrips sjostedti

(Trybom), on bean and cowpea crops, the higher the cropping density, the greater is the level of infestation. The explanation for this is probably that the more host plants there are per given area, the greater and closer is the available resource for exploitation by thrips, and therefore the greater their density becomes. This reasoning would explain the lower pest densities recorded for planting densities which were lower than the optimum.

2.4.2.4. Effect of planting time on beanfly infestation.

Luginbill and Ainslie (1917) recommended planting corn, sorghum, and other crops as early as possible to enable the plant to get a head start before pests begin their depredation. Funderburk _et al_.(1987) noted that planting date influenced the growth rate of lesser Cornstalk borer population in several crops. Mack and Backman (1990) reported that the use of such cultural practices as changing the planting date, would be a useful method of managing some insect pests. According to Musick _et al_.(1980); Bergman and Turpin (1984, 1986) the delayed planting of corn, _Zea mays_ L., reduced survival to the adult stage, delayed chronological occurrence of lifestages, and reduced damage to corn roots by a natural infestation of the western corn rootworm. It is stated that agromyzid beanfly infestations seem to be severe during the relatively dry period after rainy seasons (Morgan, 1938; Swaine, 1968; Lee, 1976; Kwon et al., 1980). Accordingly, beans planted during the short rains often suffer severe damage if there is an intervening drought (Nderitu et al.,1990b). Some workers reported that beanfly infestation increases with a delay in planting dates in a season (Okinda, 1979; Kwon et al.,1981; Talekar and Chen, 1983). Also Subasinghe and Amarasena (1983) reported that early planting has been observed to be beneficial to farmers and it appears that large numbers of them are encouraged to adopt this practice with timely land preparations. Other workers have given contradictory information suggesting that beanfly infestation increases with early planting dates (Kooner et al.,1977; Singh et al.,1981).

The general planting time acceptable by the farmers may be the early planting with the first rainfall. This practice could have beneficial effect on the reduction of beanfly infestation.

2.4.2.5. Biological control of beanfly.

All insect species have natural enemies (parasites, parasitoids, predators and pathogens) that attack their various life stages. The impact of these natural enemies ranges from a temporary or minor effect to the death of the host or prey. Biological control has several distinct advantages over many other types of control. It is relatively safe since many natural enemies are host-specific or restricted to a few closely related species. Therefore it is unlikely that nontarget species will be affected. Biological control is relatively permanent in good conditions of biological agents, thus efficient natural enemies often continue to have an effect year after year. It is also economical, since once efficient native or imported natural enemies are present, little else needs to be done exept to avoid disruptive practices (Stehr, 1982).

A large number of Hymenopteran species are known to parasitise the beanfly, and the high incidence of parasitism recorded makes natural control of beanfly potentially feasible. The percentage of parasitism on beanfly however is variable, ranging from 5 to 94% (Santokh, 1982; Abate, 1991). Tengecho *et al*.,(1988) reported parasitization of the puparia to be 3.5 and 16.2% in *O.spencerella* and *Ophiomyia phaseoli*, respectively. In a determination of natural enemies of *Ophiomyia phaseoli*, Fellows and Amarasena (1977) found a range of hymenopteran parasites with overall parasitism reaching about 40%.

Biological control of beanflies has not been researched much in the tropics, although, Van der Goot (1930) in Java, and Greathead (1968) in East Africa made detailed studies on the biology and extent of parasitism of various beanfly species. All parasites recorded were pupal parasites, attacking beanflies during the larval stage but apparently not killing them before they become pupae. Then, the adult parasites emerge by breaking off the puparium wall (Talekar, 1987). The mode of parasite infestation of larvae is uncertain, since the larval stage is completed inside the plant. Probably, the parasites lay eggs in the larvae through the thin epidermis. Also, the possibility that the parasite may lay eggs in the prepupae or pupae by piercing through the thin membrane, cannot be ruled out. Beanfly parasitism is extensive but sufficient flies survive to cause substantial damage. As the beanflies are hidden in the plant until they are adults, access by predators and parasites is limited. There are no records of parasites or predators that infest the adult beanfly (Talekar, 1987).

Greathead (1968) in East Africa reported a parasite complex of nine species on the three species of Ophiomyia. The life cycle of Opius phaseoli (Plate 4) synchronised with that of its host Ophiomyia phaseoli. It is a density-dependent larval parasite that emerges from the host pupa. Thus, Greathead (1968) suggested that it was the most effective parasite of Ophiomyia phaseoli in the area. Opius phaseoli also parasitises O.spencerella (Burikam, 1978). Another parasite of O.spencerella was found to be Eucoilidea sp. It is not density-dependent and is inefficient in the control of its host. Since O.spencerella lays most of its eggs in the hypocotyl, the developing larvae are more protected from attack than are larvae of Ophiomyia phaseoli. Therefore, the

Plate 4. Main parasitoid of beanfly: <u>Opius phaseoli</u>.

lack of effective parasitism may help make this species of beanfly the most abundant in East Africa (Greathead, 1968). Abate (1991) reported that beanfly and its parasitoids are widely distributed throughout the major bean-growing areas of Ethiopia. Their numbers varied from one locality to another and appeared to be influenced by seeding dates. The braconid, Opius phaseoli, was the major parasitoid found attacking beanfly on haricot bean and cowpea, whereas species of Chalcidoidea were more abundant on wild host plants. The Pteromalids, Sphegigaster spp., were the most common parasitoids among the Chalcidoidea. Greathead (1968) reported that two braconids, Opius importatus and Opius phaseoli, have been successfully introduced from East Africa into Hawaii, where they are reported to be giving good control of the beanfly. However, Oree and Hallman (1989) reported that some Chalcidoids (Eulophidae, Eupelmidae, Eurytomidae and Pteromalidae) may be facultative hyperparasites of Opius spp. or other parasites. Therefore, candidates in these families should not be imported until it is shown that they are not hyperparasitic.

The use of natural enemies of beanfly could be an important component of an integrated pest management programme because, once natural enemies are established in an area, they are permanent and may not require further input by man.

2.4.2.6. Chemical control of beanfly.

Insecticides are currently the most powerful tool available for use in pest management. They are highly effective, rapid in curative action, adaptable to most situations and relatively economical. Insecticides are reliable for emergency action when insect pest populations approach or exceed the economic threshold level. Chemical pesticides will continue to be one of the most dependable weapons of entomologists for the foreseeable future. Contrary to the thinking of some, the use of pesticides for pest control is not an ecological sin (NAS, 1969). Despite the impressive credentials however, too much use of insecticides leads to such disadvantages as pest resistance, outbreaks of secondary pests, adverse effects on nontarget organisms, objectionable pesticide residues and direct hazards to users (Smith, 1970).

The most commonly used method for controlling beanfly is the use of chemical insecticides. The insecticide is applied to give protection within the first four weeks after germination (Talekar, 1987). The recommended control method at present in Sri Lanka is a schedule of foliar sprays with systemic organophosphate insecticides, commencing at the two-leaf stage of the plants. The spray is repeated every two weeks when necessary (Wijesekara and Abeytunge, 1983). However, Sri Lankan farmers found this treatment expensive and did not adopt the practice readily.

Also organophosphorus and carbamate seed treatments give protection to growing seedlings against beanfly. The effect of the insecticide lasts for four to eight weeks. In that way, it gives protection over the vulnerable seedling stage of the plant. Seed treatments are more effective than foliar sprays in protecting seedlings, since spray recovery by seedlings is poor due to low leaf-to-ground area ratio (Verma, 1974). Therefore, the protection afforded during the vulnerable seedling stage, the ease of application and the potential to conserve and promote biological control agents in an integrated pest management programme, by reducing the number of foliar sprays, are some of the advantages of the seed treatment method (Wijesekara and Abeytunge, 1983). Thus, coating of seeds with insecticide is a prophylactic method, cheap and effective means of protecting beans from bean fly damage. Walker (1959) reported that coating the seeds with a liquid treatment or a wettable powder mixed with water provides more uniform coating and greater retention than do dry formulations.

Roongsook _et al_.(1973); Hussein (1978) reported that systemic insecticides like phorate and carbofuran, when banded along the seeds at sowing, gave satisfactory control of _O. phaseoli_ at certain locations. However, the effectiveness of these insecticides is influenced by soil pH. As pH approaches 7, these chemicals degrade rapidly, and their residual effects inside the plant are reduced. Sharma _et al_.(1981) found that placing (1-3 kg/ha) granules of carbofuran below pea seeds provided better control of bean fly than placing the granules above the seeds or side-dressing them after germination. Broadcasting of equal amounts of the granules before sowing was not effective. In some areas where beanfly attack is very heavy, both seed or soil treatments plus foliar sprays may be necessary to prevent significant damage. For instance, in the most seriously affected areas of Kenya, sprays of endosulfan and dimethoate were recommended in addition to seed dressing with aldrin, in order to prevent significant losses to beans by the pest (Khamala, 1979). It is reported that granular applications of carbofuran (0.7 and 1 kg ai/ha) in the furrow at planting gave good control (Singh et al.1979). Foliar sprays may not control O. spencerella, which lays eggs in the stem and hypocotyl and rarely in the foliage as effectively as they do O. phaseoli. However, foliar sprays or carbofuran seed treatment should not be used where bean foliage will be consumed. Oree and Hallman (1989) suggested that to avoid possible phytotoxicity, seed treatments with carbofuran should not be above 3g per kilogram of seed and foliar sprays above 0.1% concentration in water. Moorthy and Tewari (1987) reported that application of carbofuran followed by endosulfan gave maximum protection against beanfly damage but did not significantly increase yield over the control. Residue levels of carbofuran in soybean foliage and pods were not safe until 80 days after treatment with 1.65 kg ai/ha (Handa et al.1977).

2.4.2.6.1. Disadvantages of insecticide use in bean production.

Increase in yield does not necessarily result from better control of the pest with insecticides (Anonymous, 1976). The use of chemicals, eg. seed treatment, may also have several side effects. For instance, it is reported in Tanzania that seed treatment and spraying endosulfan during flowering reduced yields of beans (Bosch,1990). Spraying at flowering, reduced yield by 25% while seed treatment reduced yield by 16% due probably to phytotoxicity. Both treatments gave effective control of insect pests. Therefore, several other factors need to be investigated before conclusions can be drawn on the relationship between yield and level of beanfly attack on beans. Oree and Hallman (1989) reported that the ideal product for control of beanfly would be the affordable one which gives good control without causing economic damage to the plant or leaving unacceptable residues in the bean seeds or leaves, if they are to be consumed, or in the environment. Studies conducted in Sri Lanka showed that a spray of endosulfan at a rate of 2.8 kg/ha leaves 25.87mg/kg of residue in/on foliage. The residues in the bean plants persisted beyond 22 days (Garg *et al*., 1987). The residues of endosulfan in/on foliage of beans was below the tolerance limit of 2.0 mg/kg for endosulfan in/on vegetables in 15 days (Anonymous, 1975). Perihar and Gupta (1990) reported that waiting periods of 7 days are recommended for green pods. No endosulfan residues were present in the grain samples collected after harvest. Garg et al.(1987) affirmed that the use of endosulfan as foliar spray for the control of insect pests would thus be safe from the point of view of residues in/on foliage, if the waiting period is observed.

Wijesekera and Abeytunge (1983) recommended the use of monocrotophos seed treatment to control beanfly in the vulnerable stage. This is important because hymenopteran parasites can control Ophiomyia phaseoli up to about 40% in the field (Fellows and Amarasena, 1977). Thus seed treatment will enable the farmer to reduce the number of foliar sprays recommended and will also enhance the parasite activity (Wijesekera and Abeytunge, 1983). Grain legume production in Sri Lanka is mainly in small subsistence farms planted as mixed crops. In most locations, economic constraints and lack of equipment and water limit the use of insecticides (Fellows and Amarasena, 1977).

CHAPTER 3: MATERIALS AND METHODS.

3.1. EXPERIMENTAL SITE.

The field experiments described here were conducted in Oyugis in the Homa Bay District of Western Kenya. Oyugis is a bean growing area where beanfly is one of the major contraints to production. As a result, natural infestation of experimental fields easily occurred. Rainfall pattern is bimodal and corresponds to two cropping seasons: a long rainy season from February/March to June/July and a short rainy season from August/September to December/January. The location is at an altitude of 1500 m above sea level and has a mean rainfall of 1500 mm/year. The soil type is luvisols with a pH of 6; other soil elements were as follows: Na% 0.34, K% 0.46, Ca% 5.13, Mg% 1.4, Mn% 1.0, P% 11.33, N% 0.13, C% 1.30. Soil reaction varied from moderately to slightly acid. Major nutrients potassium, calcium, magnesium and manganese were in sufficient amounts. Nitrogen, phosphorus and carbon were low (NAL, 1992).

3.2. GENERAL METHODS APPLIED.

The study was conducted on a farmer's field. All data were obtained from field experiments conducted in 1991 and 1992, covering four cropping seasons: two long rains and two short rains. During each growing season, the experiments were planted on two hectares. The field plots were ploughed by a tractor except for the last season of 1992 where an ox plough was used. The ploughing was done two to three weeks before planting. This allowed the weeds to dry. Before planting, the experimental plots were harrowed by hand using hoes by breaking lumps of earth and removing all weeds from plots. Plots were 6 m long x 4 m wide. The central 4 m x 3 m of ten rows was used for various assessments and yield parameters. The remaining outer portion was reserved for destructive sampling. Bean varieties GLP 2 (Rose Coco) and GLP 24 (Canadian Wonder) used by local farmers in the area were planted in all experiments. Their features are presented in Table 3.1.

Table 3.1 : Varietal characteristics of the bean cultivars used (Anon, 1978).

	GLP 2	GLP 24
1. Plant characteristics:		
a. Growth type	determinate	indeterminate
b. Flower colour	white	white
c. Leaf characters	dark green	light green golden shine
d. Days to 50% flowering	42	46
e. Days to maturity	90	95
f. Pod length (cm)	13	11
g. Seeds per pod	5	4
2. Seed characteristics and quality:		
a. Seed appearance	large red flecks on cream	small purple
b. 100 seed weight (g)	52	34
c. Crude protein (%)	25.04	23.5
d. Crude oil (%)	1.17	1.4
e. Cooking time	fast	fast
f. Palatability	good	good
3. Disease reaction:	Tolerant to blight, bean common mosaic virus, anthracnose, angular leaf spot, rust and halo blight	Resistant to angular spot but susceptible to bean common mosaic virus. Tolerant to anthracnose, halo blight and rust.
4. Area suitability	high rainfall areas but is also suited for the medium rainfall areas during long rains	medium rainfall

Two seeds were planted in each hole. The experiment was randomized complete block design (RCB) with three replications. Weed control was achieved by hand hoeing at 3 weeks after plant emergence (w.a.e). The experimental assessments were done at 2, 4, 6, 8 w.a.e. They included measurement of a sample of 20 plant height, a record of the percentage of dead plants per plot and visual damage score. The beanfly infestation was evaluated by dissecting a sample of 20 plants/plot. Natural infestation was assessed by keeping beanfly larvae and pupae in glass tubes until the emergence of parasitoids. At harvest a sample of grain yield from 20 plants was used for the assessment of yield components. For each sample of 20 plants, plant height was measured from the root and stem junction to the top of the highest leaves. The percentage of dead plants per plot was recorded. Visual damage scores at 2, 4, 6, 8 w.a.e were estimated for each plot using a 1 to 9 scale developed de novo as shown in Table 3.2.

Table 3.2: Damage score scale for the assessment of beanfly damage in bean.

1 = No infection symptom.
2 = 1 - 5% of plants in plot damaged, stunted or dead.
3 = 5 - 10% "
4 = 10 - 20% "
5 = 20 - 30% "

Table 3.2.(continuation)

6 = 30 - 40% of plants in plot damaged, stunted or dead.

7 = 40 - 50% "

8 = 50 - 60% "

9 = more than 60% "

Beanfly infestation was evaluated by uprooting 20 plants/plot and keeping them in polythene bags. The stem of each plant in the sample was washed, dissected and the number of beanfly larvae and pupae found were recorded. The beanfly larvae and pupae were then kept in glass tubes to allow the natural enemies to emerge from the pupae.

At harvest the number of plants per plot, number of pods per plant, number of seeds per pod, 100 grain weight and grain yield were recorded. Analysis of variance was conducted separately for each parameter and separation of means was by Tukey's Studentized Range (HSD) or "t" Test (LSD). A computer programme SAS was used for analysis (Stephenie, 1987). Significance levels were determined at 5% level $P<0.05$. Analysis was based on log (x+1) or arcsine (x/100) transformation but the untransformed means were presented in the tables.

CHAPTER 4: EFFECT OF SOIL FERTILITY ON BEANFLY POPULATION, DAMAGE AND YIELD.

4.1. INTRODUCTION

The demand for beans is very high in eastern and central African countries. Relatively high population density (e.g for Rwanda 276 population/km^2 PRB, 1990) has led to shorter fallow periods, and infrequent use of fertilizers have resulted in highly degraded soils. Diagnostic research done in the Great Lakes Region (Rwanda, Burundi and Zaire) of Africa has shown that soil fertility was the principal limiting factor of bean production (Trutman, 1987). The rate of stand reduction in crops grown on infertile soils was higher than for plants grown in fertile soil (Van der Goot, 1930). Bean grown in these infertile soils are very weak and thus highly susceptible to beanfly attack (Trutman, 1987). Fertilizer, generally has positive effects on insect pest occurrence. For example, nitrogen application makes the plants more vigorous and able to support and/or attract more insects (Heathcoate, 1974). At the same time, the ability of the crop to tolerate or compensate for insect attack is often improved by increasing crop vigour with fertilizer application (Mumford and Baliddawa, 1983). The increase in soil fertility promotes plant growth, and thereby helps the plant to grow through beanfly infestation (Talekar, 1987).

The bean is a legume and thus capable of symbiotic nitrogen fixation with the appropriate Rhizobium strains (Gates, 1945; Gomez and Schoonhoven, 1977). Soil, varietal or inoculation difficulties can limit fixation and force the plant to rely on soil or fertilizer nitrogen (Leonard, 1931; Dupree, 1965 and CIAT, 1976). Nitrogen deficiency is most common in soils with low organic matter. In soils where phosphorus is the principal limiting factor, beans may not respond to nitrogen until sufficient phosphorus is applied (Mancia, 1973). Nitrogen fixation may also be ineffective in the absence of adequate amounts of phosphorus (Lathrop, 1946; Dupree, 1965 and CIAT, 1976) since Rhizobium spp. are sensitive to low phosphorus levels.

The effect of nitrogen and phosphorus on beanfly infestation including the attractiveness of the beanflies to the bean plants, their feeding, growth, longevity and fecundity has not been studied. Therefore, the objective of the study was to establish the effect of soil fertility on beanfly infestation (Plate 5) and determine the possibility of employing soil fertility in the management of beanfly infestation.

Plate 5. Experimental plot on the effect of soil fertility on beanfly population level, damage and grain yield.

4.2. METHODS

The experiments were planted on March 6 and August 16 of 1991, April 2 and August 23 of 1992. The plants were spaced at 45 cm intervals between rows and 15 cm within rows. The treatments consisted of manure at 20t/ha containing 226 kg/N, 60kg Ca, 22 kg K and 22 kg/P (Cavalot, 1992) , four nitrogen levels (0, 30, 60 and 90 kg N/ha). The treatments for 1992 included a factorial combination of nitrogen as calcium ammonium nitrate (0, 45, 90 kg N/ha, 20 tons of manure/ha) and three levels of Phosphorus (0, 45, 90 kg P_2O_5/ha). The manure was made by mixing cow dung with plant residue in a compost pit where it stayed for three months for decomposition. The manure was spread uniformly on the plot and covered with soil before planting. The fertilizers were applied in furrows at planting time and covered by the soil before planting the seeds. The insecticide, endosulfan 50% wp, was applied as wet seed dressing at the rates of 5g ai /kg of seeds (long rains of 1991), 1.5g ai /kg of seeds (short rains of 1991) and 3g ai/kg of seeds (long and short rains of 1992). Seeds were dried and sown within two days after coating to avoid loss of seed viability (Allen and Smithson, 1986). During the long and short rains of 1992, another treatment of insecticide, Carbofuran 5% granules (Furadan 5G) systemic insecticide was used at the rate of 2kg ai/ha. The carbofuran granules were applied uniformly in the furrows before planting the seeds.

Weeding was done at 3 weeks after plant emergence (w.a.e). Moisture and dry matter of bean plants at 2, 4, 6, 8 w.a.e were determined in the laboratory. The samples kept in paper bags were first dried in the sun for 2 weeks and then oven-dried at 80°C for a further 48 hours. Moisture content was calculated as [100(X-Y)]/X, where X was fresh plants weight and Y dry plants weight. Grain moisture was determined using a moisture tester (1175 15302 Dicky-John Corporation Auburn, USA) and yields expressed at 12% moisture content.

During the long rainy season of 1992 a supplementary experiment was undertaken at Mbita Point Field Station to study the causes of yield depression of insecticide treated beans. Planting date was on April 9 of 1992. The treatments consisted of three rates of endosulfan 50% wp, (5g ai/kg of seeds, 3g ai/kg of seed and 1.5g ai/kg of seeds); 2 kg ai/ha (2g/m) of carbofuran 50% wp (furadan 5G) and a zero insecticide control. Ten plant samples were taken randomly per plot at 4 w.a.e on May 14 of 1992. Harvesting took place on June 30 of 1992.

4.3. RESULTS AND DISCUSSION.

Effect of soil fertility on beanfly infestation.

Two species of beanfly, Ophiomyia phaseoli Tryon and Ophiomyia spencerella Greathead were identified in Oyugis. The species Ophiomyia spencerella was more dominant (89%) than O.phaseoli (11%) in Oyugis. Nitrogen fertilizer significantly (P<0.001) increased infestation of O.spencerella, but the effect on O. phaseoli was not clear because of its low numbers (Table 4.1). During the long rainy seasons of 1991 and 1992, the numbers of beanfly larvae and pupae recorded were 12-66% higher at all levels of fertilizer application than with no nitrogen (Table 4.2). Phosphorus fertilizer also increased significantly the infestation of O.phaseoli. When nitrogen and phosphorus fertilizers were applied together, beanfly infestation increased. Increase in phosphorus also increased beanfly population. The maximum interaction was obtained with 45 kg/ha of nitrogen and 90 kg/ha of phosphorus (Fig.4.1). There was no difference in the infestation levels between the two bean varieties used (Table 4.2). During the long rainy season of 1991, the population of beanfly in both bean varieties (GLP 2 and GLP 24) did not increase in the 20 tons manure fertilized plots. This is probably because nitrogen was not immediately available due to the slow mineralisation

Table 4.1: Relative abundance of beanfly species *O. phaseoli* and *O. spencerella* collected at 4 weeks after emergence (w.a.e.) following different fertilizer application rates during the long rainy season of 1992.

Fertilizer (Ha)		Frequency of beanfly species/20 plants	
Nitrogen	Phosphorus	*O. phaseoli*	*O. spencerella*
0 N	0 P	2.3±2.0 abc	12.6±5.0 a
	45P	1.6±1.2 abcd	12.3±2.4 ab
	90P	0.6±0.6 dc	17.3±3.0 a
45N	0 P	3.6±2.2 ab	15.0±4.0 a
	45P	1.3±0.3 abcd	12.6±3.3 a
	90P	1.3±1.3 bcd	13.3±2.2 a
90N	0 P	3.3±0.3 a	13.3±3.3 a
	45P	1.3±1.0 abcd	18.3±0.6 a
	90P	0.6±0.3 bcd	12.6±6.0 a
20T Manure	0 P	1.3±0.3 abcd	14.6±7.0 a
	45P	2.0±0.6 abc	11.6±1.0 ab
	90P	1.6±0.3 abc	15.6±2.0 a
Contr. carb.	0P 0N	1.0 abcd	2.3 bc
Contr. endos.	0P 0N	0.0 d	0.0 c
Total		20.8 (11%)	169.1 (89%)

Statistical analysis:

F value :	Nitr.	1.6^{NS}	6.9^{***}
	Phosp.	3.5*	0.1^{NS}
CV% :		67.2	46.6
SE :		0.4	4.1

Means followed with the same letter in a column are not significantly different at 5% level (P<0.05) by "t" Test (LSD) mean comparison. Analysis was carried out on log (x+1) transformed data. Untransformed means are presented here.

* significant, P<0.05; *** significant, P<0.001;

NS, not significant.

Table 4.2 : Effect of soil fertility on beanfly infestation on two bean varieties (GLP 2 and GLP 24) during the long and short rainy seasons of 1991.

Fertilizer levels	Mean no.beanfly larvae and pupae/20 plants					
	Long rains of 1991			Short rains of 1991		
	GLP 2	GLP 24	Average	GLP 2	GLP 24	Average
0 N	16.3 b	17.6 b	17.0 b	2.6 a	2.6 a	2.6 a
30 N	37.0 a	15.3 b	26.1 ab	1.6 a	2.3 a	2.0 a
60 N	26.0 ab	34.3 a	30.1 a	6.0 a	3.3 a	4.6 a
90 N	27.3 ab	24.6 ab	26.0 ab	2.6 a	0.3 a	1.5 a
20t manure	18.0 b	17.3 b	17.6 b	4.0 a	2.6 a	3.3 a
Statistical analysis:						
F value :	10.0***	6.5**	4.5**	2.4^{NS}	1.8^{NS}	2.6^{NS}
CV% :	18.1	24.1	28.3	54.6	84.2	65.5
SE :	2.6	3.0	2.7	1.1	1.1	0.7
LSD 5% :	12.7	14.8	11.5	5.2	5.3	3.2

Means followed with the same letter in a column are not significantly different at 5% level (P<0.05) by Tukey (HSD) mean comparison.

** significant, P<0.01; *** significant, P<0.001; NS, not significant.

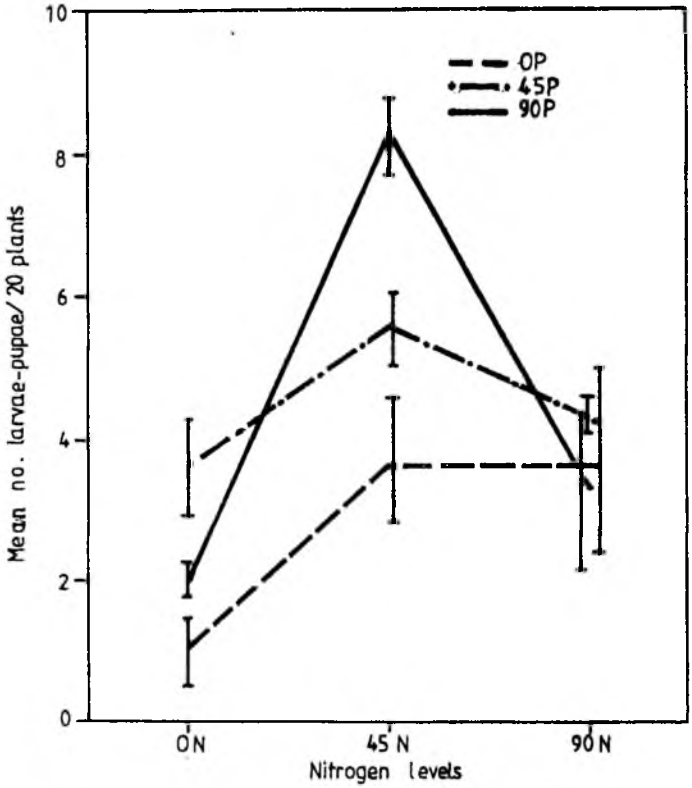

Fig.4.1: Effect of nitrogen and phosphorus fertilizer on beanfly infestation.

of manure. Table 4.2 shows that during the short rainy season of 1991 the beanfly infestation was less than during the long rains of 1991. Because of the generally low infestation during the short rains of 1991, the effect of fertilizers on the beanfly infestation was not pronounced. The mean number of beanfly larvae and pupae per 20 plants at two weeks after plant emergence was 3.7. Then the infestation increased slowly to reach a peak of 15.8 larvae and pupae per 20 plants at four weeks (Fig.4.2).

The beanfly species _Ophiomyia spencerella_ was more predominant at this site (Table 4.1) than _O.phaseoli_ and represented 89% while _O.phaseoli_ was only 11%. The species _O. spencerella_ could have been predominant because it lays most of its eggs in the hypocotyl, where the developing larvae were more protected from parasitoid attacks than were larvae of _O. phaseoli_ whose eggs are laid on both upper and lower surface of young leaves. Furthermore the life cycle of its main parasitoid _Opius phaseoli_ is synchronised with that of the host _O. phaseoli_. As it has been suggested, lack of effective parasitism may make the species _O. spencerella_ the more abundant species in East Africa (Greathead, 1968). These findings support the suggestions by Greathead (1968) that _O.spencerella_ may be more important on beans than _O.phaseoli_ in East Africa as well as those advanced by Spencer (1973)

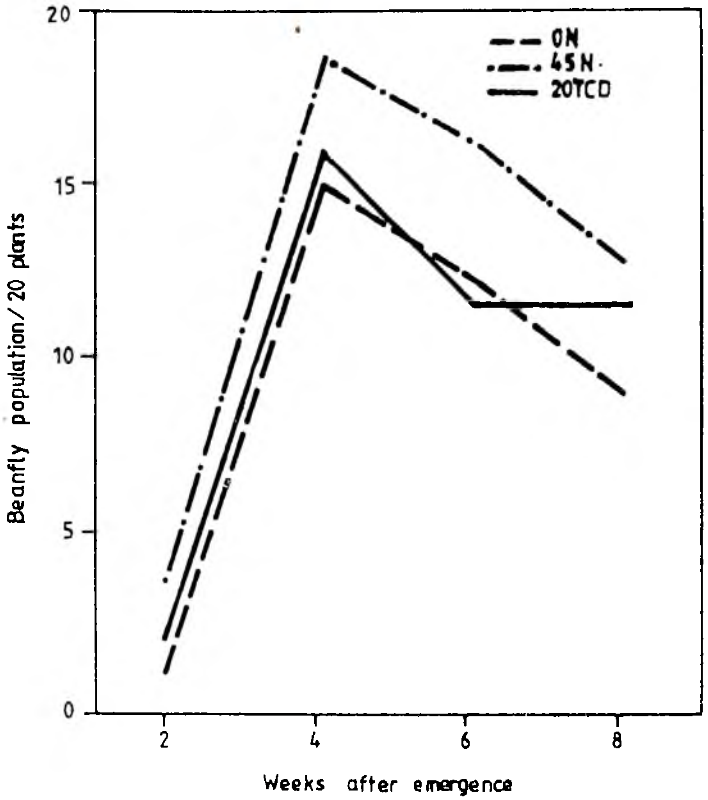

Fig. 4·2 Population fluctuations of beanfly under three fertilizer levels that O.spencerella was indigenous to Africa and therefore is expected to be abundant in Kenya. An increase in beanfly infestation ranging between 12% and 66% was recorded with increasing levels of nitrogen 30N, 60N and 90N kg/ha (Table 4.2). The bean plants treated with fertilizers were more infested by the beanfly because those plants had more nutrient and higher moisture content. Increased rates of nitrogen fertilizer make the plants succulent by increasing tissue softness and water content. Plant tissues become softer as the carbohydrates are diverted for protein synthesis rather than the construction of cell walls (Tisdale and Nelson, 1975). Such plants allowed easy penetration of beanfly larvae. They also had sufficient amounts of nutrients and provided enough food to the beanfly. Therefore beanflies growing in such plants were expected to be highly fecund and produce many progeny. For an insect to grow and reproduce, it has to successfully locate the source of high nitrogen in the plant, consume a sufficient amount and efficiently utilize it. However the effect of nitrogen fertilisation on insect incidence varies depending on the insect species, host plant species, soil fertility with regard to nitrogen and other elements, and possibly other environmental factors. Kiraly (1976), Trolldenier and Zehler (1976) stated that increasing plant nitrogen through fertilisation lowers phenolic content and lignification, therefore predisposing the plant to insect infestation. Plant analysis (Table 4.3) showed that application of the nitrogen and phosphorus fertilizers, increased the plant nitrogen, potassium, calcium and zinc and reduced iron (Fe). The amount of nitrogen uptake in 20 bean plants after nitrogen application of 0 N, 45 N, 90 N was 107g, 157g and 170.5g respectively. Application of a high dose of phosphorus (90 kg/ha) reduced the amount of nitrogen in the plants. In unfertilized plots, the bean plants were poorly infested due to the absence of nutrients. Nitrogen, calcium, and zinc were low in the unfertilized plants. The iron content was higher. These plants were more lignified and did not allow easy penetration by the beanfly larvae. In the fertilized plots the moisture content of the bean plants increased between 1.5% to 2% (Fig.4.3). In those plants the infestation was higher than in the unfertilized ones. In the 20 tons manure/ha fertilized plots, the beanfly population was low initially because the mineralisation of manure was slow and so did not boost the plant growth as the inorganic fertilizer did. Thus, in the 20 tons manure plots, the beanfly population did not rise until 6 and 8 w.a.e because the slow mineralisation in this type of manure had a delay on the lushness of the plant. Increase in insect infestation in plants treated with fertilizers has also been reported by Ralph et al.(1989) who found that infestation of European corn borer Ostrinia nubilalis (Lepidoptera: Pyralidae) increased in corn intercropped with soybean after application of 60 to 120

Table 4.3: Chemical composition of bean plants treated at different levels of nitrogen and phosphorus fertilizer at 6 w.a.e.

Fertilizers		N%	P%	K%	CA%	MG%	Feppm	Znppm
0N	0P	2.7	0.5	2.7	1.0	0.5	2288.6	72.3
	45P	2.8	0.4	2.8	1.5	0.5	2639.0	94.3
	90P	2.7	0.4	2.7	1.5	0.6	2205.6	100.0
45N	0P	2.9	0.4	3.1	1.5	0.6	2361.0	94.0
	45P	3.3	0.5	3.1	1.4	0.5	1839.0	83.3
	90P	2.7	0.4	3.2	1.4	0.6	1333.3	86.0
90N	0P	2.8	0.5	3.4	1.2	0.6	1000.0	83.3
	45P	3.1	0.3	2.9	1.2	0.5	1567.0	77.6
	90P	2.7	0.4	3.0	1.5	0.5	1877.6	86.3
20tons manure	0P	2.7	0.4	3.4	1.6	0.6	1878.0	99.6
	45P	3.0	0.5	3.1	1.6	0.6	1600.0	94.3
	90P	2.7	0.4	3.2	1.4	0.5	1755.3	99.6

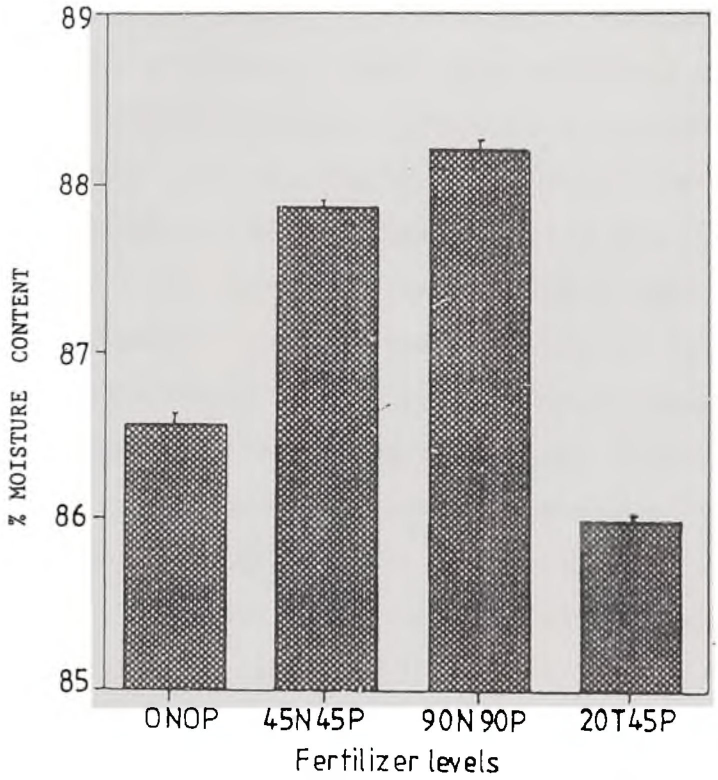

Fig. 4.3: Effect of fertilizer application on moisture content of bean variety (GLP 2) 4 w.a.e during the LR of 1992.

kg/ha of nitrogen. The infestation was correlated to more soft leaf tissue at the higher nitrogen rates. Similarly, Heathcoate (1974) stated that the use of nitrogen application has positive effects on insect pest occurrence by making the plant more vigorous and able to support and/or attract insects more strongly. During the short rains of 1991 the beanfly infestation was in general lower than in the long rains of 1991 (Table 4.2). During the short rains of 1991 the rainfall was low (Appendix 5) and appeared not to favour beanfly development. Although Santokh (1982), Subasinghe and Amarasena (1983) suggested that _O_. _phaseoli_ seems to be inhibited by high precipitation and tends to increase during the dry period after rain, beanfly prefers humid areas and avoids sunny areas for its biological activities because of its susceptibility to rapid dehydratation in direct sunlight (Santokh, 1982). At two weeks after plant emergence the beanfly infestation appeared low, though the nitrogen effect was evident, indicating early nitrogen assimilation (Fig.4.2). The beanfly attacks the crop within a week of germination. Its larval stage lasts around ten days and the pupal stage a further ten days (Greathead, 1968). Dissection of the bean stem at 2 w.a.e showed low beanfly population which increased at 4 w.a.e when first generations were in their last larval and pupal stages. Beyond 8 w.a.e the infestation started to decline because the bean plant became lignified with the exception of variety GLP 24 that has a vegetative development that takes a little longer. The bean varieties GLP 2 and GLP 24 were almost equally susceptible to beanfly infestation.

The soil and bean plants analysis confirmed the low levels of nitrogen at the study site in Oyugis (Table 4.3). When nitrogen was applied alone, its assimilation was not effective because of lack of phosphorus. It was only after applying the combination of nitrogen and phosphorus that it was possible to obtain good nitrogen assimilation and an effect on bean plants and beanfly infestation. Thus, phosphorus helped to increase beanfly infestation through better assimilation of nitrogen. This finding is in agreement with the suggestion that nitrogen fixation may be ineffective in the absence of adequate amounts of phosphorus (Lathrop and Keirstead, 1946; Dupree, 1965; CIAT, 1976).

Effect of soil fertility on the percentage of dead plants.

There was no significant difference between the percentage of dead plants caused by beanfly infestation at the different nitrogen levels with exception of the variety GLP 24 in LR 1991 (Table 4.4). Larvae destroyed the bean plant phloem and other plant tissues. In that way they prevented the mineral elements from reaching the stem and the plant as a whole. Hence infested plants died as a result of lack of sufficient nutrients and moisture. However, the positive

Table 4.4: Effect of beanfly infestation at different fertilizer levels in causing dead plants in two bean varieties four weeks after bean emergence during the long and short rainy seasons of 1991.

Fertilizer levels (Ha)	Percentage of dead plants					
	Long rains of 1991			Short rains of 1991		
	GLP 2	GLP 24	Average	GLP 2	GLP 24	Average
0 N	9.0 a	4.0 c	6.5 b	8.3 a	10.3 a	9.3 a
30 N	9.0 a	8.6 ab	8.8 ab	10.0 a	9.0 a	9.5 a
60 N	10.0 a	10.0 a	10.0 a	11.3 a	8.6 a	10.0 a
90 N	9.6 a	10.0 a	9.8 a	6.6 a	15.6 a	11.1 a
20 T manure	9.6 a	4.6 bc	7.3 b	9.3 a	13.3 a	11.3 a

Statistical analysis:

F value :	0.2^{NS}	16.9***	7.4***	0.6^{NS}	0.5^{NS}	0.2^{NS}
CV% :	16.1	14.8	16.3	41.2	50.3	45.9
SE :	0.8	0.6	0.5	2.2	3.3	1.9
LSD 5% :	4.2	3.2	2.4	10.6	16.1	8.2

Means followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison.

interaction between nitrogen and phosphorus increased bean plants vigour and enabled them to tolerate the beanfly infestation and overcome its damaging effects.

Effect of soil fertility on moisture content.

The moisture content of the bean plants increased between 1.5 to 2% when a combination of nitrogen and phosphorus were applied, which significantly increased ($P<0.01$) with higher levels of nitrogen and phosphorus (Fig.4.3).

Moisture content increased at fertilizer levels of 45 kg of N /45 kg of P and 90 kg of N /90 kg of P. At higher plants nutrient levels, the plants had more moisture content and were thus soft and easier for beanfly to bore the bean stems. Conversely, unfertilized plots with less nutrients had less water, hence the stems remained lignified, so that the beanfly could not achieve easy penetration. The moisture content was optimal between 4 and 6 w.a.e. This moisture content and actual beanfly attack starting with the first week of plant emergence provided an infestation peak period between 4 and 6 w.a.e. At 8 w.a.e moisture decreased together with beanfly infestation.

Effect of soil fertility on dry matter.

Dry matter accumulation in bean plants also increased with fertilizer application, compared to unfertilized plots (Fig.4.4; Appendix 1, 2). Combination of phosphorus and nitrogen also improved dry matter yield. A good balance between nitrogen and phosphorus (45 kg of N / 45 kg of P; 90 kg of N / 90 kg of P) improved dry matter accumulation more than in unfertilized soil (0 kg of N/0 kg of P). In this case the relation between beanfly infestation and dry matter accumulation was well defined. Probably a good nitrogen phosphorus interaction facilitated the beanfly infestation.

Effect of soil fertility on parasitoids.

It was found that the beanflies were controlled naturally by six species of parasitoids: Opius phaseoli (Hymenoptera: Braconidae), Psilus sp.(Hymenoptera: Diapriidae), Pediobius sp.(Hymenoptera: Eulophidae), Eupelmus sp.(Hymenoptera: Eupelmidae), Herbertia sp.(Hymenoptera: Pteromalidae) and Sphegigaster sp.(Hymenoptera: Pteromalidae).

An assessment of the effect of soil fertility on the six species of parasitoids found on beanfly revealed a close association between the number of parasitoids and beanflies (Fig.4.5, 4.6). Parasitoid emergence from pupae increased when beanfly infestation increased in high soil fertility.

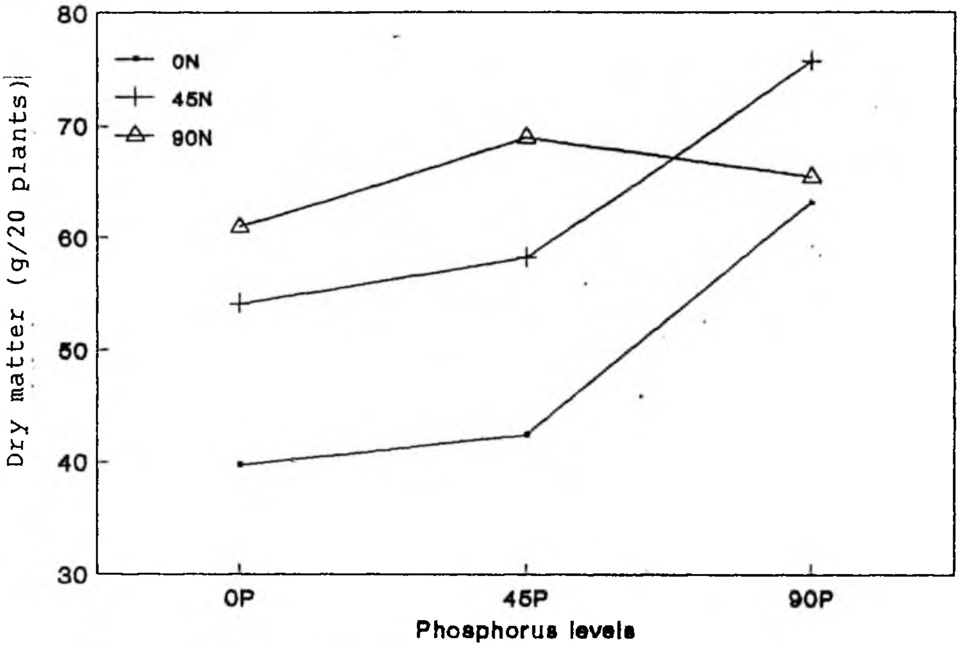

Fig.4.4 Effect of nitrogen and phosphorus application on dry matter content of bean variety (GLP 2) 4 w.a.e during the long rains of 1992.

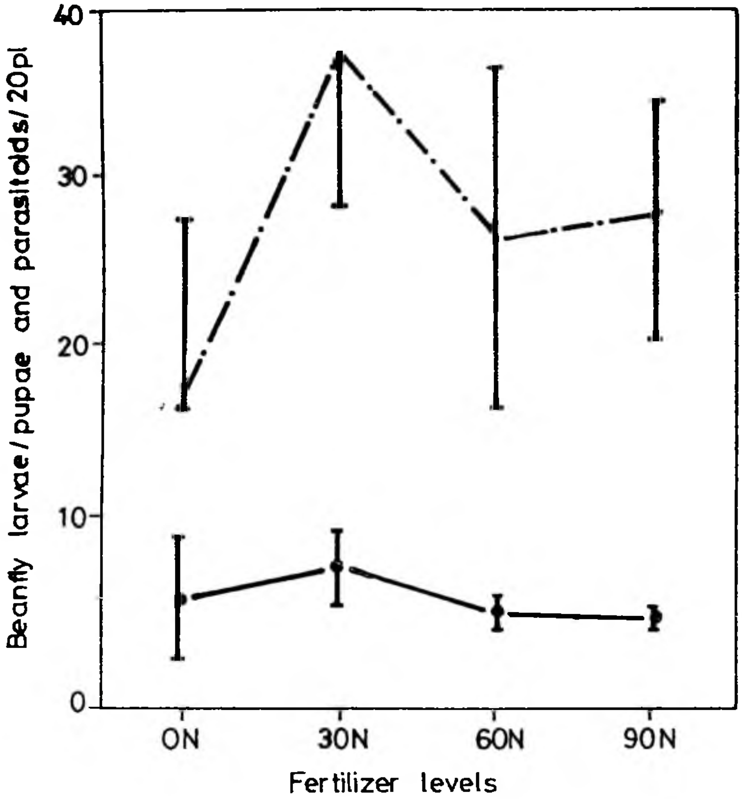

Fig. 4·5 Relationship of parasitoids at different fertilisation levels to number of bean-flies 4 w.a.e. (GLP2) LR of 1991.

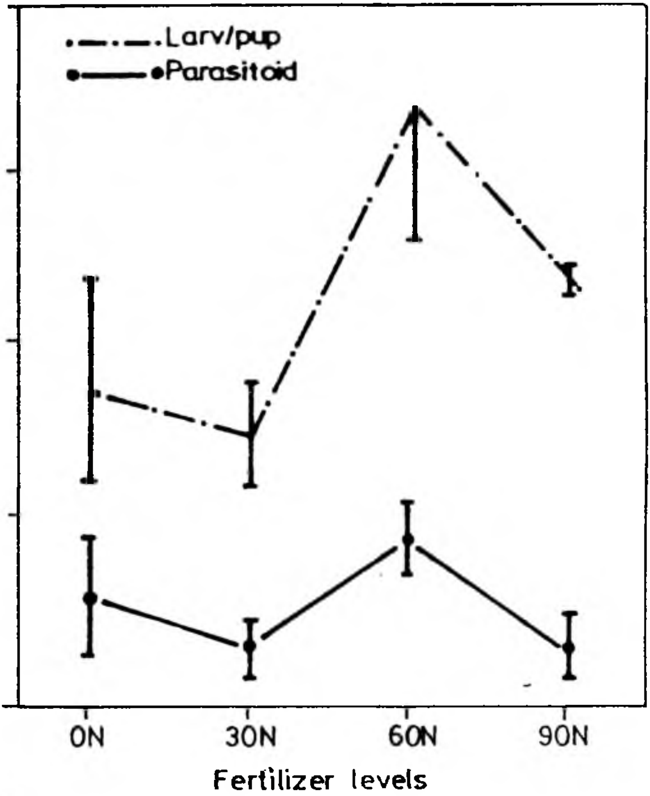

Fig. 4·6 Relationship of parasitoids at different fertilisation levels to number of bean-flies 4 w.a.e. (GLP24) LR of 1991.

During the long rains of 1991 at 4 w.a.e, the parasitoids reduced the beanfly population by 20-26% at 0N, 30N, 60N, 90N kg/ha. The interaction of nitrogen and phosphorus on parasitoids was highly significant (P<0.01). When phosphorus was applied alone the mean number of parasitoids of beanfly recorded in 20 plants was 0.5, but when applied with 90 kg/ha of nitrogen, the mean number of parasitoids was 1.3.

It has already been noted that higher fertilizer levels increased beanfly population. Since beanfly parasitoids emerged from the pupae, the increase in beanfly population also increased beanfly parasitoids, because they were host density-dependent (Fig.4.5, 4.6). This observation is in agreement with Greathead (1968) who suggested that the main parasitoid *Opius phaseoli* of two species of beanfly (*Ophiomyia phaseoli* and *O. spencerella*) present in Oyugis was density-dependent. The effect of parasitoids in the regulation of beanfly population varied between 20-26%. The most common parasitoid was *Opius phaseoli*. The other five species were not very frequent. Assessments showed that the parasitoids emerged only from pupae and not from larvae. For each infested pupa no adult beanfly emerged and such pupa produced only one parasitoid.

The level of parasitism of beanfly in Oyugis was at an acceptable range (20-26%) because Santokh (1982), Abate (1991), Fellows and Amarasena (1977) reported parasitoids effect to be between 5-94%. However parasitism is variable according to Tengecho et al.,(1988) who reported it to be 3.5 and 16.2%, respectively, for O. spencerella and Ophiomyia phaseoli.

Relationships between fertilizer application and nodule formation and grain yield.

The results of studies on nodule formation and their dry matter accumulation are presented in Table 4.5. Phosphorus application significantly ($P<0.01$) increased both numbers and dry matter of nodules. Nitrogen when applied alone neither had effect on nodule formation nor dry matter accumulation. It was found that beanfly infestation did not affect the number of nodules (Table 4.5).

During the long rains of 1992, grain yield increased when a combination of nitrogen and phosphorus was applied (Table 4.6). In the plots where there was no interaction between nitrogen and phosphorus, which are deficient in Oyugis soils, grain yield was low. The effect of beanfly infestation on yield loss was obtained by comparing the yield from the infested control and the infestation-free plots. Yield reduction estimated in this way was 48% (Table 4.6). Although the plants treated with a combination of nitrogen and phosphorus were more affected by the beanfly infestation, their yield was not much affected.

Table 4.5: Effect of nitrogen and phosphorus fertilizers on the number of bean plant nodules and their dry matter at 6 w.a.e during the long and short rainy seasons of 1992.

Fertilizer (Ha) Nitrogen	Phosphorus	Nodules no./10 plants		Dry matter (g)/10 plants	
		LR 1992	SR 1992	LR 1992	SR 1992
0N	0P	177.6 abc	138.3 cde	0.1 de	0.04 de
	45P	208.3 abc	163.6 cde	0.3 abcd	0.08 bcde
	90P	632.6 a	269.0 abcd	0.4 a	0.13 abcd
45N	0P	87.0 bc	111.0 de	0.1 cde	0.10 abcde
	45P	213.6 ab	197.0 bcde	0.2 abcde	0.05 de
	90P	349.0 a	410.3 a	0.3 abc	0.18 ab
90N	0P	78.3 c	86.0 e	0.1 de	0.01 e
	45P	173.0 ab	355.0 ab	0.1 e	0.07 bcde
	90P	192.6 ab	113.0 de	0.2 abcde	0.04 de
20T Manure	0P	147.3 abc	198.3 bcde	0.1 de	0.20 a
	45P	403.3 a	298.6 abc	0.4 ab	0.16 abc
	90P	389.3 a	235.6 bcde	0.4 a	0.11 abcde
Contr. carb. 0N 0P		127.3 abc	99.3 de	0.1 de	0.06 cde
Contr. endos. 0N 0P		171.6 ab	99.3 de	0.1 bcde	0.06 cde

Statistical analysis:

F value :	Nitr.	1.7^{NS}	2.1^{NS}	2.8*	5.5***
	Phosp.	9.4***	7.4***	10.1***	0.9NS
CV% :		19.4	37.3	60.7	71.2
SE :		0.7	84.1	0.1	0.05

Means followed with the same letter in a column are not significantly different at 5% level ($P<0.05$) by "t" Test (LSD) mean comparison. Analysis was based on log (x+1) transformed data. Untransformed means are presented here.

* significant, $P<0.05$; *** significant, $P<0.001$;

NS, not significant.

Table 4.6: Effect of beanfly infestation at different fertilizer levels on grain yield during the long rainy season of 1992.

Fertilizer Nitrogen	Phosphorus	grain yield kg/ha
0 N	0 P	353.3 f
	45 P	1086.3 dc
	90 P	2333.0 ab
45 N	0 P	1690.0 bc
	45 P	2308.0 a
	90 P	2598.0 a
90 N	0 P	2232.3 ab
	45 P	2573.3 a
	90 P	2047.3 ab
20 T manure	0 P	2515.7 a
	45 P	2269.0 ab
	90 P	2149.0 ab
Contr. carb.	ON OP	741.3 de
Contr. endos.	ON OP	521.6 ef

Statistical analysis:

F value :	13.6***
CV % :	4.1
SE :	0.2

Means followed with the same letter in a column are not significantly different at 5% level (P<0.05) by "t" Test (LSD) mean comparison.

Plants treated with fertilizers had sufficient nutrients which presumably helped them compensate for damaged parts. Fertilizers increase plant vigour which enables it to carry higher pest numbers but suffers less yield loss due to infestation. This therefore allows the plant to tolerate a higher infestation through compensatory mechanisms. Such plants provided good yield. On the other hand, the unfertilized plants succumbed to beanfly attack because of their low nutrient levels. In that case the plants either died or stayed very weak and yielded little grain.

Effect of insecticides on beanfly infestation.

Endosulfan coated on bean seeds before planting completely suppressed beanfly infestation during the entire vegetative period. Carbofuran (Furadan 5G) applied in furrows at planting also significantly reduced beanfly infestation (Table 4.7). Grain yield was increased by insecticides application by 32% with endosulfan and 52% with carbofuran. An increase in the rate of endosulfan reduced the number of bean plants per plot though the difference was not significant (Table 4.8). Despite the high contribution of endosulfan in reducing beanfly infestation, its effect on yield was less than that of carbofuran. That may have been due to

Table 4.7: Effect of insecticides endosulfan and carbofuran on beanfly infestation and grain yield.

Treatments	Rate	Mean no. beanfly 80 plants	Root nodules 10 plants	grain yield (kg/ha)
Endosulfan	3g ai/kg seed	0.6 c	171.6 a	521.6±95.5 ab
Carbofuran	2kg ai/ha	12.5 b	127.3 b	741.3±34.0 a
Control		43.3 a	177.6 a	353.3±6.0 b

Means followed with the same letter in a column are not significantly different at 5% level by "t" Test (LSD) mean comparison.

Table 4.8: Effect of insecticides used in the control of beanfly infestation on the number of bean plants.

Treatments	Mean no.plants 24 m^2
Control	331 a
1.5 g ai endosulfan/kg seeds	286 a
3 g ai endosulfan/kg seeds	281 a
2 kg ai carbofuran/ha	275 a
5 g ai endosulfan/kg seeds	274 a

Statistical analysis:

F value : 1.1^{NS}
CV % : 13.5
SE : 22.5
LSD 5% : 110.2

Means followed with the same letter in a column are not significantly different at 5% level by Tukey mean comparison.

phytotoxicity. Bosch (1990) also reported that seed treatment with endosulfan reduced yield by 16% and by 25% when it was sprayed at flowering in Tanzania.

The control treatment with endosulfan fully protected the plants from beanfly infestation (Table 4.7). Endosulfan is not a systemic insecticide, but was able to protect bean seedlings from beanfly infestation up to two months after planting because of its chemical structure. It has two -O- and one S=O groups which indicates that it has water solubility and can penetrate plant tissue due to the layer of lipid in the epidermis of plant surfaces and can be translocated readily within the plant (Talekar, 1991 Personal communication). The slight water solubility of endosulfan was more than adequate for it to act as a localised systemic. This translocation was adequate to protect young bean seedlings. Talekar (1991 Personal communication) reported that coating of this chemical on to the seed helped easy penetration in cotyledons and that as the nutrients move soon after germination from cotyledons to newly developing roots and shoots, some endosulfan molecules are also translocated along with them.

CHAPTER 5: EFFECT OF BEAN/MAIZE INTERCROPPING ON BEANFLY POPULATION AND DAMAGE.

5.1. INTRODUCTION

Intercropping is a common feature of small-scale agriculture in tropical and subtropical Africa as in the Asian and American tropics (Aiyer, 1949; Okigbo and Greenland, 1976; Talekar, 1987). Specific intercropping systems have been developed over centuries in different regions and they are closely adapted to the prevailing ecological and socio-economic conditions. Previous agronomic studies at the ICIPE have demonstrated that certain combinations in intercropping systems e.g.sorghum-cowpea or maize-cowpea reduce the attack and damage to the plants by stem-borers (Amoako-Atta *et al*.,1983). Talekar(1987) quoting Van der Goot (1930) observed that the intercropping of soybean with egg plant (*Solanum melongena*) and yam bean (*Pachyrhizus erosus*) reduced *Ophiomyia phaseoli* infestation. Studies conducted at the Asian Vegetable Research and Development Center (AVRDC) showed that intercropping of mungbean with muskmelon, soybean, blackgram, pearl millet, watermelon, cantaloupe, ginger, tomato or local grass significantly reduced bean fly infestation (AVRDC, 1979). Moreover, in Nigeria where soybeans have been intercropped with sorghum, maize and citrus no serious pest problems have been reported (Jackai and Singh, 1987).

The mechanisms of low insect pest incidence in intercroping however, have been little studied. Several hypotheses have been advanced: firstly the plant cover with two crops shade soybean plants and reduce beanfly access (Talekar, 1987). Secondly, the effect of intercropping is also said to be related to host preference, chemical repellant/masking of plant odours, time wasting of insects, visual effects, enhanced natural enemy complex and change in the environmental conditions (moisture, temperature, light intensity etc) (Baliddawa, 1985). Thirdly the mechanism of intercropping may include the introduction of physical barriers, confusing or diverting odours, visual disruption and dilution of host concentration, thus plant appearance may be reduced (Feeney, 1976).

Many farmers in Oyugis (Kenya) practise intercropping mostly of leguminous crops (beans, cowpea, groundnut) and maize or sorghum. They also intercrop beans with banana. The farmers prefer intercropping because it allows them to harvest different crops from one plot at diffent times. A study of the effect of such cropping system locally used for the management of beanfly was therefore carried out. At the study site other insect pests such as aphids and thrips were present. However their effect on bean crops was minor compared to beanfly. The effect of intercopping beans and maize on beanfly has not been studied. These would be useful in divising cultural control options under the framework of IPM for beanfly.

Consequently, in the present study the objective was to quantify the advantage of insect pest reduction in intercropping (Plate 6).

5.2. METHODS

The experiment was planted on March 5 and August 15 of 1991, April 1 and August 22 of 1992. The hybrid maiize 6.22 which is a staple food crop was intercropped with bean varieties GLP 2 and GLP 24. Bean seeds were treated with the insecticide endosulfan 50% wp at the rate of 5g ai per 1kg of seeds (LR91), 1.5g ai per 1kg of seeds (SR91) and 3g ai per 1kg of seeds (long and short rains of 1992). The experiments consisted of four treatments: bean monocrop seed treated with endosulfan 50% wp, bean monocrop seed untreated, maize intercropped with bean seed treated with endosulfan 50% wp and maize intercropped with beans seed untreated. Plant spacing used by local farmers for beans and maize was adopted. Plants were spaced at 60 cm between rows and 15 cm within rows for

Plate 6. Experimental plot on the effect of intercropping of beans and maize on beanfly infestation.

beans and 30 cm within rows and 60 cm between rows for maize. In order to maintain the same bean density, during long and short rains of 1992, the spacing in the intercropping were 60 cm between rows and 15 cm within rows for beans and 60 cm inter-rows and 30 cm intra-rows for maize. In bean monocrop, the spacing was 60 cm between rows and 15 cm within the rows. At this spacing plant density of maize was 55,555 plants/ha and beans was 111,111 plants/ha in the intercropping and for beans 111,111 plants/ha in the monocrop. The light intensity under canopy was measured with a point sensor (LI-185 B, Licor, USA), at four different places in each plot. Relative light intensity (light transmission ratio) was calculated against a reference light above the canopy for each plot. The temperature under bean canopy was measured twice a day at 10.00 AM and 2.00 PM using a Protimeter Ha T65 Thermohygrometer probe, ELE International Limited, England. The soil moisture content was also recorded. In each plot, a soil sample of 200 grams was taken from four different places. Its fresh weight was recorded before oven-drying to constant weight. The moisture was obtained as [100(X-Y)]/X, where X was fresh soil weight and Y dry soil weight.

5.3. RESULTS AND DISCUSSION.

Effect of intercropping on beanfly infestation.

Table 5.1 shows the results obtained from this experiment over the 4 cropping seasons. These results revealed that generally no significant differences could be detected in the beanfly populations whether the crop was grown as a monocrop or when intercropped with maize. The only significant difference obtained during the long rains in 1991 appears not to be representative for all infestation assessments and so cannot be considered to be important. The maize plants had no protective effect on the infestation of beans planted simultaneously with maize. However, high infestation was recorded when beans were planted in a field containing six weeks-old maize (Fig.5.1). A study of the microclimatic conditions prevailing under the two cropping conditions showed that light distribution under the bean canopy was significantly higher ($P<0.01$) in the monocrop than in the intercrop only during the long rains of 1991 and short rains of 1992 (Table 5.2). The light reaching the ground in the bean monocrop was 10-30% more than in the intercrop in the two varieties GLP 2 and GLP 24. Consequently, the temperature under bean canopy was significantly higher ($P<0.01$) in the monocrop than in the intercrop during morning hours

Table 5.1: Effect of intercropping two bean varieties (GLP 2 and GLP 24) with maize on beanfly infestation at 4.w.a.e. during the long and short rainy seasons of 1991 and 1992.

Cropping system	Mean no. larvae and pupae/20 plants			
	LR 1991	LR 1992	SR 1991	SR 1992
	Variety GLP 2			
Monocrop	22.6±1.6 b	8.3±0.3 a	3.3±0.3 a	5.6±0.6 a
Intercrop	33.3±1.0 a	10.0±1.5 a	2.6±0.3 a	5.3±1.4 a
	Variety GLP 24			
Monocrop.	24.6±2.3 a	15.6±3.5 a	2.3±0.3 a	5.6±0.3 a
Intercrop.	25.6±5.7 a	19.0±4.0 a	3.6±1.0 a	4.6±1.2 a

Statistical analysis:

	LR 1991	LR 1992	SR 1991	SR 1992
GLP 2				
F value :	146.2***	0.8^{NS}	1.0^{NS}	70.6^{NS}
CV% :	3.8	24.7	21.7	23.8
SE :	0.8	1.8	0.1	0.2
GLP 24				
F value :	0.02^{NS}	0.2^{NS}	0.2^{NS}	1.0^{NS}
CV% :	35.2	53.2	31.5	13.6
SE :	7.2	7.5	0.2	0.2

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by "t" Test mean comparison. *** significant, P<0.001; NS, not significant.

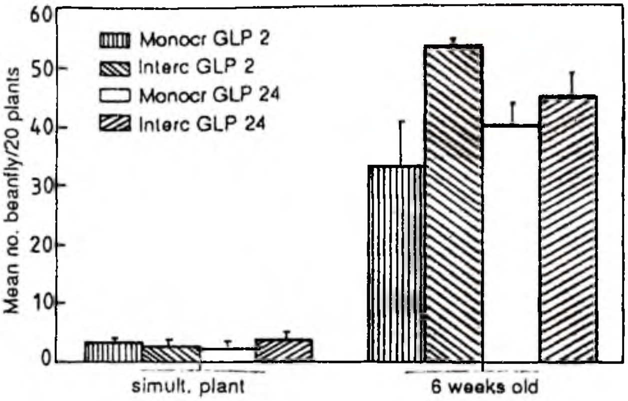

Fig. 5.1 Effect of intercropping beans with simultanous or 6 weeks-old maize on beanfly infestation, SR 1991

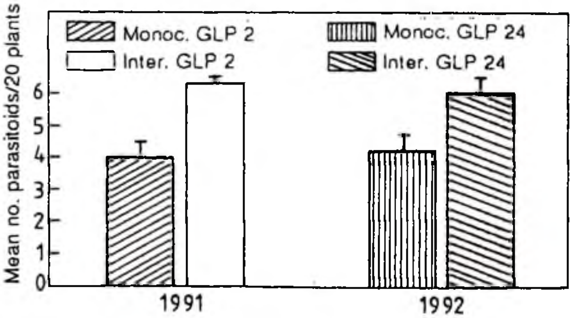

Fig. 5.2 No. of parasitoids of beanfly recorded on monocropped beans (varieties GLP 2 and GLP 24)and beans intercropped with maize during the long rains of 1991 and 1992

Table 5.2: Effect of intercropping two bean varieties (GLP 2 and GLP 24) with maize on the light distribution under bean canopy during the long and short rains of 1991 and 1992.

Cropping system	Light intensity			
	LR 1991	LR 1992	SR 1991	SR 1992
	Variety GLP 2			
Monocrop.	0.41±0.1 a	0.41±0.2 a	0.29±0.0 a	0.86±0.0 a
Intercrop.	0.30±0.1 b	0.35±0.1 a	0.23±0.0 a	0.70±0.0 a
	Variety GLP 24			
Monocrop	0.42±0.1 a	0.54±0.1 a	0.31±0.0 a	0.86±0.0 a
Intercrop	0.23±0.0 b	0.35±0.1 a	0.27±0.0 a	0.65±0.0 b

Statistical analysis:

GLP 2

F value :	90.7**	0.1^{NS}	1.7^{NS}	2.4^{NS}
CV% :	3.9	46.2	21.2	16.7
SE :	0.01	0.014	0.04	0.1

GLP 24

F value :	25.2**	2.9^{NS}	4.3^{NS}	16.7*
CV% :	14.4	29.7	7.4	5.3
SE :	0.03	0.1	0.01	0.1

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by "t" Test (LSD) mean comparison.

(Table 5.3). A similar trend was shown in the afternoons although the differences here were not significant. An analysis of moisture content in the soils of the two cropping situations was not significant but the soil in the intercropping tended to be wetter. In variety GLP 2 the soil moisture obtained in intercropping was 5.9% higher than in monocropping while in the bushy variety GLP 24 it was 7.6% higher (Table 5.4).

The beanfly infestation started within a week after bean emergence. At that time the maize plants were still too short to exert any protective action, such as barrier effect towards the beanflies. In order to increase the protective effect of intercropping on beanfly, the beans were also intercropped with six weeks-old maize. However, the infestation remained still higher in the intercrop than in monocrop. Therefore it can be concluded that intercropping beans and maize did not have any reducing effect on beanfly infestation. However, the effect of bean and maize intercropping on the bean thrips <u>Megalurothrips</u> <u>sjostedi</u> was significant $P<0.01$. The bean thrips population was reduced by 25% in intercropping (Appendix 4).

The study of microclimatic conditions prevailing in the intercrop explains the possible preference by beanfly for beans in the bean and maize intercrop than in pure bean

Table 5.3: Effect of intercropping two bean varieties (GLP 2 and GLP 24) with maize on temperature under canopy at 4 w.a.e.

Cropping system	Temperature °C	
	10.00 AM	2.00 PM
	Variety GLP 2	
Monocrop	31.0±2.0 a	35.0±0.4 a
Intercrop	27.8±1.0 b	33.5±1.0 a
	Variety GLP 24	
Monocrop	32.0±2.0 a	35.0±0.7 a
Intercrop	30.4±1.6 b	34.9±0.3 a

Statistical analysis:

GLP 2

F value :	4.1***	0.7^{NS}
CV% :	1.7	1.7
SE :	0.04	0.03

GLP 24

F value :	1.3***	0.01^{NS}
CV% :	1.3	0.8
SE :	0.03	0.02

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by "t" Test (LSD) mean comparison.

Table 5.4: Effect of intercropping two bean varieties (GLP 2 and GLP 24) with maize on soil moisture content at 4 w.a.e.

Cropping system	% moisture content
	Variety GLP 2
Monocrop	21.8 ± 0.1 a
Intercrop	23.1 ± 2.1 a
	Variety GLP 24
Monocrop	22.2 ± 0.7 a
Intercrop	23.9 ± 0.8 a

Statistical analysis:

GLP 2

F value :	0.5^{NS}
CV% :	9.5
SE :	1.7

GLP 24

F value:	5.8^{NS}
CV% :	3.7
SE :	0.7

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by "t" Test (LSD) mean comparison.

stands. In beans intercropped with maize less light penetrated the bean canopy than in the monocrop. The bean plants in monocrop received more light ranging from 10 to 30% than those in the intercrop. This meant that the beanfly avoided exposure to the direct light prevailing in the monocrop. Similarly, the temperature in intercrop which ranged from 27°C to 30°C was within the optimal requirement of the beanfly, which is 15-30°C, whereas the temperature in the monocrop was higher, averaging 31-32°C. Furthermore, the soil moisture was more in intercropping, averaging 23.5%, while it was 22% in the pure bean stands. The difference in soil moisture in intercropping may keep the environment humid and prevent dehydration of the beanfly in such stands and allow its optimal development. The cumulative effect of all these microclimatic conditions prevailing in intercrop may have favoured the infestation of the beanfly. These findings therefore suggest that beanfly infestation was increased by shade (low light intensity), lower temperature (15-30°C) and higher soil moisture. The infestation in beans intercropped with 6 weeks-old maize was favoured by the microclimatic conditions created by the already developed maize. These plots were not exposed to the intense sunlight and so sufficient moisture was retained. These conditions were favourable for beanfly development. Also, beans in monocrop planted with a delay of 6 weeks after the first rains were more highly infested than those planted with the first rains. This may be due to a beanfly population build-up from surrounding fields. Better environmental conditions for beanfly development and growth were obtained in the long rains than in the short rains. For instance average rainfall in vegetative growth phase (March-May of 1991 and 1992) in the long rains was 582 mm compared to 395 mm (August-October) of short rains. Similarly, relative humidity was higher (daily mean 45.4%) in the long rains than in the short rains (daily mean 26%). Also slightly higher temperatures were observed in the long rains (23.9℃) than in short rains (23.3℃). The climatic conditions prevailing during the long rains were comparable to the conditions offered by intercropping which responded more to beanfly requirements. In the monocrop the beanfly was more exposed to direct light, higher temperature and lower moisture.

The results obtained here are in agreement with those of Santokh (1982) who suggested that beanfly prefers shaded areas for its biological activities. The same author proposed that infestation in shaded areas is higher (36%) than in open ones (12.8%) because beanfly is susceptible to rapid dehydration in direct sunlight. Its optimal temperature is reported to be 15-30℃ (Santokh, 1982). In the present study beanfly avoided exposed plants in the monocrop and preferred those in the intercrop. These findings are supported by some reports that intercropping favours some pests on cowpea eg.beetles (Ootheca spp.) which have no difficulty in spreading through plots of cowpea intercropped with maize (Gerard, 1976; Karel *et al.*,1980; Anon, 1980). Similarly, Gethi and Khaemba (1991) recorded significantly more pod-sucking bugs on cowpea intercropped with maize than cowpea planted as a pure crop. In general, beanfly infestation was more during the long rains for both seasons than the short rains. It is clear that climatic conditions (light intensity, temperature and relative humidity) were more favourable for beanfly development during the long rains than the short rains of 1991 and 1992. In 1991 the total rainfall during the three months of vegetative (sampling) period were 580 mm in the long rains and 454 mm in the short rains. In 1992 the corresponding values were 584 mm and 335 mm. Only slight temperature changes were observed between the two rainy season periods over the 2-year period (see Appendix 5).

An analysis of the percentage of dead plants showed no significant differences between monocropped and intercropped beans (Table 5.5). However in the monocrop, dead plants were more due to their exposure to sunlight.
The evapotranspiration was more here and reduced the moisture content in the plants. Therefore, a plant infested by beanfly and which loses a high amount of its moisture content will dry up quickly. In the bean plants located under maize in the intercrop, water loss was much less despite a high

Table 5.5: Effect of beanfly infestation on the number of dead plants in monocrops and intercrops of two bean varieties (GLP 2 and GLP 24) with maize.

Cropping system	Percentage of dead plants			
	LR 1991	LR 1992	SR 1991	SR1992
		Variety GLP 2		
Monocrop	14.0±2.6 a	3.9±0.4 a	14.3±1.0 a	1.5±0.2 a
Intercrop	16.0±2.5 a	3.4±0.4 a	12.0±1.5 a	3.5±1.3 a
		Variety GLP 24		
Monocrop	11.0±1.2 a	4.9±0.6 a	18.3±2.6 a	7.8±0.6 a
Intercrop	11.6±1.0 a	4.2±1.3 a	16.6±3.8 a	8.5±3.1 a

Statistical analysis:

GLP 2

	LR 1991	LR 1992	SR 1991	SR1992
F value :	1.7^{NS}	0.3^{NS}	1.0^{NS}	1.0^{NS}
CV% :	12.4	29.6	21.7	38.2
SE :	1.5	0.8	2.3	2.4

GLP 24

	LR 1991	LR 1992	SR 1991	SR1992
F value :	0.05^{NS}	0.2^{NS}	0.6^{NS}	0.0^{NS}
CV% :	32.0	42.5	14.1	30.4
SE :	2.9	1.6	2.0	4.0

Means in same variety followed with the same letter in a column are not significantly different at 5% level by "t" Test (LSD) mean comparison.

infestation. The maize cover created microclimatic conditions which reduced temperature and increased soil moisture. Therefore, exposure of attacked bean plants to dry climatic conditions is the critical factor causing death among beanfly-attacked plants.

Effect of intercropping on parasitoids of the beanfly.

An assessment of beanfly population regulation by parasitoids showed no significant difference between monocropping and intercropping during the long rainy seasons of 1991 and 1992 (Fig.5.2, Appendix 6). The results revealed that the effect of parasitoids on beanfly regulation ranged between 17-28% in both cropping systems during the long rains of 1991 and 1992.

An increase of 40% of parasitoids in the intercrop of variety GLP 2 during the long rains of 1991 and of 23% in GLP 24 during the long rains of 1992 occurred where beanfly infestation was higher, due to host density dependence. This observation does not agree with the hypothesis of Sheehan (1986) that crop diversification resulted in lowered pest incidence because of increased natural enemy activity. However over time this may probably be the expected outcome.

Effect of intercropping on grain yield.

Grain yields were higher in monocrops than in intercrops for both bean varieties (GLP 2 and GLP 24) during the long and short rains of 1991 and 1992. Variety GLP 2 was higher yielding than GLP 24. Even when bean plant density was maintained constant in the long and short rains of 1992, the grain yield was still higher in the monocrop than in the intercrop (Table 5.6). The land use in intercropping seemed not to give any yield advantage to the beans.

It was observed that in the monocrop, the number of pods per plant, seeds per pod and grain weight were higher than in the intercrop for all the cropping seasons of 1991 and 1992. The study showed a significant difference in yield due to the cropping pattern. To increase bean yield, competition between beans and maize for environmental resources must be reduced and plant density in the intercropping should be as close to the monocrop as possible. In the trial, optimum planting density given by agronomists in the region was observed but the competition for light as a result of the shade imposed by the maize was not eliminated. At levels of intense competition, the negative effects of competition on yield will enhance the negative effects of increased beanfly attack. This was illustrated by the combination of microclimatic

Table 5.6: Yield of bean grain obtained from monocropping or intercropping with maize (kg/ha).

Cropping system	LR 1991	LR 1992	SR 1991	SR 1992
		Variety GLP 2		
Monocrop	2134 a	858 a	633 a	954 a
Intercrop	478 b	258 a	252 b	453 b
		Variety GLP 24		
Monocrop	1165 a	629 a	367 a	594 a
Intercrop	950 b	256 a	164 b	219 a

Statistical analysis:

GLP 2

F value :	28.1***	8.7^{NS}	19.6***	10.9***
CV% :	28.1	8.7	5.8	5.6
SE :	132.6	0.4	0.2	0.3

GLP 24

F value :	10.2***	2.0^{NS}	8.7***	16.7^{NS}
CV% :	19.9	13.1	5.1	5.3
SE :	98.5	0.6	0.1	0.2

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by "t" Test (LSD) mean comparison.

conditions, beanfly infestation and competition in intercropping, which reduced bean grain yield.

CHAPTER 6.: EFFECT OF WEEDING REGIMES ON THE INCIDENCE OF BEANFLY.

6.1. INTRODUCTION

Weed management has been shown to influence insect number on crops (Ofuya, 1989; Alghali, 1990c). It has been observed that weeds in grain legume fields positively correlated with insect damage (Anonymous, 1972; Kumar, 1984). The mixture of bean crops and weeds may be the subject of increased interest, due initially to their possible advantages in reducing insect pests through increasing the effects of natural enemies (Van Emden, 1965; Dempster and Coaker, 1974; Van Emden and Williams, 1974; Murdoch, 1975). Smith (1976) showed lower aphid colonization in Brassicae with weeds than in weed-free stands. This may possibly be due to reduced fecundity, less effective local dispersal, or greater mortality (Mumford *et al*.,1983). Nevertheless, the level of diversity which occurs in crop stands grown under different types of field vegetation could be important to the success of insect pests and their natural enemies (Mumford *et al*.,1983).

The effect of plant diversity on beanfly has not been studied enough to enable it to be introduced in an integrated management of beanfly. Hence, the objective of the study was to make an evaluation of the effect of weeding regimes (Plate 7) on beanfly and its natural enemies complex.

6.2. METHODS

The treatments consisted of eight weed management treatments : weed free (control); no weeding (control); weeding at 3 wae; weeding at 5 wae; weeding at 7 wae; weeding at 3 and 5 wae; weeding at 3 and 7 wae and weeding at 5 and 7 wae. During the long and short rains of 1992 the treatments were weeding at 3 wae, 5 wae, weed free and no weeding as controls. Each replicate comprised a plot of 10 bean rows planted at spacing of 45 cm between rows and 15 cm within rows. No insecticide or fertilizer applications were made. The weed population and diversity were estimated from two sampling cells (quadrats) of 1 m^2 each per plot by counting the weed species and weighing their dry matter.

Plate 7. Experimental plot on the effect of weeding regimes on the incidence of beanfly.

6.3. RESULTS AND DISCUSSION.

Effect of weeding regimes on beanfly infestation.

Different weeding regimes had no significant effect on beanfly infestation during all cropping seasons of 1991 and 1992 (Table 6.1). The beanfly infestation was higher during the long rainy seasons and lower during the short rainy seasons of 1991 and 1992. The two bean varieties GLP 2 and GLP 24 were both susceptible to beanfly infestation. Weed species present included *Syndrella nodiflora* (35.7%), *Digitaria ciliaris* (28.6%), *Cyperus rotundus* (9.2%), *Commelina benghalensis* (7.1%), *Bidens pilosa* (4.4%), *Eleusine indica* (3.8%), *Tagetes* spp. (3.7%), *Rottboelia cochinhinensis* (0.9%), *Trianthema portulacastrum* (0.7%), other broad leaves (5.5%) and other grasses (0.2%). Their dry matter was 84.4 g/m^2.

In the present study the weed plants were mostly represented by *Syndrella nodiflora* and *Digitaria ciliaris*. The effect of these weeds in enhancing parasitoids activity was not evident. Some entomophagous insects are attracted to particular plants by chemicals released even in absence of host or prey (Altieri *et al*.,1981). The weeds present in the trial may not have attracted natural enemies of the beanfly. Outbreaks of certain insect pests are considered more likely

Table 6.1: Effect of weeding regimes on beanfly infestation in two bean varieties (GLP 2 and GLP 24) at 4 w.a.e.

Weeding regimes	Mean no.beanfly larvae and pupae/20 plants			
	LR 1991	LR 1992	SR 1991	SR 1992
		Variety GLP 2		
3 w.a.e	25.0 a	9.3 a	0.3 a	5.6 a
5 w.a.e	29.6 a	15.3 a	1.0 a	4.0 a
No weeding	19.0 a	19.6 a	1.3 a	4.6 a
Weed free	22.0 a	18.3 a	0.3 a	5.6 a
		Variety GLP 24		
3 w.a.e	12.6 a	26.0 a	2.3 a	2.3 a
5 w.a.e	19.0 a	25.3 a	1.6 a	4.3 a
No weeding	16.0 a	23.6 a	1.0 a	4.6 a
Weed free	18.3 a	21.3 a	1.0 a	6.3 a

Statistical analysis:

GLP 2				
F value:	0.6^{NS}	4.5^{NS}	1.35^{NS}	0.5^{NS}
CV% :	23.5	9.2	91.2	19.1
SE :	0.4	0.1	0.2	0.2
GLP 24				
T value:	0.9^{NS}	0.2^{NS}	0.1^{NS}	2.3^{NS}
CV% :	13.1	8.1	89.6	18.4
SE :	0.2	0.1	0.4	0.1

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison. Analysis was carried out on log (x+1) transformed data. untransformed means are presented here. NS, not signifcant to occur in weed-free fields than in weedy ones (Van Emden, 1965; Dempster, 1969; Smith, 1976; Altieri et al.,1978). The effect of all weeding regimes had no effect on beanfly infestation. The bean canopy created a microenvironment not much different from weeds cover for beanfly development. It was suggested by McIntosh (1975) that the effect of weeds on beanfly of mungbeans was realized through camouflage. The weed cover did not prevent beanfly from locating and attacking bean plants. The empirical studies on the effects of plant diversity on arthropods (Andow, 1983a; 1986) reported that specialized crop pests tend to have lower population densities in diversified systems and polyphagous crop pests show no particular response. It was also reported that the presence of nonhost plants reduce population densities of a specialized herbivore and only rarely increase populations (Andow, 1983a, 1986; Risch et al.,1983). According to all these suggestions, beanfly being a specialized insect pest for leguminous crops should have significantly different population density in different weeding regimes. However the beanfly population was not affected by the different weeding regimes examined here.

Effect of weeding regimes on parasitoids.

The effect of weeding regimes on parasitoids was not significant in 1991 and 1992 (Fig.6.1, 6.2). The effectiveness of parasitoids on beanfly ranged between 11-29%. The study of the effect of different weeding regimes on parasitoids did not suggest any particular time of weeding that could increase natural regulation of the beanfly population. The parasitoids emerging depended only on the number of beanfly pupae parasitised. However, Root (1973) had suggested that weeds could enhance natural enemies by providing alternate hosts or prey and by providing pollen and nectar food resources. Similarly, the enemies hypothesis states that crop diversification results in lowered pest numbers because of increased natural enemy activity (Sheehan, 1986). Experimental design is a crucial factor in demonstrating the effect of weeds on predator populations. When field plots were close in the experiment, predators moved freely between habitats. As a result it was difficult to identify differences between treatments in the composition of predator communities. The increased distances between plots also minimized migration, resulting in greater population densities and a diversity of insect predators in the weeded regimes than in the weed-free plots.

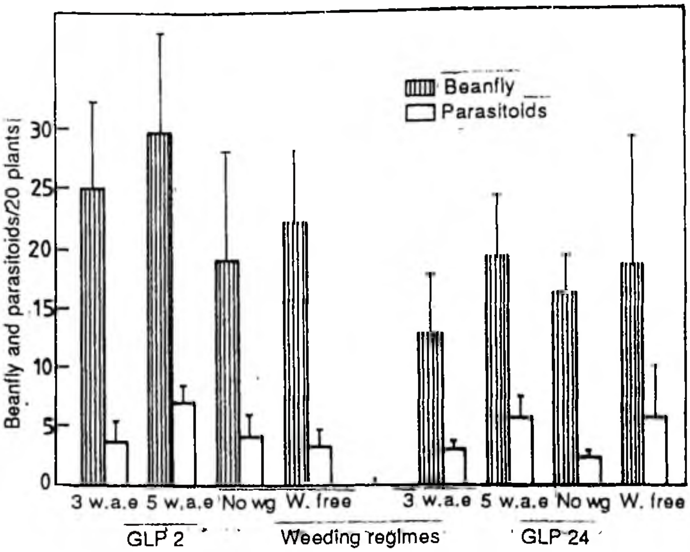

Fig. 6.1 Effect of parasitoids in regulation of beanfly at 4 w.a.e during long rains of 1991

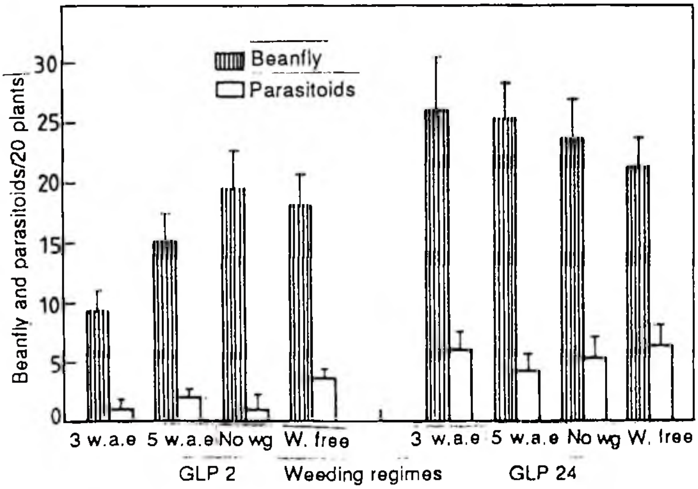

Fig. 6.2 Effect of parasitoids in regulation of beanfly at 4 w.a.e during long rains of 1992

Effect of weeding regimes on light distribution under bean canopy.

Light distribution under bean canopy was not significantly different between different weeding regimes, except during the long rains of 1992 in variety GLP 24, where light intensity was significantly low ($P<0.01$) in the unweeded plots due to the high growth of weeds (Table 6.2). Light distribution which affects relative humidity and temperature in different weeding regimes was equal in all treatments and this affected beanfly occurrence equally. Consequently the beanfly infestation was not different in the various weeding regimes. It appeared that the different weeding regimes did not create a significantly different microenvironmental conditions to affect beanfly development.

Effect of weeding regimes on grain yield.

Grain yield was significantly affected ($P<0.01$) in different weeding regimes, with exception of the long and short rains of 1991 where there were no significant differences. Yield loss was greater in unweeded plots (Table 6.3). Therefore the low yield observed in unweeded plots resulted from competition between the bean plants and weeds

Table 6.2: Effect of weeding regimes on the light distribution under bean canopy in two bean varieties (GLP 2 and GLP 24).

Weeding regime	Light intensity			
	LR 1991	LR 1992	SR 1991	SR 1992
		Variety GLP 2		
3 w.a.e	0.43 a	0.60b a	0.48 a	0.84 a
5 w.a.e	0.28 a	0.67 a	0.40 a	0.82 a
No weeding	0.26 a	0.25 a	0.45 a	0.65 a
Weed free	0.37 a	0.69 a	0.61 a	0.83 a
		Variety GLP 24		
3 w.a.e	0.39 a	0.89a	0.52 a	0.66 a
5 w.a.e	0.37 a	0.72ab	0.37 a	0.74 a
No weeding	0.28 a	0.36c	0.49 a	0.83 a
Weed free	0.31 a	0.48 bc	0.39 a	0.83 a

Statistical analysis:

GLP 2				
F value:	1.4^{NS}	4.4^{NS}	2.6^{NS}	0.6^{NS}
CV% :	34.6	29.9	19.5	23.3
SE :	0.06	0.1	0.05	0.1
GLP 24				
F value:	0.8^{NS}	20.5***	1.0^{NS}	3.4^{NS}
CV% :	27.2	14.6	29.4	9.9
SE :	0.05	0.05	0.07	0.04

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison. *** significant ,P<0.001.

NS, not significant.

Table 6.3: Effect of weeding regimes on grain yield.

Weeding regimes	Grain yield (kg/ha)			
	LR 1991	LR 1992	SR 1991	SR 1992
		Variety GLP 2		
3 w.a.e	3100 a	1565 ab	1346 a	1687 ab
5 w.a.e	2696 a	1573 ab	1061 a	1464 ab
No weeding	1883 a	670 b	584 a	1023 b
Weed free	2130 a	2157 a	775 a	2050 a
		Variety GLP 24		
3 w.a.e	2625 a	1303 ab	1223 a	1292 ab
5 w.a.e	1549 a	2290 a	591 a	1670 a
No weeding	1372 a	393 b	657 a	423 b
Weed free	2164 a	2108 a	1187a	1052 ab

Statistical analysis:

GLP 2				
F value:	0.2^{NS}	5.0*	4.0^{NS}	5.0**
CV% :	27.1	31.8	30.5	21.2
SE :	384.7	274.6	166.2	191.1
GLP 24				
F value:	4.3^{NS}	16.5***	4.0^{NS}	8.5**
CV% :	24.8	24.2	31.7	27.9
SE :	276.1	212.8	167.5	179.2

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison. * significant, $P<0.05$; ** significant, $P<0.01$; *** significant, $P<0.001$; NS, not significant.

since no significant beanfly infestation was observed. The effect of competition for sunlight, moisture and mineral nutrients need to be integrated and evaluated with the effects of weeds on the arthropod community. Andow (1983b) designed an experiment to separate the effects of decreased pest attack and increased plant competition that occur simultaneously in weed-diversified systems. Despite a great decrease in herbivore intensity, there was no detectable yield response. Apparently the reduction in yield from the intense weed competition was so large that any positive effect of reduced herbivore was swamped out. Therefore, three-way interactions among beans, weeds and bean herbivores are important when bean-weed competition is not intense. The greatest pest control benefit from weeds would be the situation where weeds do not compete strongly with the crop (Andow, 1983a). In this system, reduced pest control costs and enhanced yields are the only possible benefits. In general, if arthropod damage and weeds do not compete strongly with a crop, then weeds would enhance crop yield (Altieri et al., 1978; Andow, 1983a) and then this cropping system would be applicable. Kareiva (1983) emphasized the necessity of isolating crop-weed diversity as an independent variable. In most cases weed diversity could only have reduced herbivore abundance because it reduced the size or quality of the crop plants. Therefore weed density, diversity, plot or patch size, are all interacting factors that may influence crop quality and herbivore densities. To obtain the effects of crop-weed density on insect populations, it is necessary to consider the following points:

-The effects on the growth, development and nutritional status of the crop plants and weeds,

-The effects on the microclimate and microhabitats available for the life processes of herbivores and their natural enemies,

-The effects of potentially different levels of herbivores in the population dynamics of predators and parasites.

The weeds in the trial reduced the growth of the bean plants and increased the bean-weed competition. The microclimate within weeding regimes had no effect on beanfly population and its parasitoids.

CHAPTER 7: EFFECT OF PLANT DENSITY ON THE INCIDENCE OF BEANFLY.

7.1. INTRODUCTION

Plant density is one of the cultural practices that may affect the rate of development and population of insects as well as their behaviour in searching for food and oviposition sites (Ukwungwu, 1987). Close spacing may increase the effectiveness of natural enemies and result in more efficient control of pest populations (Ahmed and Rao, 1965). On the other hand, the micro-environment created by close spacing may favour some pest species (Israel and Rao, 1962; Wijeratne *et al*.,1981; Alghali, 1984b). Other studies have confirmed the assumption that pest populations decrease as plant density increases (Negasi and Abate, 1986). It has also been demonstrated that pests become more abundant in optimum plant density than in higher plant densities (Kyamanywa and Tukahirwa, 1988).

Although this information is useful in the development of beanfly IPM, it is lacking for beanfly on beans. The present study was therefore undertaken to examine the effect of plant spacing (Plate 8) on the incidence of beanfly. It was expected that different plant spacings will indicate the best

Plate 8. Experimental plot on the effect of plant density on the incidence of beanfly.

spacing for the reduction of beanfly infestation and increase in grain yield.

7.2. METHODS

Treatments consisted of three plant spacings, which for the long and short rains 1991 were: 30 cm x 15 cm, 45 cm x 15 cm and 60 cm x 15 cm giving plant populations of about 222,222; 166,666 and 111,111 plants respectively per ha. The normal spacing used by farmers is 45 x 15 cm. The different plant populations used in 1991 may have influenced in different ways the beanfly infestation. Therefore in the subsequent experiments it became necessary to modify the plant arrangements so that the same plant population could be obtained. During the long and short rains of 1992 therefore, the treatments were 30 cm x 30 cm, 45 cm x 20 cm and 60 x 15 cm giving a constant density of 111,111 plants/ha. Planting dates were March 4 , August 14 of 1991 and March 31, August 21 of 1992. In order to study the relation between plant moisture and beanfly infestation, the plant samples dissected for beanfly infestation were kept in paper bags and were first dried in the sun for 2 weeks and then oven-dried at 80℃ for a further 48 hours. Moisture content of bean plants was calculated as described before. The light intensity under canopy was recorded at 6 wae with a point Sensor (Li-185, Licor, USA) at four different places in each plot to study the effect of light intensity on beanfly infestation.

7.3. RESULTS AND DISCUSSION.

Effect of plant spacing on beanfly infestation.

Beanfly infestation was significantly different in the different plant densities ($P<0.001$) (Table 7.1). The infestation per unit area was higher at low plant density during the 1991 experiments. During all the cropping seasons of 1992 the inter-rows 30 cm, 45 cm, 60 cm were maintained but intra-rows were modified respectively to 30 cm, 20 cm and 15 cm to allow for constant plant density. In general the close spacings 30 x 30 cm had higher beanfly density in both bean varieties than the other spacings, and differences were significant (Table 7.2). In general, beanfly infestation was higher during the long rains of both years (1991 and 1992) than in the short rains.

The number of plants/m^2 in wider spacings (60 x 15 cm) was only 11 while in closer spacings (30 x 15 cm) the number of plants was 22. Insect population dispersal being the same per area (m^2) (Talekar, 1987), the fewer plants in wider spacings were more infested. Careful consideration of the units to be used in expressing population numbers is crucial

Table 7.1: Effect of plant spacings on beanfly infestation at 4 w.a.e. during the long and short rainy seasons of 1991.

Spacing	Mean no. beanfly larvae and pupae			
	LR 1991		SR 1991	
	m^2	10 plants	m^2	10 plants
	Variety GLP 2			
30 x 15 cm	12.2 a	5.0	0.6 a	0.3
45 x 15 cm	6.3 b	4.0	0.0 b	0.0
60 x 15 cm	11.4 a	10.0	0.9 a	1.0
	Variety GLP 24			
30 x 15 cm	7.0 b	3.0	1.7 a	0.7
45 x 15 cm	11.5 a	7.0	0.9 b	0.6
60 x 15 cm	11.1 a	10.0	1.3 ab	1.0

Statistical analysis:

GLP 2

	LR 1991	SR 1991
F value :	12.8***	9.1***
CV% :	14.1	74.4
SE :	0.1	0.1

GLP 24

	LR 1991	SR 1991
F value:	37.3***	4.5**
CV% :	8.5	27.9
SE :	0.1	0.1

Means in the same variety followed with the same letter in a column are not significantly different at 5% level ($P<0.05$) by Tukey (HSD) mean comparison. Analysis was carried out on log (x+1) transformed data. Untransformed means are present here. ** significant, $P<0.01$; *** significant, $P<0.001$.

Table 7.2: Effect of plant spacing on beanfly infestation at 4 w.a.e. during the long and short rainy seasons of 1992.

Spacing	Mean no. beanfly larvae and pupae			
	LR 1992		SR 1992	
	m^2	10 plants	m^2	10 plants
	Variety GLP 2			
30 x 30 cm	9.2 a	8.0	5.1 a	4.0
45 x 20 cm	5.5 b	5.0	3.8 ab	3.0
60 x 15 cm	5.8 ab	5.0	2.2 b	2.0
	Variety GLP 24			
30 x 30 cm	13.8 ab	12.0	4.6 a	4.0
45 x 20 cm	16.4 a	15.0	3.6 a	3.0
60 x 15 cm	10.7 b	9.0	2.9 a	2.0

Statistical analysis:

GLP 2

	LR 1992	SR 1992
F value :	4.8**	9.6***
CV% :	12.6	14.8
SE :	0.1	0.1

GLP 24

	LR 1992	SR 1992
F value :	3.7*	0.2^{NS}
CV% :	10.2	21.2
SE :	0.1	0.1

Means in the same variety followed with the same letter in a column are not significantly different at 5% level ($P<0.05$) by Tukey (HSD) mean comparison. Analysis was based on log (x+1) transformed data. Untransformed means are presented here. * significant, $P<0.05$; ** significant, $P<0.01$; *** significant, $P<0.001$; NS, not significant.

for meaningful interpretations of results and for determining general patterns among plant spacings. For example Mayse and Price (1978) found that numbers of certain arthropod species sampled in different soybean row spacing treatments were significantly different on a per plant basis, but those same population values converted to a square meter of soil area basis were not significantly different. That is why the experimental results were expressed on both plant and unit area basis. For instance in the long rains of 1991, the number of beanflies/m2 for 30 x 15 cm was 12.2 and was significantly different from 6.3 for 45 x 15 cm but when expressed on a per plant basis, the difference between them was not significant (Appendix 11). The beanfly infestation expressed per area rather than plant basis may be more meaningful because it readily differentiates the treatments of different plant populations. Sampling revealed higher beanfly infestation in wider than in closer plant inter-row spacings in 1991. However when the plant density was maintained constant in 1992, the beanfly infestation tended to increase in closer inter-row spacings. The reason could be the favourable microclimatic conditions for beanfly prevailing in closer spacings, especially light intensity, relative humidity under plant canopy and reduced temperature. The bean plants growing under such microclimatic conditions had more moisture content, making them softer and easier for beanfly penetration.

These findings are in agreement with Coaker (1987) who reported that insect numbers might be lower on dense plantings than on sparse ones. Mayse (1983) reported that many herbivores respond specifically to plant density; some proliferate in close plantings, whereas others reach high numbers in open canopy crops. Predator and parasite populations tend to be greater in high density plantings. The microclimate associated with canopy closure, which occurs earlier in dense plantings, may increase development rates of some predators and possibly facilitate prey capture. Alghali (1984b) reported that the stem borer (Diopsis thoracica) may cause more damage in rice when widely spaced than when closely spaced. Other studies have confirmed the assumption that pest populations decrease as plant density increases (Negasi and Abate, 1986). It has also been demonstrated that the pest becomes more abundant in optimum plant density than in higher plant densities (Kyamanywa and Tukahirwa, 1988). In the case of constant plant density, the beanfly infestation tended to be higher in closer spacings. Israel and Rao (1962), Alghali (1984b), Wijeratne and Fernando (1981) explained that the microenvironment created by close spacing may favour the development of some pest species.

Effect of plant spacings on dead plants.

A significantly (P<0.01) higher percentage of dead plants occurred in wide spacings during the long rains but the trend was reversed during the short rains of 1991 (Table 7.3). The percentage of dead plants for all cropping seasons of 1992 was generally low, as a result no significant differences among plant spacings were observed, except in the short rains for the variety GLP 2 (Table 7.4). A high percentage of dead plants found in wider spacings resulted from high beanfly infestation.

Evaluation of beanfly infestation by visual score.

Beanfly infestation determined by visual score (1-9) during the long and short rainy seasons of 1991 corresponded with actual beanfly population density obtained through destructive sampling. High infestation was observed in wide spacings of the varieties GLP 2 and GLP 24 during the long rains of 1991. During the short rains of 1991, infestation as given by visual score was highest in close plant spacings (Table 7.5). This evaluation was confirmed after plant dissection. The difference in infestation observed in the different plant spacings was highly significant (P<0.001). Beanfly affecting the inside of bean stems makes visual score

Table 7.3: Effect of beanfly infestation on the percentage of dead plant in different plant spacing at 4 w.a.e. during the long and short rainy seasons of 1991.

Plant spacing	Mean percentage of dead plants	
	LR 1991	SR 1991
	Variety GLP 2	
30 x 15 cm	10.0 b	15.3 a
45 x 15 cm	8.6 b	10.6 b
60 x 15 cm	15.6 a	9.3 b
	Variety GLP 24	
30 x 15 cm	6.3 b	19.3 a
45 x 15 cm	7.6 ab	12.0 b
60 x 15 cm	9.6 a	12.3 b

Statistical analysis:

	LR 1991	SR 1991
GLP 2		
F value :	59.1***	34.8***
CV% :	10.3	11.1
SE :	0.5	0.5
GLP 24		
F value :	7.2***	85.9***
CV% :	19.3	7.5
SE :	0.6	0.4

Means in the same variety followed with the same letter in a column are not significantly different at 5% level ($P<0.05$) by Tukey (HSD) mean comparison.

Table 7.4: Effect of beanfly infestation on the percentage of dead plants in different plant spacing at 4 w.a.e. during the long and the short rainy seasons of 1992

Plant spacing	Mean percentage of dead plants	
	LR 1992	SR 1992
	Variety GLP 2	
30 x 30 cm	3.3 a	3.5 a
45 x 20 cm	5.2 a	2.8 ab
60 x 15 cm	4.0 a	1.5 b
	Variety GLP 24	
30 x 30 cm	5.5 a	5.0 a
45 x 20 cm	7.0 a	5.7 a
60 x 15 cm	5.5 a	4.6 a

Statistical analysis:

GLP 2

F value :	1.4^{NS}	4.8^{**}
CV% :	49.8	44.0
SE :	0.001	0.004

GLP 24

F value :	2.2^{NS}	1.1^{NS}
CV% :	24.5	25.3
SE :	0.001	0.005

Means in the same variety followed by the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison. Analysis was based on arcsine (x/100) transformation. Untransformed means are present here.

Table 7.5: Evaluation of beanfly infestation by visual score (1-9) in different plant spacing at 4 w.a.e. during the long and short rainy seasons of 1991.

Plant spacing	Mean visual score (1-9)	
	LR 1991	SR 1991
	Variety GLP 2	
30 x 15 cm	3.3 b	4.0 a
45 x 15 cm	3.0 b	3.3 b
60 x 15 cm	5.0 a	3.3 b
	Variety GLP 24	
30 x 15 cm	2.6 b	4.6 a
45 x 15 cm	3.0 b	3.6 b
60 x 15 cm	3.6 a	4.0 b

Statistical analysis:

GLP 2

	LR 1991	SR 1991
F value :	48.5***	13.0***
CV% :	4.7	3.8
SE :	0.03	0.02

GLP 24

	LR 1991	SR 1991
F value :	19.5***	20.2***
CV% :	4.8	3.3
SE :	0.02	0.02

Means in the same variety followed with the same letter in a column are not significantly different at 5% level ($P<0.05$) by Tukey (HSD) mean comparison. Analysis was carried out on log (x+1) transformed data. Untransformed means are presented here.

alone an unreliable method of estimating infestation, though this method seems to be more practical because it does not require plant destruction. If a high precision on infestation is needed, visual score has to be supplemented by plant dissection. This concern has been expressed by Talekar (1987) who reported that there are no clearly visible external symptoms of pest attack in infested plants and that damage can be seen only when the stems are dissected. Nevertheless, in case of high infestation in infertile soils, the plant colour turns yellow and visual score may give an accurate infestation estimate. However, beans planted in fertile soil, even in case of high infestation, look healthy and visual score becomes less reliable.

Light intensity, relative humidity and temperature in different plant spacings and their effect on beanfly infestation.

Light intensity under bean plant canopy was slightly low in closer spacings of 30 x 15 cm and 30 x 30 cm than in wider spacings for both varieties GLP 2 and GLP 24 during the long rains of 1991 and short rains of 1992 (Tables 7.6, 7.7). The relative humidity under bean canopy tended to be higher in closer spacings (30 x 30 cm) by 3% than in wider spacings

Table 7.6: Effect of plant spacing on the light distribution under the plant canopy of two bean varieties (GLP 2 and GLP 24) at 4 w.a.e., during the long rainy season of 1991.

Plant spacing	Light intensity	
	GLP 2	GLP 24
30 x 15 cm	0.24±0.01 a	0.23±0.00 a
45 x 15 cm	0.27±0.01 a	0.25±0.03 a
60 x 15 cm	0.28±0.02 a	0.24±0.02 a

Statistical analysis:

F value :	4.9^{NS}	0.2^{NS}
CV% :	6.3	17.5
SE :	0.02	0.02

Means followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison.

Table 7.7: Effect of plant spacing on the light distribution under the plant canopy of two bean varieties (GLP 2 and GLP 24) at 4 w.a.e. during the short rains of 1992.

Plant spacing	Light intensity	
	GLP 2	GLP 24
30 x 30 cm	0.69±0.1 a	0.64±0.1 a
45 x 20 cm	0.78±0.1 a	0.87±0.0 a
60 x 15 cm	0.77±0.1 a	0.81±0.1 a

Statistical analysis:

F value	0.6^{NS}	2.1^{NS}
CV% :	14.6	18.6
SE :	0.06	0.1

Means followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison.

(60 x 15 cm). The difference in relative humidity between spacings was also not significant (Table 7.8). Temperature under bean canopy was 1.1℃ lower in closer (30 x 30 cm) than in wider plant spacings (60 x 15 cm) (Table 7.8). However, this difference was also not significant.

Closer spacing allowed relatively the least light intensity and temperature under bean canopy. It maintained higher relative humidity and kept evapo-transpiration low. Therefore the beanfly was favoured by such microenvironment. The plants growing in such microenvironment were more tender and were more easily tunnelled by the beanfly. That may explain the high infestation associated with close spacing with the same plant density.

Effect of plant spacings on parasitoids of the beanfly.

Beanfly parasitoids in all spacings varied between 4-19% during the long rains of 1991 (Fig.7.1) and between 3-29% during the long rains of 1992 (Fig.7.2). In general the mean effect of natural enemies on beanfly was 7.6% in closer spacings and 19% in wider spacings for both bean varieties GLP 2 and GLP 24. The number of parasitoids in different plant spacings was not significant. The effect of beanfly parasitoids was extremely low during the short rainy seasons

Table 7.8: Effect of plant spacing on relative humidity and temperature under bean canopy of the variety GLP 2 at 4 w.a.e. during the long rainy season of 1992.

Plant spacing	RH(%)	T ℃
30 x 30 cm	20.0	31.0
45 x 20 cm	19.0	32.6
60 x 15 cm	17.0	32.1

Statistical analysis:

F value :	0.6^{NS}	0.7^{NS}
CV% :	26.2	7.0
SE :	3.0	1.2
LSD 5% :	6.3	3.0

Means followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison.

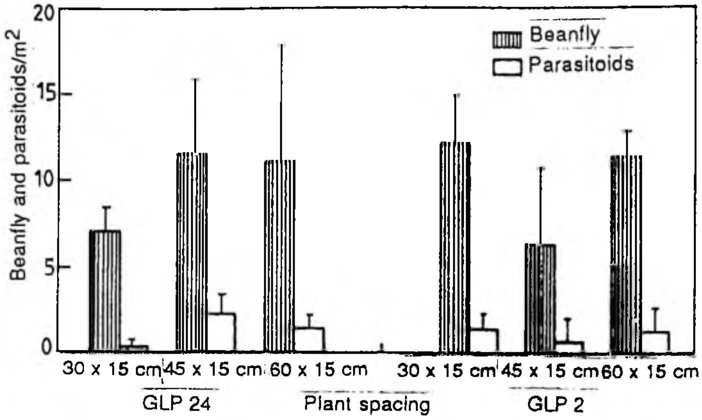

Fig. 7.1 Effect of parasitoids in regulation of beanfly at 4 w.a.e during long rains of 1991

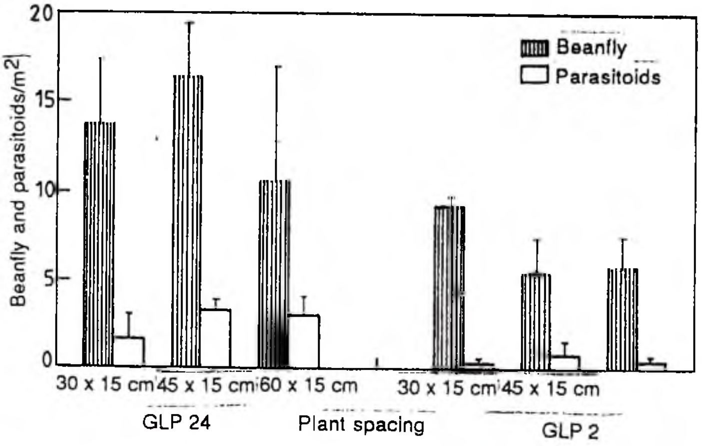

Fig. 7.2 Effect of parasitoids in regulation of beanfly at 4 w.a.e during long rains of 1992

of 1991 and 1992. Beanfly parasitoids were not directly influenced by plant spacing. But indirectly the natural enemies were more in wide spacings because beanfly infestation was also higher. Thus, natural control effect was around 7% in close spacings and 19% in wide spacings. On the contrary, Ahmed and Rao (1965) reported that close spacing may increase the effectiveness of natural enemies and result in more efficient control of pest populations.

Effect of plant spacings on grain yield.

Grain yield was higher in closer than in wider spacings for the bean variety GLP 2 during all cropping seasons of 1991 and 1992. However for the variety GLP 24 higher yield was obtained in wider spacings in the long rains. The difference in grain yield was not significant at the different plant densities (1991) but significant in the inter-row spacings (1992) (Table 7.9, 7.10).

The close spacings increased grain yield in GLP 2 for all cropping seasons. The number of plants at harvest determined grain yield. But in variety GLP 24 the grain yield increased in wide spacing. Because of its indeterminate habit, GLP 24 produced many branches and responded well to wide spacing. The close spacing provided optimum density for yield in

Table 7.9: Effect of plant spacing on grain yield during the long and short rains of 1991.

Plant spacing	Grain yield kg/ha	
	LR 1991	SR 1991
	Variety GLP 2	
30 x 15 cm	2192 a	1201 a
45 x 15 cm	2304 a	1173 a
60 x 15 cm	1755 a	747 a
	Variety GLP 24	
30 x 15 cm	1954 a	1344 a
45 x 15 cm	1599 a	1327 a
60 x 15 cm	2853 a	1310 a

Statistical analysis:

GLP 2

F value :	0.3^{NS}	2.8^{NS}
CV% :	41.0	25.2
SE :	494	151

GLP 24

F value :	3.4^{NS}	52.2^{NS}
CV% :	28.2	14.5
SE :	348.4	82.4

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison.

Table 7.10: Effect of plant spacing on grain yield during the long and short rains of 1992.

Plant spacing	Grain yield kg/ha	
	LR 1992	SR 1992
	Variety GLP 2	
30 x 30 cm	1879 a	1374 ab
45 x 20 cm	1205 b	645 b
60 x 15 cm	901 b	1539 a
	Variety GLP 24	
30 x 30 cm	1062 a	885 a
45 x 20 cm	890 a	323 b
60 x 15 cm	1637 a	337 b

Statistical analysis:

GLP 2

F value :	14.0^{**}	7.8**
CV% :	17.4	24.8
SE :	133.5	170

GLP 24

F value :	3.4^{NS}	28.2***
CV% :	30.5	20.3
SE :	210.5	60.3

Means in the same variety followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison.

variety GLP 2 and for low beanfly infestation. The important effect on grain yield was determined by the plant requirement for space for its development and food resources.

The primary objective in spacing crop plants is to maximize yield per unit area. It is reported that spacing undoubtedly affects the yield of cowpea and it can lead to a significant reduction in yield (Ezedinma, 1974). Similarly a high plant population due to close spacing may depress yield (Remison, 1980) or have no yield advantage (Kayode and Odulaja, 1985). Consequently the effect of plant spacing on yield must be considered before its effect on beanfly infestation is determined.

CHAPTER 8: INFLUENCE OF PLANTING TIME ON BEANFLY POPULATION LEVEL, DAMAGE AND GRAIN YIELD.

8.1. INTRODUCTION

Time of planting can allow susceptible stages of crops to avoid insect infestation (Baxendale and Teetes, 1983; Alghali, 1984a, 1990a, 1990b). Early planting has been found beneficial in reducing beanfly infestation (Subasinghe *et al*.,1983; Nderitu *et al*.,1990a). Under some conditions *O.phaseoli* population tends to increase during the dry period after the rains (Morgan, 1938; Swaine, 1968; Lee, 1976; Kwon *et al*.,1980). Thus the study of pest populations can enable the adjustment of bean planting date to minimize damage by *O. phaseoli* (Subasinghe *et al*.,1983). However, planting dates are determined by the cropping system and rainfall pattern and not by insect pest infestation (Talekar, 1987). Van der Goot (1930) reported that a 3-week delay in planting after the beginning of the dry season in Indonesia increased plant mortality considerably. There is no doubt that early planting would result in the highest yield (Farias and Winch, 1987). Bean crop planted late in the season tends to be severely damaged due to high beanfly population levels which build up in the course of the season (Nderitu *et al*.,1990b). Thus, planting date influences growth rate of beanfly populations in beans. However, planting dates are site specific. To enable generalizations to be made, experiments have to be carried out in defined areas. Therefore, an investigation was designed to study the effect of five different planting dates (Plate 9) on beanfly occurrence with the aim of identifying the optimal time of planting for the reduction of beanfly infestation. The impact of climatic factors on beanfly infestation such as temperature, rainfall, relative humidity and light intensity was also investigated in order to determine unfavourable ambient conditions that can minimise beanfly attack of beans.

8.2. METHODS

The experiment consisted of five successive planting dates (Table 8.1). Plant spacings were 45 cm between rows and 15 cm within rows. During the long rains of 1992 at each planting time, an additional batch of control seeds treated with carbofuran 5% G was included. Light intensity under canopy was determined with a point sensor (Li-185 B, Licor, USA) in four places in a plot. Relative light intensity (light transmission ratio) was calculated against a reference light above the canopy for each plot. During the experiment, meteorological data including rainfall, relative humidity and temperature were recorded.

Plate 9. Experimental plot on the effect of planting time on beanfly population level, damage and grain yield.

Table 8.1: Planting dates during the long and short rainy seasons of 1991 and 1992 at Oyugis.

Seasons	1st planting (1st rains)	2nd planting (2 weeks)	3rd planting (4 weeks)	4th planting (6 weeks)	5th planting (8 weeks)
1. Long rains 1991 (Feb/March-June/July)	4 March 1991	18 March 1991	1 April 1991	14 April 1991	27 April 1991
2. Short rains 1991 (Aug/Sept-Dec/Jan)	14 Aug. 1991	27 Aug. 1991	9 Sept. 1991	22 Sept. 1991	5 October 1991
3. Long rains 1992 (Feb/March-June/July)	1 April 1992	14 April 1992	28 April 1992	12 May 1992	26 May 1992
4. Short rains 1992 (Aug/Sept-Dec/Jan)	22 Aug. 1992	5 Sept. 1992	19 Sept. 1992	-	-

8.3. RESULTS AND DISCUSSION.

Effect of planting time on beanfly infestation.

Beanfly infestation significantly increased ($P<0.001$) in late planted beans during all the cropping seasons of 1991 and 1992 (Fig.8.1, 8.2, 8.3, 8.4). It was lowest when planting followed the first rains. But infestation increased progressively with subsequent plantings at 2, 4, 6, 8 weeks. In three separate field plots (400 m apart) successively planted with the first rains, and at second week and fourth week, the early planting was significantly less infested ($P<0.001$)(Fig.8.4). This observation agreed with Nderitu *et al*.(1990) who reported that bean crop planted late in the season tends to be severely damaged due to high beanfly population level build-up in the course of the season.

Initial beanfly infestation probably started with beanflies from wild host plants or those that remained on bean plants in the fields. In such a period the beanfly population invading the bean plants is at its lowest level. Planting at the 2nd week and later resulted in more infestation. After about 3 weeks following the first infestation from early planting, the first beanfly generation would have been completed. Thereafter the overlapping generations would result in further infestations in the field. Therefore all

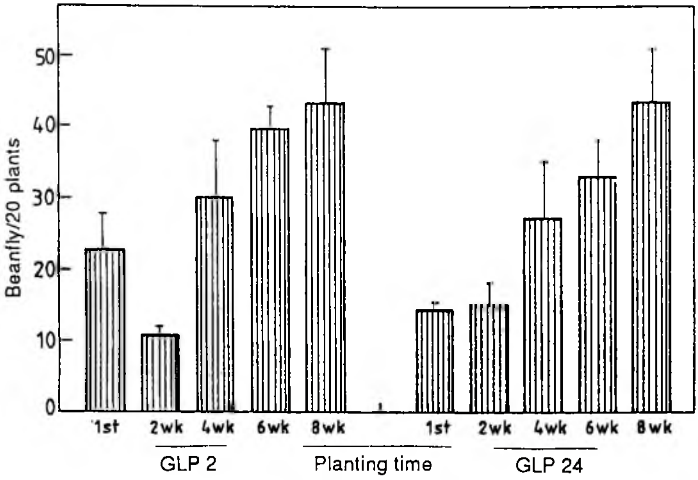

Fig. 8.1 Effect of planting time on beanfly infestation of bean varieties GLP 2 and GLP 24 during long rains of 1991

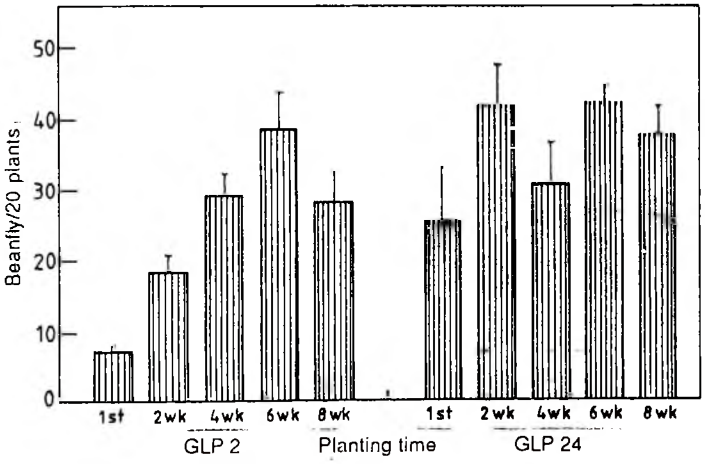

Fig. 8.2 Effect of planting time on beanfly infestation of bean varieties GLP 2 and GLP 24 during long rains of 1992

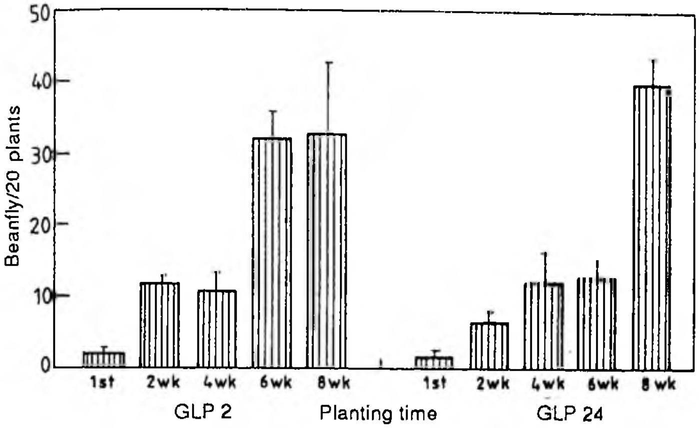

Fig. 8.3 Effect of planting time on beanfly infestation of bean varieties GLP 2 and GLP 24 during short rains of 1991

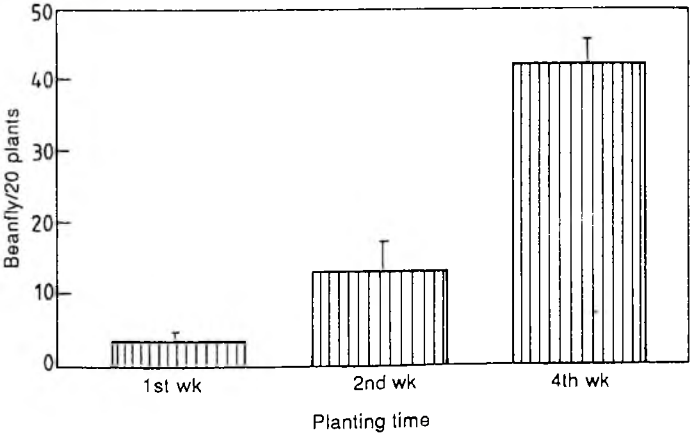

Fig. 8.4 Effect of planting time on beanfly infestation of bean varieties GLP 2 and GLP 24 during short rains of 1992

late plantings were subjected to high infestation by the newly emerged beanflies.

A high infestation was also found in three separate fields successively planted. The first field planted at the onset of the first rains was less infested. The second field planted at 2 weeks and the third field planted at 4 weeks later were increasingly infested. Despite the isolation of the fields, the last planted was most affected. The late planted beans were in the seedling stage and therefore susceptible to the beanfly attack. By that time the earlier planted beans were already lignified and attracted less beanflies. This may suggest that the beanfly migrates from long distances of at least 400 m and beyond to infest bean plants. Also since the isolated bean plants were most infested in the late planting, this would indicate that the source of infestation from wild plant host and the emigration of beanfly from field plots increased in the course of the season.

Effect of planting time on the percentage of dead plants.

The percentage of dead plants caused by beanfly was significantly higher ($P<0.01$) among those planted with a delay of 6 and 8 weeks (Table 8.2). A high percentage of dead plants observed in late-planted plots was due mainly to

Table 8.2: Effect of planting time on percentage of dead plants during the long and short rainy seasons of 1991 and 1992.

Planting time	variety	Percentage of dead plants		
		LR 1991	LR 1992	SR 1991
1st.rains	GLP 2	13.6 d	2.0 bcd	11.0 b
2 weeks	GLP 2	5.6 def	2.2 bcd	12.3 b
4 weeks	GLP 2	8.0 de	4.0 bcd	10.6 b
6 weeks	GLP 2	37.6 c	6.1 bc	10.6 b
8 weeks	GLP 2	68.0 a	5.0 bc	46.3 a
1st.rains	GLP 24	13.0 d	5.0 bc	14.3 b
2 weeks	GLP 24	4.6 def	13.0 b	17.6 b
4 weeks	GLP 24	6.5 de	19.1 b	9.3 b
6 weeks	GLP 24	23.3 d	31.4 a	10.6 b
8 weeks	GLP 24	54.0 b	11.0 b	38.0 a

Statistical analysis:

	LR 1991	LR 1992	SR 1991
F value:	29.2***	4.2**	24.5***
CV% :	70.0	70.2	64.8
SE :	8.8	4.0	7.3
LSD 5% :	12.2	11.8	10.2

Means followed with the same letter in a column are not significantly different at 5% level (P<0.05) by Tukey (HSD) mean comparison.

beanfly infestation. Drought was not a factor in the recorded plant mortality (Fig.8.5). The late planted crop had as much rainfall as the first planting. The total rainfall from planting to 4 weeks after plant emergence was well distributed for all successive planting times. For instance, in plantings with 1st rains, 2 weeks, 4 weeks, 6 weeks and 8 weeks the total rainfall from planting to the last sampling was respectively 306.1 mm, 445.9 mm, 499.8mm, 447 mm and 419.6 mm.

Effect of planting time on parasitoids.

The effect of parasitoids in successive plantings was not significant ($P>0.05$) (Fig. 8.6, 8.7). In sequential plantings with first rains, 2nd week, 4th week, 6th week and 8th week during the long rains of 1991 and 1992, the parasitoid regulation of beanfly obtained was between 14-19%. The occurrence of beanfly parasitoids had no preference in relation to the different planting times.

Effect of planting time on grain yield.

Grain yield was significantly different among planting times ($P<0.001$) (Fig.8.8). Early planting gave the highest yield. During the long rains of 1991 and 1992 the last planting at 8 weeks after the first rains provided only 5% in

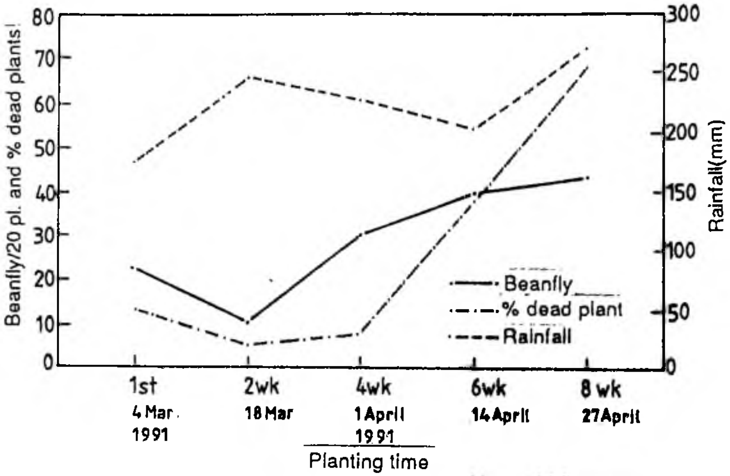

Fig. 8.5 Effect of beanfly infestation on bean plants mortality with interaction of rainfall at 4 w.a.e during LR of 1991

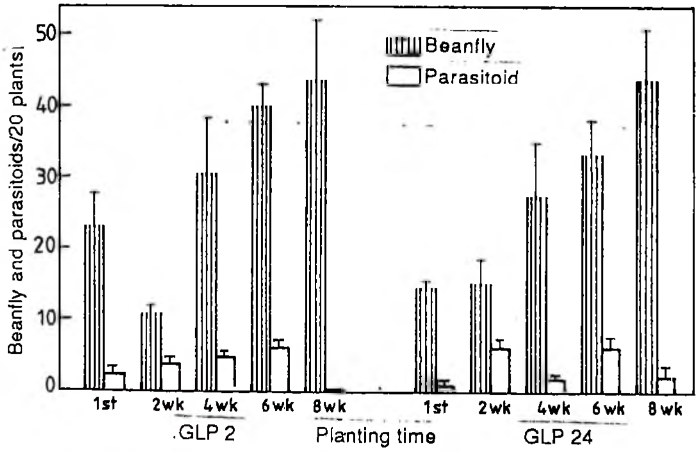

Fig. 8.6 Effect of parasitoids in regulation of beanfly in different planting times during long rainy season of 1991

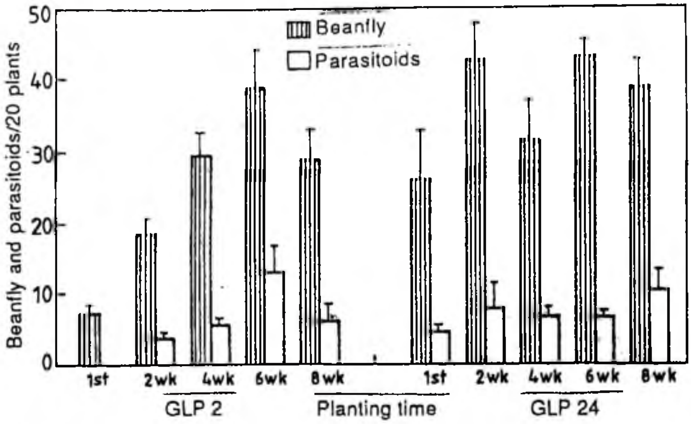

Fig. 8.7 Effect of parasitoids in regulation of beanfly in different planting times at 4 w.a.e. during long rains of 1992

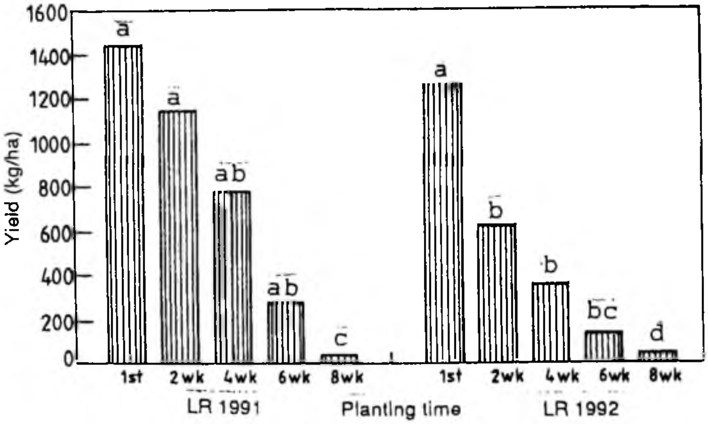

Fig. 8.8 Effect of planting time on grain yield of the variety GLP 2

1991 and 7% in 1992 of the yield (GLP 2 and GLP 24 combined) of first planted plots. During the short rains the last plantings at 8th week did not provide any grain yield. The correlation coefficient between beanfly and yield was -0.38. In late plantings the effect of beanfly on grain yield was more pronounced. Also quite a high number of the plants died and contributed in grain yield reduction.

CHAPTER 9: GENERAL DISCUSSION AND CONCLUSIONS.

The agromyzid beanfly (Ophiomyia spp.) is one of the most important key insect pests attacking beans in the field. The most common method for controlling beanfly is the use of insecticides. Therefore, other possible methods of control needed to be investigated. One such method is the use of cultural practices.

Studies reported here have examined a wide range of cultural practices as management strategy of beanfly infestation. These included the effects of soil fertility, plant diversity, plant spacing and date of planting, at Oyugis Division, Homa Bay District, Western Kenya, during four cropping seasons of 1991 and 1992.

Two species of beanfly were identified in Oyugis, Ophiomyia phaseoli Tryon and O. spencerella Greathead. O. spencerella was predominant in the site probably because it lays most of its eggs in the hypocotyl where larvae were more protected from parasitoid attacks than were larvae of O. phaseoli whose eggs are laid on the surface of young leaves. Parasitisation of O. spencerella was also less than that in Ophiomyia phaseoli. The life cycle of the main parasitoid Opius phaseoli, was found to be well synchronised with that of its host, Ophiomyia phaseoli.

A major constraint to low bean yield in the Great Lakes Region of Africa is declining soil fertility (Trutman, 1987).

The situation is worsening because there is little or no use of organic or inorganic fertilizer. It has been shown that proper use of fertilizers can help maintain or improve growth of beans under poor soil fertility conditions. In this way plants suffer less damage from beanfly attack. Nitrogen, a key element in plant nutrition was the most deficient in soils of the study site in Oyugis. Nitrogen fixation probably was ineffective due to the absence of adequate amounts of phosphorus (CIAT, 1976). As a legume crop, beans are capable of symbiotic nitrogen fixation with appropriate Rhizobium strain. However nitrogen fixation was not realized fully because Rhizobium spp. were sensitive to low phosphorus levels.

A study of the effect of nitrogen on the occurrence of beanfly showed an infestation ranging between 12-66% with increasing levels of nitrogen. The bean plants treated with fertilizers were more heavily infested. Such plants had more nutrient and moisture content. They became softer and allowed easy penetration to beanfly larvae. They also had enough nutrients and beanfly developing in such plants were expected to have good fecundity and high progeny. It was observed that the combination of nitrogen and phosphorus application improved nitrogen assimilation and allowed for a high beanfly infestation. Also phosphorus applied alone combined with available nitrogen in the soil slightly increased beanfly infestation. The response of beanfly to manure treated plants was delayed. The mineralisation of manure was slow and had no effect on bean plants until 6 to 8 weeks after plant emergence. The unfertilized bean plants had less nutrient and did not provide the beanfly adequate food requirement for growth and development. The unfertilized plants were also more lignified and difficult for beanfly penetration (Tisdale and Nelson, 1975). However such plants suffered from beanfly attack and either died or remained/appeared weak and produced little grain yield with a yield reduction of 48%. Although the plants treated with fertilizers were more infested by beanfly, they compensated for the beanfly attack and gave high grain yield.

Beanfly was regulated by six hymenopteran species of parasitoids (_Opius phaseoli_, _Psilus_ sp., _Pediobius_ sp., _Eupelmus_ sp., _Herbertia_ sp. and _Sphegigaster_ sp.). The most frequent was _Opius phaseoli_. The effect of beanfly regulation by parasitoids varied between 20-26% (due to fertility), 17-28% (due to intercropping), 11-29% (due to weeding), 7.6-19% (due to spacing)and 14-19% (due to planting time). Thus the average beanfly regulation by parasitoids was 14-24%. Beanfly regulation by parasitoids was similar in all experiments. The parasitoids emerged from the pupae and each pupa produced only one parasitoid. The parasitoids attack beanflies during the larval stages but apparently do not kill them before they become pupae. Talekar (1987) reported that the mode of parasite infestation of larvae is uncertain, since the larval stage is completed inside the plant. May be the parasitoids lay eggs in the larvae through the thin epidermis but it is possible that the parasitoids may lay eggs in the prepupae or pupae by piercing through the thin membrane. Although beanfly parasitism is extensive, sufficient flies survive to cause substantial damage.

Efficacy of endosulfan and carbofuran on beanfly was evaluated. Both products were effective. However, in unfertilised soil, even if beanfly infestation was suppressed, the grain yield was not much improved due to a reduction in plant stands caused by phytotoxicity. The use of insecticides in fertile soil did not contribute to grain yield increase. The reason for this is probably that the fertilised bean plant recovered from beanfly attack and therefore did not need insecticides.

A good beanfly management strategy should emphasize on improving soil fertility but rely less on chemical insecticides.

A study of the effect of plant diversity on beanfly infestation was carried out as an intercropping experiment in which bean was intercroped with maize. Weeding regimes were also studied in another experiment. It has been demonstrated by Litsinger (1975), Tahvanainen and Root (1972) that climatic diversity in diversified plant communities tends to reduce the probabilities of phytophagous pest population explosion. In intercropping systems an optimum synchrony between pests and their natural enemies are likely to be important in efficient pest regulation. The effect of increasing diversity in cropping systems on pest populations has often been considered in terms of stabilizing parasite and predator populations and/or increasing their activity. However in the trial described here, beanfly infestation was more variable when bean was intercropped with maize than in pure stands of bean. In simultaneous planting of bean and maize, the young plants of maize had no effect on beanfly infestation starting within a week after bean emergence. Furthermore bean intercropped with six weeks-old maize were more infested. The infestation was favoured by the microclimatic conditions created by the already developed maize. The microclimatic conditions prevailing in the intercrop may explain the preference of beanfly for bean in the bean and maize intercrop compared to pure bean stands.

Light penetration in the bean canopy was less in bean intercropped with maize than in the monocrop. Thus beanfly avoided exposure to direct light prevailing in the monocrop. These results agree with that of Santokh (1982) that beanfly prefers shady than sunny areas for its biological activities. Similarly, the temperature in the intercrop, ranging from 27-30℃ was within the optimal requirement (15-30℃) of the beanfly. In the monocrop temperature was higher, averaging 31-32℃. Furthermore, there was more soil moisture in the intercropping; this prevented dehydration of beanfly thus allowing optimal development. During the vegetative growth phase (March-May) in the long rains the rainfall was 582 mm compared to 395 mm in the short rains (August-October). Similarly, relative humidity was higher (daily mean 45.4%) in the long rains than in the short rains (daily mean 26%). Therefore, the long rainy season offered wetter conditions to beanfly comparable to those in intercropping. In the short rains, drier conditions prevailed. The beanfly regulation by parasitoids was not favoured by intercropping as expected but was only related to the high infestation which occurred in intercropping. Grain yield was reduced in intercropping due to competition between beans and maize for environmental resources.

The intercropping of bean and maize offers the farmer a yield of beans grown under maize and maximizes land use and provides food security. However it does not reduce beanfly infestation while it is efficient on other insect pests like bean thrips where population was reduced by 25% in intercrops. The mechanism of intercropping in reducing bean thrips may include the introduction of physical barriers by maize, confusing or diverting odours, visual disruption and dilution of host concentration, thus plant apparency may be reduced (Feeny, 1976).

In order to maximize bean production, bean-maize intercropping system should be designed to reduce beanfly infestation and bean-maize competition.

An assessment of weeding regimes on beanfly infestation was undertaken as an aspect of plant diversity. Weeds are generally not wanted in the field because of their direct competition with the crop plants for sunlight, water and mineral nutrients. However, a proper management of weeds can affect the biology and population dynamics of beneficial insect fauna and thereby reduce insect pest densities. Crop-weed interactions are site specific and vary according to the plant species involved, environmental factors and management practices. Weeds are components mediating a number of crop-insect interactions with major effects on final yields. However the effect of different weeding regimes on beanfly infestation was not noticeable. In the studies reported here weed species were mostly Syndrella nodiflora and Digitaria ciliaris. The presence of weeds in different weeding regimes had not created a microenvironmental condition significantly different from that of bean canopy which should affect beanfly population. The weeds present in the trial did not change the microenvironment, provide alternative food or have any attractant effect on natural enemies. Thus, the effect of natural enemies was not significantly different between weeding regimes. Weeding regimes strategy of beanfly control would be applicable in a case of reduced pest control costs and enhanced yields. Practically, the use of weeds should be realized by sowing them directly near crops, or as cover crop or planting trees and shrubs as border crops to stimulate movement of natural enemies into the crop (Altieri *et al*. 1977a).

Plant density which is one of the cultural practices may affect the rate of development and population of insects as well as their behavior in searching for food and oviposition sites (Ukwungwu, 1987). The trial on the effect of plant density on beanfly infestation showed infestation increase at lower plant densities due to the beanfly dispersal pattern. However when the plant density was constant, a high beanfly infestation was recorded in close inter-row spacings due to the microenvironmental conditions favourable for beanfly development. At different plant populations a high infestation was found in wide spacing. The number of plants per unit area (m^2) was only 11 in wide spacing against 22 in close spacing. The insect population dispersal being the same per area (m^2), the fewer plants in wide spacings were more infested. In constant plant density the beanfly infestation increased in closer spacings. Here the microclimatic conditions were favourable for beanfly development. The light intensity was lower, the relative humidity under plant canopy was higher and temperature was reduced. These findings agree with Alghali (1984 b) that the stem borer (*Diopsis thoracica*) may cause more damage in rice when widely spaced than when closely spaced. In constant plant density, the beanfly infestation tended to be higher in closer spacing. The reason could be the microclimatic change. The observation is supported by Israel and Rao (1962); Alghali (1984b); Wijeratne et al.(1981) that the microenvironment created by close spacing may favour the development of some pest species.

Grain yield was influenced rather by plant requirement for space for its development and food resources than by beanfly infestation. Therefore the effect of plant spacing on yield must be considered before its effect on beanfly infestation.

Time of planting can allow susceptible stages of crop to escape insect infestation. Therefore the use of such cultural practices as changing the planting date, would be a useful method of managing some insects (Mack and Backman, 1990). The study of population dynamics would enable the adjustment of bean planting date to minimize damage by beanfly (Subasinghe et al.1983).

The present study showed a low beanfly infestation in early planted plots with the first rains. The beanfly infestation increased highly in late planted beans. Initial beanfly infestation may start with a source of infestation from wild host plants or from old bean plants in the surrounding fields. The early planted beans are infested by a lowest initial population of beanfly. Thereafter the overlapping beanfly generations take place in the first planted fields. Therefore all late planted beans are subjected to the high infestation from the first planted fields. In order to avoid the infestation from early planted fields to the late ones, the successive plantings were done in separate field plots 400 m apart. The first planted was still less infested. This suggests that the source of infestation of the late planted beans did not come only from surrounding fields planted early, but may come also from quite long distances, at least 400 m apart or beyond searching for food. Grain yield was higher in early planting due to lower beanfly infestation. Early planting should be adopted to reduce beanfly occurrence and to increase grain yield.

The results of these studies on cultural practices as management tool of beanfly infestation suggest the necessity of soil analysis of bean planting area to identify the chemical soil elements available to allow a proper use of nitrogen and phosphorus fertilizers. Also a monocropping system, a plant density of 222.222 plants/ha (30 x 15 cm) and an early planting time were good cultural practices that can be combined to form a component of integrated beanfly management and increase bean production.

REFERENCES

Abate, T. (1991). The beanfly, Ophiomyia phaseoli (Tryon) (Dipt.: Agromyzidae), and its parasitoids in Ethiopia. J. Appl. Ent. 111: 278-285.

Abul-Nasr, A. and M.A.H. Assem. (1968). Studies on biological processes of the beanfly Melanagromyza phaseoli (Tryon). Bull. Soc. Ent. Egypt 52: 283-295.

Acland, J.D. (1985). East African Crops. A introduction to the production of field and plantation crop in Kenya, Tanzania and Uganda. Produced by Longman Group (FE) LTD pp.20-25.

Agarwal, R.A. (1969). Morphological characteristics of sugarcane and insect resistance. Ent. exp. Appl 12: 767-776.

Ahmad, S. (1983). Herbivorous Insects: Host-Seeking Behavior and Mechanisms. Academic Press, N.Y., 1983.

Ahmed, M.K. and R.S. Rao. (1965). The influence of cultural practices on the stem borer (Schoenobius incertulas Walker) attack in rice. Madras Agric. J., 52: 311-313.

Aiyer, A.K.Y.N. (1949). Mixed Cropping in India. Indian J. Agric. Sc. 19: 439-543.

Alghali, A.M. (1984a). Studies on the biology, damage and crop loss assessment of the sorghum midge, (Contarinia sorghicola Coq) (Diptera: Cecidomyiidae). Insect Sci. Applic. 5: 253-258.

Alghali, A.M. (1984b). Effect of plant spacing on the infestation levels of rice by the stalk-eyed borer, (Diopsis thoracica West) (Diptera: Diopsidae). Trop. Agric. (Trinidad), 61: 74-75.

Alghali, A.M. (1990a). Effects of some agrometeorological factors on the legume pod-borer, (Maruca testulalis Geyer) (Lepidoptera: Pyralidae) fluctuations on two cowpea varieties in Nigeria. J. African Zool. (in press).

Alghali, A.M. (1990b). Effect of some agrometeorological factors on flower thrips, (Megalurothrips sjostedti Trybom) (Thysanoptera: Thripidae) fluctuations in cowpeas. Malaysian J. Pl. Protect. Trop.(in press).

Alghali, A.M. (1990c). Weeding as a component of insect pest management for grain cowpea (Vigna unguiculata Walps) production in Nigeria. Trop. Agric. (Trinidad) (in press).

Ali, A.M. (1957). On the bionomics and control of the beanfly, (Agromyza phaseoli Coq). Bull. Soc. Ent. Egypt **41**: 551-554.

Allen, D.J. and J.B. Smithson. (1986). Proceedings of the Beanfly Workshop Arusha-Tanzania, Pan-African Workshop Series, 1: 8-9.

Altieri, M.A., A. van Schoonhoven and D.J. Doll. (1977a). The ecological role of weeds in insect pest management systems: A review illustrated by (Phaseolus vulgaris) cropping systems. Pans 23: 195-205.

Altieri, M.A., D.J.Doll and A. van Schoonhoven. (1977b). Interacciones entre insectos y malezas en mono y policultivos de maiz y frijol. Rev. Comalfi (Colombia) 4: 171-208.

Altieri, M.A., C.A. Francis, A. van Schoonhoven and D.J.Doll. (1978). A review of insect prevalence in maize (Zea mays L.) and (Phaseolus vulgaris polycultural systems. Field Crops Res. 1: 33-49.

Altieri, M.A., W.J. Lewis, D.A. Nordlund, R.C. Gueldner and J.W. Todd. (1981). Chemical interactions between plants and Trichogramma Wasps in Georgia soybean fields. Prot. Ecol. 3: 259-263.

Altieri, M.A. and D.K. Letourneau (1982). Vegetation management and biological control in agroecosystems. Crop. Proc., 1: 405.

Altieri, M.A. and D.K. Letourneau. (1984). Vegetation diversity and insect pest outbreaks. CRC Crit. Rev. Plant Sci., 2(2): 131.

Amoako-Atta, B. (1982). Intercropping. A case study on the stem/pod borer interactions with maize cowpea sorghum cropping paterns in Kenya. ICIPE. pp.123.

Amoako-Atta, B., E.O. Omolo and E.K. Kidega. (1983). Influence of maize, cowpea and sorghum intercropping systems on the pod borer infestations. Insect Sci. Applic. 4(1/2): 47-57.

Ampong-Nyarko, K., K.V. Sheshu Reddy, R.A. Nyangor and K.N. Saxena. (1992). Reduction of insect pest attacks on sorghum and cowpea by intercropping. Trop. Pest Manag. (in press).

Andow, D.A. (1983a). Effect of agricultural diversity of insect populations. In: Envir. Sound Agric., Lockeretz, W., Ed.,Praeger Publishers, N.Y., 1983, Chap.5.

Andow, D.A. (1983b). Plant diversity and insect populations: interactions among beans, weeds and insects. Ph.D. Thesis, Cornell Univ., Ithaca, N.Y.,1983.

Andow, D.A. (1986). Plant diversification and insect population control in agroecosystems. In: Some Aspects of Integrated Pest Management, Pimentel, D.,Ed.,Dpt of Entom., Cornell Univ., Ithaca, N.Y.,1986, Chap.5.

Anon. (1978). Kenya Statistical Abstracts. Ministry of Finance, Kenya Governement.

Anon. (1980). Annual Report, Coast Agricultural Research Station (Mtwapa: Ministry of Agriculture).

Anonymous. (1972). Grain legume Improvement Programme. In: 1972 IITA Annual Report, Ibadan, Nigeria, pp.28-40.

Anonymous. (1974). CIAT Annual Report, Cali, Colombia, pp.286.

Anonymous. (1975). Report of the Eighth Session of Codex Committee on Pesticide Residues. Codex Alimentarius Commission, FAO/WHO, Geneva. pp.7.

Anonymous. (1976). AVRDC Mung Bean Report, 1976, Shanhua, Taiwan, ROC., pp.72.

Anonymous. (1977). IITA Annual Report, Ibadan, Nigeria. pp.98.

Archer, T.L., A.B. Onkin, R.L. Matheson and E.D. Bynum. (1982). Nitrogen fertilizer influence on greenbug (Homoptera: Aphididae) dynamics and damage to sorghum. J. econ. Ent. 75: 695-698.

Arkin, G.F.and H.M. Taylor, Eds.(1981). Modifying the Root Environment to Reduce Crop Stress. Am. Soc. Agric. Eng., St.Joseph, Michigan, pp. 407.

Ashdown, D. (1977). Life of the Insects. Texas Tech. Univ., Lubbock, pp.135.

Auclair, J.L. (1957). Developments in resistance of plants to insects. Annu. Rep. Ent. Soc. Ont. 88: 7-17.

Auclair, J.L. (1976). Feeding and nutrition of the pea aphid, Acrythosiphon pisum (Harris) with special reference to amino acids. In: Host Plants in Relation to Insect Behavior and Reproduction. Ed. by T. Jermy. Plenum Press. 29-34.

AVRDC Progress Report. (1979). Intercropping for beanfly control, pp. 47.

AVRDC Progress Report. (1980,1982, 1984, 1986).

Babu, C.S.J. (1978). Bionomics and control of beanfly Ophiomyia phaseoli (Tryon) (Diptera: Agromyzidae). Mysore J. Agric. Sci. 12: 522-523.

Baliddawa, C.W. (1985). Plant species diversity and pest control: an analytical review. Insect Sci. Applic. 4: 479-487.

Baron, M. (1972). The influence of phosphate and potassium fertilizers on the population dynamics of aphids, Sitobion avenae (Fabr.). Rev. Appl. Ent. 62 (3): 224-225.

Barfield, B.J. and J.F. Gerber, Eds., (1979). Modification of the aerial Environment of crops. Am.Soc. Agric. Eng., St. Joseph, MI, 538 pp.

Baxendale, F.P. and G.L. Teetes. (1983). Factors influencing adult emergence from diapausing sorghum midge Contaria sorghicola (Diptera: Cecidomyiidae). Environ. Ent. 12: 1078-1082.

Beckhan, C.M. (1970). Effect of nitrogen fertilization on the abundance of cotton insects. J. econ. Ent. 63(4): 1219-1220.

Bergman, M.K. and F.T. Turpin. (1984). Impact of corn planting date on the population dynamics of corn rootworms (Coleoptera: Chrysomelidae). Environ. Ent. 13: 898-901.

Bergman, M.K. and F.T. Turpin. (1986). Phenology of field populations of corn rootworms (Coleoptera: Chrysomelidae) relative to calendar date and heat units. Environ. Ent. 15: 109-112.

Bernays, E.A.; Chamberlain,D.J. and Leather, E.M. (1981). Tolerance of acridids to ingested condensed tannin. J. Chem. Ecol. 7: 247.

BNR.(1988; 1989; 1990; 1991). Statistiques sur l'exportation. Banque Nationale du Rwanda.

Bosch C. (1990). Agricultural Research and Extension in Bukoba District. Working paper no.6.

Burikam, I. (1978). Ecological investigation of the beanfly, Ophiomyia phaseoli (Tryon) (Diptera: Agromyzidae). Pesticides (India) 7: 19-21.

Caldwell, N.E.H. (1945). Bean pests in Queensland. Queensl. Agric. J. 60: 156-171.

Cavalot, C. (1992). Manure analysis. Agricultural Research Institute of Rwanda (ISAR) at Rubona.

Chiang, H.S. and N.S. Talekar. (1980). Identification of sources of resistance to the beanfly Ophiomyia phaseoli and two other agromyzid flies O. centrosematis, Melanagromyza sojae in soybean Glycine max and mungbean, Vigna radiata. J. econ. Ent. 73(2): 197-199.

Chiang, H.S. and D.M. Norris. (1983a). Morphological and physiological parameters of soybean resistance to agromyzid beanflies. Environ. Ent. 12: 260-265.

Chiang, H.S. and D.M. Norris. (1983b). Physiological and anatomical stem parameters of soybean resistance to agromyzid beanflies. Environ. Ent. 12: 260-265.

Chiang, H.S. and D.M. Norris. (1983c). Phenolic and tannin contents as related to anatomical parameters of soybean resistance to agromyzid beanflies. J. Agric. Food Chem. 31: 726-730.

Chiang, H.S. and D.M. Norris. (1984). Purple stem, a new indicator of soybean stem resistance to beanflies (Diptera: Agromyzidae). J. econ. Ent., 77: 121-125.

Chiang, H.S. and D.M. Norris. (1985). Expression and stability of soybean resistance to agromyzid beanflies. Insect Sci. Applic., 6(3): 265-270.

CIAT. (1976). Bean Production Systems. In: CIAT Ann. Rept. 1975., Cali, Colombia, pp. 129-136.

Clifford, S.G., M.A. Altieri and A.C. Bellotti. (1989). Cassava intercropping and pest incidence: a review illustrated with a case study from Colombia. Trop. Pest Manag., 35(4): 339-344.

Coaker, T.H. (1987). Cultural methods: The crop. In: Integrated pest management Edited by A.J. Burn, T.H. Coaker, P.C. Jepson, 1987 Harcourt Brace Jovanovich, Publishers pp.69-88.

Crossekey, R.W. (1980). Catalogue of Diptera of the Afrotropical Region.

Davis, J.J. (1969). Beanfly and its control. Queensland Agric. J. 95: 101-106.

De Loach, C.J. (1970). The effect of habitat diversity to predation. Proc. Tall. Timbers Conf. on Ecol. Anim. Control by Habitat Management. Tallahassee 2: 223-241.

Dempster J.P. (1969). Some effects of weed control on the numbers of the small cabbage white (Pieris rapae) on brussel sprouts. J. Appl. Ecol. 6: 339-345.

Dempster,J.P. and T.H. Coaker. (1974). Diversification of crop ecosystems as means of controlling pests. In: Biology in Pest and Disease Control. (Edited by J.D. Prirce and E.M. Salomon). pp.106-114. John Wiley & Sons. N.Y.

Dissemond A. and H. Hindorf. (1990). Influence of sorghum/maize/cowpea intercropping on the insect situation at Mbita/ Kenya. J. Appl. Ent. 109: 144-150.

Dupree, M.(1965). Observations on the life history of the lesser cornstalk borer. J. econ. Ent. 58: 1156-1157.

El-Saadany, G., M.I. Abdel Fattah and Mazouki. (1977). Effect of fertilizer on aphids and leaf-hoppers on potato in Egypt. Rev. Appl. Ent. 65(8): 1379.

Esau, K.(1976). Anatomy of Seed Plants. 2nd. ed., John Wiley & Sons, Inc., N.Y.

Ezedinma, F.O.C.(1974). Effects of close spacing on cowpeas (Vigna unguiculata) in Southern Nigeria. Exp. Agric. 10: 289-298.

Fang, M.N. and C.P.Chang. (1984). Crop injury and seasonal occurrence of melon fly, Dacus cucurbitae Coquillett in Central Taiwan (Trypetidae: Diptera). Plant Prot. Bull. Taiwan. 26: 241-248.

FAO.(1991). FAO Production, 1990. Vol.44.

Farias, J.M. and J.E. Winch. (1987). Effect of planting date and harvest stage upon yield, yield distribution and quality of sorghum sudangrass in Northern Mexico. Trop. Agric. (Trinidad), 64(2): 87-90.

Feeny, P.(1970). Ecology, 51: 565.

Feeny. P.(1976). Plant apparency and chemical defense. Recent Adv. Phytochem. 10: 1-39.

Fehr, W.R. and C.E. Caviness. (1977). Stages of Soybean development special Report 80. Coop. Ext. Serv. Agric. Home Econ. Exp. Stn. Iowa State University, Ames. 12 pp.

Fellows, R.W. and J. Amarasena. (1977). Natural parasites of some major grain legumes in the dry zone. Trop. Agriculturist. (Sri Lanka) CXXX, 111(2): 83-89.

Funderburk, J.E., D.C. Herzog and R.E. Lynch. (1987). Seasonal abundance of lesser cornstalk borer (Lepidoptera: Pyralidae) adults in soybean, peanut, corn, sorghum and wheat in northern Florida. J. Ent. Sci. 22: 159-168.

Gain, D. and G.G. Kundu. (1986). Seasonal incidence of the bean stem miner, Melanagromyza sojae (Zehntner) in soybean at Delhi (India). J. Ent. Res., 10(2):152-154.

Gangrade, G.A. and M. Kogan (1980). Sampling stem flies in soybean. In: Sampling Methods in Soybean Entomology (Ed. by M. Kogan & D.C. Herzog), Springer-Verlag, Berlin.

Garg P.K., S.P. Singh and S.F. Hameed. (1987). Dissipation of endosulfan residues in/on mustard crop. J. Ent. Res., 11(2): 158-160.

Gates, D. (1945). Bean insect control. Nebraska Agr. Exp. sta. Ann. Rept., pp.58-61.

Gerard, B.M. (1976). The effect of plant density on maize and cowpea insect pest. In: Symposium on intercropping in semi-arid areas, Morogoro, Tanzania.

Gethi, M. and B.M. Khaemba. (1991). Damage by pod-sucking bugs on cowpea when intercropped with maize. Trop. Pest Manag. 37(3): 236-239.

Glass, E.H. (1975). Integrated pest management: Rationale, potential, needs and implementation. Ent. Soc. Amer. Spec. Publ. 75(2): 141.

Gomez, L.A. and A.V. Schoonhoven. (1977). Oviposicion del Empoasca kraemeri en frijol y evaluacion del parasitismo por Anagrus sp. Rev. Colombiana de Ent. 3: 29-38.

Greathead, D.J. (1968). A study in East Africa of beanflies (Diptera: Agromyzidae) affecting Phaseolus vulgaris and their natural enemies, with the description of new species of Melanagromyza Hend. Bull. Ent. Res. 59: 541-561.

Handa, S.K., A.K. Dikshit, M.D. Awasthi and N.S. Bhattacharjee. (1977). Residues of phorate, disulfoton and carbofuran in soybean crop. Indian J. Ent. 39: 354-356.

Harris, E.J., J.M. Takara and T. Nishida. (1986). Distribution of the melon fly, Dacus cucurbitae (Diptera: Tephritidae) and host plant on Kauai, Hawaiian Islands. Environmental Entomology, 15: 488-493.

Harris, K.M. (1992). Identification Service Report in International Institute of Entomology (London-England).

Hatfield, J.L. and I.J. Thomason, Eds. (1982). Biometeorology in Integrated Pest Management. Academic, New York: 491

Heathcoate, G.D. (1974). The effect of plant spacing, nitrogen fertilizer and irrigation on the appearance of symptoms and spread of virus yellows in sugar-beet crops. J. Agric. Sci. 83: 53-60.

Helenius, J. (1990). Effect of epigeal predators on infestation by the aphid Rhopalosiphum padi and on grain yield of oats in monocrops and mixed intercrops. Ent. exp. Appl. 54: 225-236.

Ho, T.H. (1967). The beanfly (Melanagromyza phaseoli Coq.) and experiments on its control. Malaysian Agric. J. 46: 149-157.

Howard, F.S. and E.G.Guillermo. (1980). Bean Production Problems: Disease, Insect, Soil and Climatic constraints of Phaseolus vulgaris. CIAT , Apartado Aereo 6713, Cali, Colombia, January 1980.

Howe, W.L. (1949). Factors affecting the resistance of certain cucurbits to the squash borer. J. econ. Ent., **42**: 321-326.

Huignard, J. (1985). Importance des pertes dues aux insectes ravageurs des graines. Problèmes posés par la conservation des légumineuses alimentaires, source de protéines végétales. Cah. Nutr. Diét. XX, 3, 1985.

Hussein, M.Y.B. (1978). Soil application of granular carbofuran to control beanfly, Ophiomyia phaseoli (Tryon). Pertanika, **1**: 36-39.

ICRISAT. (1976, 1977d). Annual Report. Hyderabad, India.

ISAR. (1982). Compte-rendu. In: Journées d'études du Département des Productions Végétales sur la culture du haricot au Rwanda à l'ISAR.

Israel, P. and Y.S. Rao. (1962). Influence of spacing on the incidence of the rice stem borer. Oryzae **1**: 58-60.

Jackai, L.E.N. and S.R. Singh. (1987). Entomological Research on Soybeans in Africa. In: Soybeans for the Tropics. Edited by S.R. Singh, K.O. Rachie and K.E. Dashiell, 1987, John Wiley & Sons Ltd.

Jansson, R.K. and Z. Smilowitz. (1986). Influence of nitrogen on population parameters of potato insects: abundance, population growth and within plant distribution of the green peach aphid, Myzus persicae (Homoptera: Aphididae). Environ. Ent. 15: 49-55.

Jones, R.J. (1965). The use of cyclodiene insecticides as liquid seed dressings to control beanfly (Melanagromyza phaseoli) in species of Phaseolus and Vigna marina in southeastern Queensland. Aus. J. Exp. Agric. Animal Husb. 5: 458-465.

Jones, F.G.W. (1976). Pests, resistance and fertilizers. Proc. Intn. Potash Inst., 12: 233-358.

Junyi, G., L.Fanyi, C. Zhanglin, X. Jikang and M. Yuhua. (1991). Inheritance of resistance to the beanfly (Melanagromyza sojae Zehntner). Soybean Genetics Newsletter 18: 104-106.

Kareiva, P.M. (1983). Influence of vegetation texture on herbivore populations: resource concentration and herbivore movement. In: Variable Plants and Herbivores in Natural and Managed Systems, R.F. Denno and M.S. McClure, Eds.,Academic Press, N.Y. pp.259.

Karel, A.K., D.A. Lakham and B.S. Nduguru. (1980). Intercropping of maize and cowpea, effect of plant population on insect pest and seed yield. In: Proc. Second Symposium on Intercropping in Semi-Arid Areas, Morogoro, Tanzania, pp.102-109.

Katiyar, O.P. (1972). The effect of seed rates and fertilizer levels on the incidence of borers at Raipur. J. Sci. Res. (Banaras Hindu Univ.), 22(1): 129-133.

Kayode, G.O. and A. Odulaja. (1985). Response of cowpea (Vigna unguiculata) to spacing in the savana and rain forest zones of Nigeria. Exp. Agric. 21: 291-296.

Kayumbo, H.Y. (1976). Crop protection in mixed-crop ecosystems. In: Symposium on intercropping in semi-arid areas, Morogoro, Tanzania, pp.8 (mimeo).

Khamala, C.P. (1979). Beanfly (Agromyzidae: Diptera) infestation of bean fields, their influence on the performance of Phaseolus vulgaris and some aspects of their control in Kenya. In: Symposium on Grain Legume Improvement in East Africa, Univ. of Nairobi, Kenya.

Kiraly, Z.(1976). Plant disease resistance as influenced by biochemical effects of nutrients in fertilizers. In Fertilizer use and plant health. Proc. 12th Colloq. Int., Izmir, Turkey, pp. 33-46, 1976.

Kogan, M. (1977). The role of chemical factors in insect/plant relationships. In: Proc. XV. Int. Congr. Ent., 211-227.

Kogan, M. (1982). Plant resistance in pest management. In: Introduction to insect pest management. Second Edition, A Wiley-Interscience Publication. John Wiley & Sons.

Kooner, B.S., H. Singh and S. Kumar. (1977). Effect of dates of sowing on the incidence of stem-fly, Melanagromyza phaseoli (Tryon) in pea crop. J. Ent. Res. 1: 100-103.

Kumar, R. (1984). Insect Pest Control. London, Edward Arnold.

Kwon, S.H., K.N. Chung, Y.I.Lee, J.R. Kim and J. Ryu.(1980). Response of soybean varieties and planting dates to the beanfly, *Melanagromyza* sp. damage. *Korean J. Breed*. 12: 30-34.

Kyamanywa, S. and E.M.Tukahirwa. (1988). Effect of mixed cropping beans, cowpeas and maize on population densities of bean flower thrips, *Megalurothrips sjostedti* (Trybom) (Thripidae). *Insect Sci. Applic*. 9(2): 255-259.

Lall, B.S. (1959). On the biology and control of the beanfly, *Agromyza phaseoli* Coq (Diptera: Agromyzidae). *Science and culture* 24: 531-532.

Lamb, K.P. (1978). Pest of winged bean and their control in Papua New Guinea. Dept. of Biol. Univ. of Pap. N. Guinea Port Mosby. Pest Gr. Leg. Ecol. and Contr. 53-58.

Lathrop, F.H. and L.G.Keirstead. (1946). Black pepper to control the bean weevil. *J. econ. Ent.*, 39: 534.

Lee, S.Y. (1976). Notes on some Agromyzid flies destructive to soybeans in Taiwan. *Formosan Sci*. 30: 54-62.

Leonard, M.D. (1931). A preliminary report on the lima bean pod-borer and other legume pod-borers in Puerto Rico. *J. econ. Ent*. 24: 466-473.

Litsinger, J.A. (1975). Diversity and stability: their roles in insect management strategies for agroecosystem. In: Cropping systems specialist course. Lecture Syllabus, Los Banos, Philippines, IRRI, Handout. 57: 12.

Luginbill, P. and G.G. Ainslie. (1917). The lesser cornstalk borer. USAID Ent. Bull. 529: 1917.

Mack, T.P. and C.B. Backman. (1990). The effect of two planting dates and three tillage systems on the abundance of lesser cornstalk borer (Lepidoptera: Pyralidae), other selected insects, and yield in peanut fields. J.econ. Ent. 83(3): 1034-1041.

Maltais, J.B. (1951). The nitrogen content of different varieties of peas as a factor affecting infestations by Macrosiphon pisi (Kltb) (Homoptera: Aphididae). A preliminary report. Can. Ent. 83: 29-32.

Mancia, J.E. (1973). Evaluacion de variedades de frijol tolerantes al picudo de la vaina Apion godmani Wagn. SIADES, 2: 15-20.

Manohar, S. and M. Balasubramanian. (1980). Note on the oviposition behaviour of agromyzid stemfly, Ophiomyia phaseoli (Tryon) (Diptera: Agromyzidae) in blackgram. Madras Agric. J. 67: 470-471.

Marcovitch, S. (1935). Experimental evidence on the value of strip cropping as a method for the natural control of injurious insects, with special reference to plant lice. J. econ. Ent. 28: 62.

Martin, G.A., C.A. Richard and S.D. Hensley. (1975). Host resistance to Diatraea saccharalis (F): Relationship of sugarcane internode hardness to larval damage. Environ. Ent. 4: 687-688.

Matee, J.J. and A.K. Karel. (1983). Investigation on chemical control of beanfly, Ophiomyia phaseoli (Tryon) on common beans, Phaseolus vulgaris (L.). Tanzania Bean Researcher's Meeting, Univ. Dar es Salaam, Morogoro, pp.10.

Mattson, W.J. and N.D. Addy. (1975). Phytophagous insects as regulators of forest primary production. Science, **190**: 515-522.

Mattson, W.J. (1980). Herbivory in relation to plant nitrogen content. Ann. Rev. Ecol. Syst., **11**: 119-161.

Mayse, M.A. and P.W. Price. (1978). Seasonal development of soybean arthropod communities in east central Illinois. Agro-Ecosystems, **4**: 387-405.

Mayse, M.A. (1983). Cultural control in crop fields: a habitat management technique. Environ. Mgmt. **7**: 15-22.

McClure, M.S. (1980). Foliar nitrogen: A basis for host suitability for elongate hemlock scale, Fiorinia externa (Homoptera: Diaspididae). Ecology, **61**: 72-79.

McIntosh, R.P. (1975). Plant ecology, 1947-1972. Ann. M. bot. Gdn. **61**: 132-165.

McNeill, S. and T.R.E. Southwood. (1978). The role of nitrogen in the development of insect/plant relationships. In: J.B. Harborne, Ed., Biochemical Aspects of Plant and Animal Coevolution, Academic, N.Y.,pp.77-98.

Metcalf, C.L., W.P. Flint and R.L. Metcalf. (1962). Destructive and Useful Insects. MeGraw-Hill, N.Y.,pp.1087.

MINAGRI. (1983).Rapport Annuel du Ministère de l'Agriculture et de l'Elevage du Rwanda.

Moorthy K.P.N. and G.C. Tewari. (1987). Management of stemfly _Ophiomyia phaseoli_ (Tryon) on French beans with reduced insecticidal doses. _Entomon_. 12(4): 363-366.

Morgan, W.L. (1938). For beanfly control use white oil nicotine sulphate mixture. _Agric_. _Gaz_. _N.S.W_. (Australia) 49: 22-24.

Mumford, J.D. and C.W. Baliddawa. (1983). Factors affecting insect pest occurence in various cropping systems. _Insect Sci_. _Applic_. 4(1/2): 59-64.

Murdoch, W.W. (1975). Diversity, complexity, stability and pest control. _J_. _Appl_. _Ecol_. 12: 795-807.

Musick,G.J., H.C. Chiang, W.H. Luckmann, Z.B. Mayo and F.T. Turpin. (1980). Impact of planting dates of field corn on beetle emergence and damage by the western and the northern corn rootworms in the Corn Belt. _Ann_. _Ent_. _Soc_. _Amer_. 73: 207-215.

NAL. (1992). Soil Test Report. National Agricultural Laboratories (NAL) of Kenya Agricultural Research Institute (KARI).

Nangju, D. (1976). Effect of harvest frequency on yield quality and variability of indeterminate cowpea seed. J. Agric. Sci., Cambridge **84**: 225-235.

Narayanasamy, P., P. Baskaran, M. Balasubramanium and V. Adaikalam. (1976). Different levels of N,P,K on the incidence of insect-pests. In: India Symposium on Modern Concepts in Plant Protection, Udaipur, March, 1976.

NAS.(1969). Insect pest management and control. Publ. 1695, Washington, D.C.

National Academy of Science. (1969). Insect-pest management and control. Publ. 1695, Washington, D.C.

Nderitu, J.H., H.Y. Kayumbo and J.M. Mueke. (1990a). Beanfly infestation on common beans (Phaseolus vulgaris L.) in Kenya. Insect Sci. Applic. **11**(1): 35-41.

Nderitu, J.H., H.Y. Kayumbo and J.M. Mueke. (1990b). Effect of date of sowing on beanfly infestation of the bean crop. Insect Sci. Applic. **11**(1): 97-101.

Negasi, F. and T. Abate. (1986). Studies on the control of beanfly Ophiomyia phaseoli (Tryon) (Diptera: Agromyzidae). Ethiopian J. Agric. Sci. **8**(1): 47-59.

Norris, D.M. and M. Kogan. (1980). Biochemical and morphological basis of resistance. In: Breeding Plants Resistant to Insects (Ed. by F.G. Maxwell & P.R. Jennings), John Wiley & Sons, N.Y.

Ofuya, T.I. (1987). Effect of plant spacing in cowpea (Vigna unguiculata) on damage by the black cowpea moth, Cydia ptychora (Lepidoptera: Tortricidae). J. Appl. Biol. **111**: 773-776.

Ofuya, T.I. (1989). Effect of weed removal regimes on post-flowering insect damage and grain yield of cowpea, Vigna unguiculata (L) Walp. in a rain forest area of Nigeria. Trop. Agric. (Trinidad), **66**(2): 142-144.

Okigbo, B.N. and D.J. Greenland. (1976). Intercropping systems in tropical Africa. In: Multiple cropping, eds.(63-101) R.I. Papendick, P.A. Sanchez and G.B. Triplett, Madison, Wisconsin USA: Am. Soc. Agr.

Okinda, A.F. (1979). Influence of the beanfly (Diptera: Agromyzidae) on the performance of french beans (Phaseolus vulgaris L.) and some aspects of its chemical control in Kenya. M.Sc. Thesis, Univ.of Nairobi, Kenya.

Oree, A. and G.H. Hallman. (1989). Agromyzid stem flies attacking Phaseolus vulgaris L. beans. CIAT, Apartado Aereo 6713, Cali, Colombia.

Otanes, F. (1918). The beanfly. Philippine Agriculturist 7: 2-31.

Parihar, N.S. and A. Gupta. (1990). Dissipation of endosulfan in geen foliage, pods and grains of red gram (Cajanus cajan L.). Trop. Pest Manag. 36(1): 15-16.

Persin, S.A. (1971). The action of "P" fertilizer on pests of cereal crops. Rev. Appl. Ent. 60(12): 961-962.

Pimentel, D. (1961). The influence of plant spatial patterns on insect populations. Ann. Ent. Soc. Am. 54: 61-69.

Pimentel, D. (1986). Species diversity and insect population outbreaks. Ann. Ent. Soc. Am. 54: 76-86.

Population Reference Bureau. (1990). World Population Data Sheet of the Population Reference Bureau, Inc. Demographic data and estimates for the countries and regions of the world.

Prestidge,R.A. (1982). Instar duration, adult consumption, oviposition and nitrogen utilisation efficiencies of leafhoppers feeding on different quality food (Auchenorrhyna: Homoptera). Ecol. Ent. 7: 91-101.

Ralph, C.M., J.T. Arnason, J.D.H. Lambert, P. Isabelle, H.D.Voldeng and D.L. Smith. (1989). Reduction of European Corn Borer (Lepidoptera: Pyralidae) damage by intercropping corn with soybean. J. econ. Ent. 82(5): 1455-1459.

Raros, E.S. (1973). Prospects and problems of integrated pest control in multiple cropping. In: IRRI Saturday Seminar, Los Banos, Phillipines, pp.20.

Raros, E.S. (1975). Bionomics of the beanfly, Ophiomyia phaseoli (Tryon) (Diptera: Agromyzidae) and its parasites in Hawaii. Ph.D. Dissertation, Univ. of Hawaii, Honolulu.

Rejesus, R.S. (1978). Pests of grain legumes and their control in the Philippines. Pest Gr. Leg. Ecol. Control, 47-52.

Remison, S.U. and T. Okunariwo. (1979). The performance of cowpea varieties at a wide range of densities in southern guinea savanna zone of Nigeria. Nigerian J. Agric. Sci. 1: 93-96.

Remison, S.U. (1980). Varietal response of cowpea to a range of densities in a forest zone. Exp. Agric. 16: 201-206.

Risch, S.J. (1979). Effect of plant density on the population dynamics of several beetle pests in monocultures and polycultures of corn, beans and squash in Costa Rica. Ph.D.thesis, Univ. of Michigan, 215 pp.

Risch, S.J. (1981). Insect herbivore abundance in tropical monocultures and polycultures: an experimental test of two hypotheses. Ecology, 62: 1325.

Risch, S.J., D. Andow and M.A. Altieri. (1983). Agroecosystem diversity and pest control: data, tentative conclusions and new research directions. Env. Ent. 12: 625-629.

Rodriguez, J.G. (1951). Mineral nutrition of the two-spotted spider mite, Tetranychus bimaculatus Hervey. Ann. Ent. Soc. Amer.,44: 511-526.

Rodriguez, J.G., Ed. (1972). Insect and Mite Nutrition. Elsevier/North Holland, Amsterdam, 702 pp.

Roongsook, D., T. Sitchawat, F.W. Knapp and A. Tiemtaisong. (1973). The effect of phorate and malathion on beanfly control and yield of mungbean. Thai J. Agric. Sci. **6**: 283-286.

Root, R.B. (1973). Organisation of a plant arthropod association in simple and diverse habitats: the fauna of collards (Brassica deracea). Ecol. Monographs **43**: 95-124.

Salam M.A. and S. Subramanian. (1989). Nitrogen-insecticide synergism on growth and yield of lowland rice in three seasons. Trop. Agric. (Trinidad), **66**(4): 297-304.

Santokh, S. (1982). Ecology of the Agromyzidae (Diptera) associated with leguminous crops in India. Memoirs of the School of Entomology, no 8.

Saunders, D.S. (1982). Insect Clocks. Pergamon Press, Oxford, pp.409.

Saxena, H.P. (1978). Pest of grain legumes and their control in India. In: Pests of Grain Legumes and their Control, 15-23.

Scriber, J.M. (1982). Nitrogen nutrition of plants and insect invasion. In: R.D.- Hauck, Ed., Nitrogen in Crop Production, Amer. Soc. Agron. Madison, WI, pp. 441-460.

Sepswasdi, P. (1976). Control of soybean insect pests in Thailand. In: R.M. Goodman, ed. Expanding the Use of Soybeans, pp.104-107. INTSOY Series no.10. Univ. of Illinois, Urbana-Champaign.

Sharma, S.K., M.K. Puri and V.K.R. Shinde. (1981). Assesment of biological efficacy of carbofuran granules against Melanagromyza phaseoli Coq. Pesticides (Bombay), 15: 25-26.

Sheehan, W. (1986). Response by specialist and generalist natural enemies to agroecosystem diversification: a selective review. Environ. Entomol. 15: 456-461.

Shri, R. and M.P. Gupta. (1988). Effect of nitrogen, phosphorus and potassium on the population of insect pests of fodder mustard (Brassica campestris L.) and its seed yield in India. Trop. Pest Manag. 34(4): 435-475.

Singh, B.B., H.H. Hadley and R.L. Bernard. (1971). Morphology of pubescence in soybeans and its relationship to plant vigour. Crop Sci. 11: 13-16.

Singh, G., P.N. Mishra and S.C. Tiwari. (1979). Efficacy of some insecticides in controlling the stemfly of pea. Indian J. Agric. Sci. 49: 50-52.

Singh, G., P.N. Mishra and B.K. Srivastava. (1981). Effect of date of sowing peas on the damage caused by Ophiomyia centrosematis. Indian J. Agric. Sci. 51: 340-343.

Slansky, F.and P.P. Feeny. (1977). Stabilization of the rate of nitrogen accumulation by larvae of the cabbage butterfly on wild and cultivated food plants. Ecol. Monogr., 47: 209-228.

Smith, J.C. (1976). Influence of crop background on aphids and other phytophagous insects on Brussels sprouts. Ann. Appl. Biol. 83: 1-13.

Smith, R.F. (1970). Pesticides: Their use and limitations in pest management. In: R.L. Rabb and F.E. Guthrie, eds.,Concepts of pest management. North Carolina State Univ., Raleigh, North Carolina, pp.103-113.

Speight, H.R. and J.H. Lawton. (1976). The influence of weed cover on the mortality imposed on artificial prey by predatory ground beetles in cereal fields. Oecologia 23: 211-233.

Spencer, K.A. (1959). A Synopsis of the Ethiopian Agromyzidae (Diptera). Trans. Royal Ent. Soc. London 111: 237-329.

Spencer, K.A. (1973). Agromyzidae (Diptera) of Economic Importance. The Hague, The Netherlands, Dr.W.Junk B.V. pp.418.

Stehr, F.W. (1982). Parasitoids and predators in pest management. In: Intr. to Insect Pest Manag. 2nd. Eds.(Eds. R.L. Metcalf, W.H. Luckmann) pp.135-144.

Steiner, K.C. (1982). Intercropping in tropical smallholder agriculture with special reference to West Africa. Eschborn: GTZ. pp.303.

Stephenie, P.J. (1987). SAS Institute Inc. SAS/STAT.tm. Guide for Personal Computer, Version 6 Edition. Cary,NC: SAS Institute Inc. pp.1028.

Subasinghe, S.M.C. and R.W. Fellowes. (1978). Recent trends in grain legume pest research in Sri Lanka. In: Insect Pests of Grain Legumes: Ecology and Control Ed.S.R. Singh, H.F. Van Emden and T.A. Taylor, Academic Press, London pp.37-41.

Subasinghe, S.M.C. and J. Amarasena. (1983). Seasonality and control of the beanfly, Ophiomyia phaseoli (Tryon) (Diptera: Agromyzidae) attacking grain legumes. Trop. Agriculturist. 139: 75-84.

Swaine, G. (1968). Studies on the biology and control of pests of seed beans (Phaseolus vulgaris) in northern Tanzania. Bull. Ent. Res. 59: 313-338.

Tahvanainen, J.O. and R.B. Root. (1972). The influence of vegetational diversity on the population ecology of a specialized herbivore Phyllotreta crucifera (Coleoptera: Chrysomelidae). Oecologia (Berlin) 10: 321-346.

Takashi, F. (1964). Reproduction Curve with Two Equilibrium Points: A consideration in fluctuations of insect populations. Res. Pop. Ecol. 6: 28-38.

Talekar, N.S. and B.S. Chen. (1983). The Beanfly Pest Complex of Tropical Soybean. In: Soybean in Tropical and Subtropical Cropping Systems. Proc.of a Symp. Tsukuba, Japan, pp.257-271. (Ed. S. Shanmugasundaram and E.W. Sulzberger).

Talekar, N.S. (1987). Insects Damaging Soybean in Asia. In: Soybeans for the Tropics Research, Production and Utilisation. Ed. S.R. Singh, K.O. Rachie and K.E. Dashiell, John Wiley & Sons Ltd, pp: 212-217.

Tengecho, B., C.L. Coulson and H.A. D'Souza. (1988). Distribution and effect of beanflies, Ophiomyia phaseoli and O. spencerella, on beans at Kabete, Kenya. Insect Sci. Appl. 9: No. 4: 505-508.

Tingey, W.M. and S.R. Singh. (1980). Environmental factors influencing the magnitude and expression of resistance. In: F.G. Maxwell and P.R. Jennings, Eds.,Breeding Plants Resistant to Insects, Wiley. N.Y. pp. 89-113.

Tisdale, S.L. and W.L. Nelson (1975). Soil fertility and fertilizers. 3 Ed. Macmillan, New-York.

Trolldenier, G. and E. Zehler (1976). Relationships between plant nutrition and rice diseases. In Fertilizer use and plant health. Proc. 12th. Colloq. Int. Potash Insect., Izmir, Turkey, pp. 85-93, 1976.

Trutman, P. (1987). Recherche sur l'efficacité d'enrobage des semences avant le semis contre les maladies transmises par les semences, les maladies racinaires et la mouche du haricot. In: Séminaire National sur l'Utilisation des Intrants, Kigali-Rwanda.

Ukwungwu, M.N. (1987). Some effects of plant densities and carbofuran on the damage by _Diopsis thoracica_ West and _Maliarpha separatella_ Rag. and yield of rice in Nigeria. _Trop_. _Pest Manag_. 33(4): 280-282.

Vaithilingam, C., M. Balasubramanium and P. Baskaran.(1978). Role of accelerated K nutrition in the pest management of paddy leaf roller. In: Symposium on Insect Pest Management, Udaipur, India, 1976.

Van den Bosch R. and V.M. Stern.(1969). The effect of harvesting practices on insect populations in alfalfa. In: Proc. Tall Timbers Conf. on Ecol. Anim. Control by Habitat Management. Tallahassee _1_: 47-69.

Van der Goot, P. (1930). Agromyzid flies of some native legume crops in Java. In:Tropical Vegetable Information Service, AVRDC, Shanhua, Taiwan.

Van Emden, H.F. (1965). The role of uncultivated land in the biology of crop pests and beneficial insects. _Scient_. _Hort_. 17: 121-136.

Van Emden, H.F. and G.F. Williams. (1974). Insect stability and diversity in agroecosystems. _Rev_. _Ent_. 19: 455-957.

Verma, B.K. (1974). Control of pests by soil treatment with insecticides. _Pans_. 20(1): 10-15.

Waghary, R.N. and S.R.Singh. (1965). Influence of host plant nutrition of _Aphids craccivora_ Koch. _Indian J_. _Ent_. 27: 196-201.

Walker, P.T. (1959). Insecticide studies on East African agricultural pest. III. Seed dressings for the control of the beanfly, Melanagromyza phaseoli (Coq.) in Tanganyika. Bull. Ent. Res. 50: 781-783.

Wallace, L.E., F.H. McNeal and M.A. Berg. (1973). Minimum stem solidness required in wheat for resistance to the wheat stem sawfly. J. econ. Ent. 66: 1121-1123.

Way, M.J. and G.D. Heathcote. (1966). Interactions of crop density of field beans, abundance of Aphis fabae Scap., virus incidence and aphid control by chemicals. Ann. Appl. Biol. 57: 409-423.

Way, M.J. and M.E. Cammell. (1981). Effects of weeds and weed control on invertebrate pest ecology. In: Pathogens and Vegetation (Edited by M.J. Thresh), pp. 443-458.

Wheatley, G.A. (1972). Role of biology in the control of pests and diseases of vegetable crops. In: Biology in Pest and Disease control (Eds. D.J. Price and M.E. Solomon), 277-293, Blackwell, Oxford.

Wijeratne Banda, P.M. and M.H.J.P.Fernando. (1981). Some aspects of pest management in grain legumes in Sri Lanka. In: Symp. Sri Lanka Assoc. Adv.Sci. pp.19.

Wijesekera. G.A.W.and K.G.W. Abeytunge. (1983). Seed treatment with insecticides for the control of Ophiomyia (Melanagromyza) phaseoli (Tryon) on cawpea in Sri Lanka. Trop. Agriculturist. 139: 1983.

William J.R. and S.H. Gage. (1990). Influence of bean-tomato intercropping on population dynamics of the potato leaf hopper (Homoptera: Cicadellidae). Environ. Ent. 19(3): 534-543.

Appendix 1: Effect of nitrogen on used parameters per 20 plants during long rainy season of 1992.

Nitrogen levels	beanfly larv/pup	beanfly parasitoids	% dead plants	number nodules	nodules weight(g)	dry matter(g)	% moisture
0 N	15.0 b	0.6 b	3.3 ab	177.6 ab	0.1 ab	39.6 b	86.5 a
45 N	18.6 a	1.3 b	1.8 b	87.0 ab	0.13 a	54.1 a	86.0 a
90 N	16.0 a	2.6 a	1.7 ab	78.3 b	0.12 b	60.9 a	86.6 a
20 T mnure	16.0 a	2.0 ab	3.9 a	147.3 a	0.13 a	62.1 a	87.3 a
Statistical analysis:							
CV% :	27.6	121.6	27.3	18.8	58.7	6.7	2.9
SE :	0.1	0.2	1.0	0.4	0.04	0.1	0.9

Means followed with the same letter in a column are not significantly different at 5% level ($P<0.05$) by "t" Test mean comparison. Analysis was carried out on log (x+1) transformed data for beanfly, parasitoids, number of nodules, nodule weight, dry matter and on arcsine (x/100) transformation for percentage of dead plant and moisture.

Appendix 2: Effect of phosphorus on used parameters per 20 plants during long rainy season of 1992.

Phosphorus levels	beanfly larv/pup	beanfly parasitoids	% dead plants	number nodules	nodules weight(g)	dry matter(g)	% moisture
0 P	15.0 b	0.6 ab	3.3 a	177.6 b	0.1 b	39.6 b	86.5 a
45 P	14.0 a	1.0 a	2.1 a	208.3 a	0.29 a	42.4 ab	83.8 a
90 P	18.0 a	0.0 b	3.1 a	632.6 a	0.45 a	63.2 a	81.4 a
Statistical analysis:							
CV% :	27.6	121.6	27.3	18.8	58.7	6.7	2.9
SE :	0.1	0.1	0.9	0.3	0.04	0.1	0.7

Means followed with the same letter in a column are not significantly different at 5% level by "t" Test mean comparison. Analysis was carried out on log (x+1) transformed data for beanfly, parasitoids, number of nodules, nodule weight, dry matter and on arcsine (x/100) transformation for percentage of dead plant and moisture.

Appendix 3: Effect of soil fertility on beanfly parasitoids per 20 plants during long rainy season of 1991.

Fertilizer levels	Variety GLP 2	Variety GLP 24	Average
0 N	5.0 a	6.0 a	5.5 a
30 N	7.0 a	3.3 a	5.1 a
60 N	4.3 a	9.6 a	7.0 a
90 N	4.0 a	3.6 a	3.8 a
20 T manure	3.0 a	6.0 a	4.5 a
Statistical analysis:			
F value :	1.1^{NS}	2.5^{NS}	1.0^{NS}
CV % :	35.5	31.7	33.4
SE :	0.3	0.3	1.1

Means followed with the same letter in a column are not significantly different at 5% level by "t" Test (LSD) mean comparison.

Appendix 4: Effect of intercropping two bean varieties (GLP 2 and GLP 24) with maize on thrips infestation.

Cropping system	Mean no.thrips/ 10 bean flowers
	Variety GLP 2
Monocrop	296.3 ± 6.5 a
Intercrop	179.6 ± 49.2 b
	Variety GLP 24
Monocrop	248.3 ± 27.6 ab
Intercrop	219.6 ± 21.1 b

Statistical analysis:

F value :	5.7**
CV% :	23.4
SE :	30.3

Means followed with the same letter in a column are not significantly different at 5% level ($P<0.05$) by "t" Test (LSD) mean comparison.

Appendix 5: Climatic conditions in Oyugis during the long and short rainy seasons of 1991 and 1992.

Month	Total rainfall		Daily mean temp °C		Daily mean RH (%)	
Long rains	1991	1992	1991	1992	1991	1992
March	79.9	-	27.6	-	51	-
April	219.1	235.6	23	24.2	37	32.2
May	281.2	161.2	22.5	23.6	48.2	32.2
June	-	187.3	-	23.2	-	31.4
Short rains						
Aug.	152.7	47.0	24	23	25.1	30
Sept.	124.8	115	23	23	25.3	32.4
Oct.	176.4	173.4	23.2	23.5	28	35.3

Appendix 6: Effect of beans monocrop and intercropping of beans and maize on beanfly parasitoids per 20 plants.

Cropping system	LR 1991 GLP 2	GLP 24	LR 1992 GLP 2	GLP 24
Monocrop	4.0 a	3.6 a	0.6 a	4.3 a
Intercrop	5.6 a	3.6 a	0.6 a	5.3 a

Statistical analysis:

F value :	6.2^{NS}	0.0^{NS}	0.0^{NS}	0.1^{NS}
CV% :	16.8	38.5	86.6	70.7
SE :	0.6	1.1	0.3	0.8

Means followed with the same letter in a column are not significantly different at 5% levels by "t" Test (LSD) mean comparison.

Appendix 7: Yield of bean grain obtained from monocropping or intercropping with maize with a control with endosulfan during the short rainy season of 1992

Cropping system	Grain yield (kg/ha)	
	GLP2	GLP 42
Monocrop	954 b	594 a
Intercrop	453 c	219 a
Monocrop Contr.	1870 a	
Intercrop Contr.	439 c	

Statistical analysis:

	GLP2	GLP 42
F value :	10.9***	16.7^{NS}
CV% :	5.6	5.3
SE :	0.3	0.2

Means followed with the same letter in a column are not significantly different at 5% levels (P<0.05) by "t" Test (LSD) mean comparison.

Appendix 8: Effect of intercropping beans and maize on beanfly infestation, LR 1991.

Cropping system	Variety	Mean no. beanfly larvae and pupae/20plants			
		2 wae	4 wae	6 wae	8 wae
Monocrop	GLP 2	12.6±6.2	22.6±1.6	24.0±9.1	8.6±0.6
Intercrop	GLP 2	15.3±2.2	33.3±1.0	19.6±2.4	12.0±3.4
Inter. strt.	GLP 2	0.3±0.3	0.0±0.0	0.0±0.0	0.0±0.0
Monocrop	GLP 24	14.3±3.5	24.6±2.3	13.3±6.7	7.0±0.6
Intercrop	GLP 24	9.6±6.2	25.6±5.7	19.3±4.5	8.6±1.6
Inter. strt.	GLP 24	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0

Statistical analysis:

F value :	crop.syst.	0.1^{NS}
	varieties	1.9^{NS}
	seed trt.	119.3***
CV% :		84.1
SE :		4.2
LSD 5% :		3.0

Appendix 9: Effect of beans and maize intercropping on beanfly infestation during LR 1992.

Cropping system	Variety	Mean no. beanfly larvae and pupae/20 plants			
		2 wae	4 wae	6 wae	8 wae
Monocrop	GLP 2	0.3±0.3	8.3±0.3	27.6±3.8	17.0±1.0
Intercrop	GLP 2	0.6±0.3	10.0±1.5	20.3±5.6	26.6±1.3
Inter.strt	GLP 2	0.3±0.3	0.6±0.3	0.3±0.3	0.0±0.0
Monocrop	GLP 24	6.6±2.7	15.6±3.5	20.6±5.9	16.0±1.5
Intercrop	GLP 24	6.3±2.9	19.0±4.0	21.0±5.0	15.3±2.9
Inter.strt	GLP 24	0.3±0.3	0.3±0.3	1.3±0.6	5.3±0.8

Statistical analysis:

F value :	crop. syst.	0.1^{NS}	0.4^{NS}	0.6^{NS}	4.5**
	variety	6.8***	6.5**	0.3^{NS}	1.1^{NS}
	seed trt.	8.4***	57.4***	109.5***	106.7***
CV % :		146.3	58.4	44.1	41.1
SE :		1.6	2.3	2.9	2.4
LSD 5% :		2.3	3.5	4.3	3.5

Appendix 10: Effect of weeding regimes on beanfly parasitoids during the long rains of 1992.

Weeding regime	variety	Mean no. beanfly parastoids/20 plants		
		4	6	8
3 wae	GLP 2	1.0±1.0	2.6±1.2	2.3±1.0
5 wae	GLP 2	2.0±0.6	1.0±0.6	1.6±1.2
No weeding	GLP 2	1.0±1.0	3.3±1.3	3.6±1.0
Weed free	GLP 2	3.6±0.6	1.3±0.3	0.6±0.3
3 wae	GLP 24	6.0±1.5	1.0±0.6	0.6±0.3
5 wae	GLP 24	4.3±1.2	1.0±0.0	1.6±0.3
No weeding	GLP 24	5.3±2.0	0.6±0.6	0.6±0.3
Weed free	GLP 24	6.3±1.7	0.6±0.3	0.6±0.3

Statistical analysis:

F value	: w.regime	1.0^{NS}	1.0^{NS}	1.4^{NS}
	variety	15.3***	5.0**	5.0**
CV%	:	60.6	94.2	85.0
SE	:	1.3	0.8	0.7
LSD 5%	:	3.7	2.2	2.1

Appendix 11: Effect of plant spacing on beanfly infestation at 4 w.a.e. during the long and short rains of 1991

Spacing	Mean no.beanfly larvae and pupae/20 plants			
	LR 1991		SR 1991	
	GLP 2	GLP 24	GLP 2	GLP 24
30 x 15 cm	11.0 b	6.3 b	0.6 ab	1.6 ab
45 x 15 cm	8.6 b	15.6 a	0.0 b	1.3 b
60 x 15 cm	20.6 a	20.0 a	1.3 a	2.3 a
Statistical analysis:				
F value :	12.8***	37.3***	9.1***	4.5**
CV% :	14.1	8.4	74.4	27.9
SE :	0.1	0.1	0.1	0.1

Means followed with the same letter in a column are not significantly different at 5% level (P<0.05) by Tukey (HSD) mean comparison. Analysis was carried out on log (x+1) transformed data. Untransformed means are present here.

Appendix 12: Effect of plant spacing on beanfly infestation at 4 w.a.e. during the long and short rains of 1992.

Spacing	Mean no.beanfly larvae and pupae/20 plants.			
	LR 1992		SR 1992	
	GLP 2	GLP 24	GLP 2	GLP 24
30 x 30 cm	16.6 a	25.0 ab	9.3 a	8.3 a
45 x 20 cm	10.0 b	29.6 a	7.0 ab	6.6 a
60 x 15 cm	10.6 ab	19.3 b	4.0 b	5.3 a

Statistical analysis:

F value :	4.8**	3.7*	9.6***	0.2^{NS}
CV% :	12.6	10.2	14.8	21.2
SE :	0.1	0.1	0.1	0.1

Means folowed with the same letter in a column are not significantly different at 5% level (P<0.05) by Tukey (HSD) mean comparison. Analysis was carried out on log (x+1) transformed data. Untransformed means are present here.

Appendix 13: Effect of plant spacing on beanflyparasitoids during the long rainy season of 1991.

Spacing	Mean no.beanfly parasitoids/20 plants	
	LR 1991	
	GLP 2	GLP 24
30 x 15 cm	1.3 a	0.3 b
45 x 15 cm	1.3 a	3.0 a
60 x 15 cm	2.3 a	2.6 a
Statistical analysis:		
F value :	1.1^{NS}	24.3***
CV% :	81.0	32.4
SE :	0.2	0.1
	LR 1992	
30 x 30 cm	0.6 b	3.0 b
45 x 20 cm	1.6 ab	6.0 a
60 x 15 cm	2.6 a	5.6 ab
F value :	5.4**	6.5**
CV% :	50.7	21.6
SE :	0.2	0.1

Means followed with the same letter in a column are not significantly different at 5% level (P<0.05) by Tukey (HSD) mean comparison. Analysis was carried out on log (x+1)transformed data. Untransformed means are present here.

Appendix 14: Effect of planting time on beanfly infestation of bean variety GLP 2 and GLP 24 during the long and short rains of 1991 and 1992.

Planting time	variety	Mean no. larvae and pupae/20 plants		
		LR 1991	LR 1992	SR 1991
1st.rains	GLP 2	22.6 abc	7.3 c	2.0 d
2 weeks	GLP 2	10.6 c	18.3 bc	11.6 c
4 weeks	GLP 2	30.0 ab	29.3 ab	10.6 c
6 weeks	GLP 2	39.6 a	38.6 ab	32.0 ab
8 weeks	GLP 2	43.3 a	28.6 ab	32.6 a
1st.rains	GLP 24	14.3 c	25.6 ab	1.6 d
2 weeks	GLP 24	15.0 abc	42.0 a	6.3 cd
4 weeks	GLP 24	27.0 ab	31.0 ab	12.0 c
6 weeks	GLP 24	33.0 a	42.6 a	12.6 c
8 weeks	GLP 24	43.3 a	38.0 ab	39.6 a

Statistical analysis:

	LR 1991	LR 1992	SR 1991
F value:	12.7***	5.6***	30.5***
CV% :	54.0	30.1	59.8
SE :	9.0	5.2	5.2
LSD 5% :	12.5	15.5	7.2

Means followed with the same letter in a column are not significantly different at 5% level (P<0.05) by Tukey (HSD) mean comparison.

Appendix 15: Effect of planting time on beanfly parasitoids during the long rains of 1991 and 1992.

Planting time	Mean no. beanfly parasitoids/20 plants			
	LR 1991		LR 1992	
	GLP 2	GLP 24	GLP 2	GLP 24
1st.rains	5.3 a	2.1 a	0.0 b	2.1 a
2 weeks	1.8 ab	3.3 a	1.8 ab	4.5 a
4 weeks	2.3 ab	0.8 a	2.8 ab	4.3 a
6 weeks	3.3 a	3.0 a	6.5 a	4.3 a
8 weeks	0.1 b	1.5 a	3.0 ab	6.1 a
Statistical analysis:				
CV% :	94.2	103.7	134.2	70.4
SE :	0.4	0.5	0.6	0.5

Means followed with the same letter in a column are not significantly different at 5% level by "t" Test (LSD) mean comparison.

Appendix 16: Effect of beanfly infestation on grain yield (kg/ha) in soils of different fertility, SR 1991.

Fertility levels	GLP 2 (kg/ha)	GLP 24 (kg/ha)	Average (kg/ha)
0 N	1280.0 a	1418.3 a	1349.2 a
30 N	1020.3 ab	1241.0 ab	1130.7 a
60 N	619.0 b	400.7 b	509.8 b
90 N	1259.3 a	1659.0 a	1459.2 a
20 T manure	844.0 ab	1129.7 ab	986.8 ab

Statistical analysis:

	GLP 2	GLP 24	Average
F value :	5.4**	5.4**	10.9***
CV% :	20.7	30.0	25.2
SE :	122.2	202.9	112.1
LSD 5% :	586.6	991.5	479.6

Means followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison.

Appendix 17: Effect of plant spacing on the percentage of bean plants moisture and dry matter content of the variety GLP 2 at 6 w.a.e during the short rainy season of 1992.

Plant spacing	% moisture 20 plants		Dry matter(gr) 20plants	
	GLP 2	GLP 24	GLP 2	GLP 24
30 x 30 cm	83.7 a	85.2 a	67.0 a	64.1 a
45 x 20 cm	84.8 a	85.2 a	45.5 b	50.6 a
60 x 15 cm	84.3 a	85.1 a	66.7 a	45.9 a

Statistical analysis:

F value :	1.2^{NS}	0.1^{NS}	28.5***	2.5^{NS}
CV% :	2.3	1.1	9.4	27.2
SE :	0.01	0.004	2.3	5.9

Means followed with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison. Analysis of percentage moisture was based on arcsine (x/100) transformation and dry matter on log (x+1) transformed data. Untansformed means are presented here.

Appendix 18: Effect of planting time on grain yield during the long and short rainy seasons of 1991 and 1992.

Planting time	Variety	Grain yield (kg/kg)		
		LR 1991	LR 1992	SR 1991
1st. rains	GLP 2	1441 a	1245.7 a	788.3 a
2 weeks	GLP 2	1138 a	617.6 b	406.0 b
4 weeks	GLP 2	773.5 ab	347.3 b	328.3 bc
6 weeks	GLP 2	274.6 ab	128.6 bc	432.0 b
8 weeks	GLP 2	35.6 c	43.3 d	0.0 e
1st. rains	GLP 24	1041.6 a	668.3 b	515.0 b
2 weeks	GLP 24	1080.3 a	475.6 b	263.6 bc
4 weeks	GLP 24	1034.7 a	210.3 bc	634.0 a
6 weeks	GLP 24	317.8 ab	199.6 bc	175.3 bcd
8 weeks	GLP 24	94.6 c	92.3 d	0.0 e

Statistical analysis:

F value:	12.0***	16.3*	39.7***
CV% :	51.0	54.0	26.5
SE :	66.1	125.4	54.2
LSD 5% :	636.1	372.0	163.8

Means followed with the same letter in a column are not significantly different at 5% level (P<0.05) by Tukey (HSD) mean comparison.

Appendix 19: Increase of the parameters used in experiment on the effect of soil fertility on beanfly infestations in the course of the sampling period per 20 plants during the long rains of 1992.

Sampling period	Mean no. Beanfly	Percentage dead plants	Dry matter (gr)	% Moisture content	Plant Height (cm)
2 w.a.e.	3.5 c	1.6 c	23.9 d	85.0 b	27.0 c
4 w.a.e.	13.8 a	2.6 b	56.9 c	86.4 a	46.2 b
6 w.a.e.	11.7 ab	3.2 ab	146.8 b	87.5 a	53.1 a
8 w.a.e.	9.2 b	3.9 a	282.2 a	82.4 c	53.7 a

Statistical analysis:

F value:	34.7 ***	19.6 ***	200.5 ***	49.3 ***	130.4 ***
CV% :	51.2	50.6	41.4	2.4	15.7
SE :	0.7	0.2	8.1	0.3	1.1

Means with the same letter in a column are not significantly different at 5% level by Tukey (HSD) mean comparison. *** significant, $P < 0.001$