STUDIES ON THE MAIZE STALK BORER BUSSEOLA FUSCA FULLER (LEPIDOPTERA : NOCTUIDAE) WITH SPECIAL REFERENCE TO ITS BIOLOGY, ECOLOGY AND YIELD LOSS IN MAIZE

A Thesis
Submitted to the School
of
Graduate Studies
by

Munene wa Macharia

In Fulfilment of the
Requirements for the Degree
of
Doctor of Philosophy

Department of Zoology
Moi University
Eldoret, Kenya

August 1990

DECLARATION BY CANDIDATE

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

Sign------------------------ Date--1. 8. 90------

Munene wa Macharia

DECLARATION BY SUPERVISORS

This thesis has been submitted for examination with our approval as University Supervisors

Sign------------------------ Date--2. 8. 90------------------

Prof. Battan M. Khaemba

(B.Sc, Makarere, M.Sc, Ph.D, Nairobi)

Sign------------------ Date--1. 8. 90------------------

Dr. K.V. Seshu Reddy

B.Sc (Ag.), M.Sc (Ag). Ph.D, India)

Moi University, Eldoret, Kenya

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

This thesis is the outcome of invaluable assistance of various individuals whose help I now have the pleasure to acknowledge.

I would like to thank Professor B.M. Khaemba and Dr. K.V. Seshu Reddy for their supervision, constructive suggestions, constant interest in the progress of my work and continuous encouragement.

I also wish to record my gratitude to the Director of National Plant Breeding Research Centre, Njoro for placing all the facilities at my disposal. Additionally, the technical assistance rendered by all staff of Entomology Section is highly appreciated. I am grateful to Mr. J.K. Kamundia for his assistance in statistical analysis of the data.

It is with gratitude that I acknowledge the part played by my wife Wairimu and my children Macharia, Muthoni and Gichuki for their patience and understanding during ups and downs while the research was being undertaken and throughout the preparation of this thesis.

I wish also to express my profound gratitude to Professor T.R. Odhiambo, Director of ICIPE for the opportunity afforded to me to undertake my Ph.D studies under the African Regional Post-graduate Programme in Insect Science (ARPPIS).

ABSTRACT

The maize stalk borer Busseola fusca Fuller is a serious pest of maize in the highland areas of Kenya. In an effort to generate information that could be useful for integrated management of the pest, the main factors studied in the current investigations were its biology and ecology. Other studies involved its population patterns in relation to planting dates, crop losses caused by the pest and evaluation of crop loss assessment techniques used in estimation of losses due to B. fusca.

It was revealed by these studies, that development was completed with intervening larval diapause. About 30.4% of the larvae from the same egg batch underwent diapause, while the rest (69.6%) underwent normal development without experiencing an intervening diapause. Duration of non-diapause larval period was 40.9 ± 0.5 days, while in diapause larvae the duration was 238.5 ± 13.1 days. There were no significant ($P > 0.05$) differences in the durations of pre-oviposition, oviposition, post-oviposition, longevity and fecundity rate between moths originating from diapause and non-diapause generations.

Maize stalk residues with an infestation of 1.5 insects / m^2 were identified as being a major venue of the carry-over population of B. fusca as compared to other hosts. Columbus grass Sorghum almum had 1.4 insects, sudan grass S. sudanensis

0.9 insects, grain sorghum S. bicolor 0.9 insects, and napier grass Pennisetum purpureum 0.1 insects per m^2.

When the effects of mortality factors and influence of weather on diapausing B. fusca larvae during the dry season were determined, larval mortality due to Apanteles sesamiae Cameron was 12.3% indicating that the parasite could be manipulated for the control of the pest. Mortality due to other causes was 87.7%. Rainfall was negatively correlated (for 1987 : $r = - 0.45$; $P < 0.05$; for 1988 : $r = - 0.25$; $P > 0.05$) with the number of larvae. On the other hand, mean temperature was positively correlated (for 1987 : $r = 0.47$; $P < 0.05$; for 1988 : $r = 0.41$; $P < 0.05$) with larvae population. This indicated that increased rainfall and reduced mean temperatures probably influenced the larvae to pupate and emerge.

It was also revealed by studies on seasonal abundance of B. fusca moths that the pest was present throughout the year. Three peak periods were identified, the first peak occurring in April, the second peak in August and the third peak in November. Rainfall and minimum temperature were positively correlated ($r = 0.40$, $r = 0.24$ respectively) with moth catches. On the other hand, maximum temperature was negatively correlated ($r = 0.24$) with moth catches. This indicated that increased rainfall and reduced temperatures probably influenced the emergence of adult moths to lead to higher trap catches. Lunar phases of the moon significantly ($P < 0.05$) influenced the number of the moths caught. However, these lunar phases did not significantly ($P > 0.05$) influence the sex ratio of the moths caught.

Field experiments were also conducted to compare the effect of different maize stubble disposal practices on the survival of the pest during the dry season. Harrowing and deep ploughing as treatments caused 86.7% and 75.9% mortalities, respectively, which were significantly ($P < 0.05$) the highest as compared to other treatments. Burning, cut stumps and standing stalks as treatments achieved 61.2%, 30.4% and 23.2% mortalities, respectively. Compared to the standard practice of leaving harvested standing stalks in the field, harrowing and deep ploughing as treatments achieved 94.5%, and 90.7% reduction of B. fusca population relative to standing stalks treatment, respectively. It was therefore concluded that harrowing and deep ploughing held some potential as cultural control techniques for B. fusca.

The effect of early and late plantings on B. fusca infestation patterns was also investigated. No significant ($P > 0.05$) differences existed in larvae population, and stem and internode damage between the treatments. Significant ($P < 0.05$) differences in percentage plant damage was recorded, with the late planted crop being more severely damaged than the early crop.

Experiments were also conducted to evaluate the effect of

B. fusca infestation on yield and yield components of maize. The results demonstrated that the stage at which the crop was attacked is critical with young plants incurring heavier damage. It was further shown that damage increased with increased pest density. The 8 leaf was the most critical growth stage even when the infestation was low. Significant ($P < 0.05$) variations in damage existed among vegetative parameters tested. Apparently, damage on vegetative parts adversely influenced grain yield. Infestations of 2, 4, 8 and 16 larvae per plant resulted in yield reductions of 26.4%, 37.0%, 48.2% and 74.4%, respectively. When economic injury levels (EILs) were calculated, it was revealed that even slight infestation (0.01 larvae /plant) at 8 leaf stage caused economic losses. Damage at other plant growth stages was equally heavier with slight infestations (6 leaf stage = 0.03 larvae /plant ; 10 leaf stage = 0.04 larvae / plant). These observations pointed to the fact that the pest was a voracious feeder able to cause economic losses even at very low population levels.

Results of the evaluation of techniques for assessing crop losses in maize due to B. fusca showed that both methods (damaged / undamaged plants method and chemically protected / unprotected plants method) were identical in accuracy and any one of them could be used instead of both. The technique based on damaged / undamaged plants was appealing for use by farmers since it has practically no side effects.

An on-farm crop estimation of losses caused by <u>B</u>. <u>fusca</u> using the technique based on damaged / undamaged plants was conducted in five agro-ecological zones in Nakuru area of Rift Valley Province. The results obtained indicated that there were differences in potential losses among the zones that were studied. This was due to differences in levels of infestation which was attributed to varying environmental conditions.

CHAPTER 1

INTRODUCTION

1.1 Economic value and cultivation of maize in Kenya

Since the introduction of maize (Zea mays L.) into East Africa by the Portuguese in the 16th century, it only became a major food and cash crop in Kenya during the present century (Purseglove, 1972). Maize is now the dominant staple food for the majority of Kenyans (Ogada, 1971 ; Allan, 1972 ; Muthoka, 1987). It also occupies more land than all the other cereals put together (Anon., 1979a ; Anon., 1983 ; Muthoka, 1987) and because of this, it holds a key position in Kenya's economy and nutrition. Information on maize production and income earned over the last eight years (1980-1988) and production estimates on district basis in Kenya for 1986 and 1987 are summarized in Appendix 1a and b.

Although maize in Kenya is planted between altitudes 0 - 2800 m above sea level, the high potential production areas with favourable rainfall are restricted to altitudes between 1,000 and 2,100 m (Acland, 1971 ; Allan, 1972 ; Njeru, 1974). These areas occur in higher parts of Western Kenya and the Rift Valley and are characterized by a monomodal rainfall. The other high potential areas are found to the east of the Rift Valley and parts of Central Province and have a bimodal rainfall pattern (Allan, 1972 ; Allan, 1974 ; Njeru, 1974).

The successful story of increased yield production of maize in Kenya has been associated with the introduction of improved hybrid maize varieties suitable for each major agro-ecological zone (Brady, 1984 ; Efron and Kim, 1984 ; Muthoka, 1987). The main varieties grown at intermediate altitudes (1,000 -2,400 m) are hybrids H622, H632, H612, H611C, H613C, H614C, and H625 (Omolo, 1974 ; Anon., 1979a ; Anon., 1984 ; Muthoka, 1987). Their maturity periods vary from 180 - 240 days and perform well in areas with a rainfall regime of 750 - 1800 mm.

1.2 Maize production constraints in Kenya

Notable factors limiting production of maize in Kenya include poor land preparation, late planting and inadequate control of weeds, diseases and insect pests (Allan, 1972).

The weed problem is widespread and if left uncontrolled, it leads to heavy yield losses. For example, trials conducted at Kitale revealed that yield losses of up to 32% could be incurred when maize was not weeded (Anon., 1967 ; Anon., 1970). Besides weed control is often done late resulting in less yields. Predominant weed species in maize crops have been documented by Ivens (1967) and Terry and Michieka (1987).

Similarly disease problems also constitute a major constraint to maize production and those of major concern have been studied (Storey, 1928 ; Bock <u>et al.</u>, 1974 ; Rossel and Thottappilly, 1985 ; Kulkani, 1973 ; Eberhart <u>et al.</u>, 1973 ; Darrah, 1976).

Of considerable importance is crop damage by insect pests notably the stalk borers that play a significant role in the reduction of yields (Wheatley and Crowe, 1967 ; de Pury, 1968 ; Hill, 1975 ; De Lima, 1976 ; Anon., 1979a). The most important species of stalk borers according to Seshu Reddy (1983) and Warui et al., (1986) are :

(a) maize stalk borer Busseola fusca Fuller ;
(b) pink stalk borer Sesamia calamistis Hampson ;
(c) spotted stalk borer Chilo partellus Swinhoe ;
(d) coastal stalk borer C. orichalcociliellus Strand ; and
(e) sugarcane stalk borer Eldana saccharina Walker.

B. fusca and C. partellus are by far the most important, being widespread in all the maize growing African regions (Jepson, 1954 ; Ingram, 1958 ; Mohyuddin and Greathead, 1970). Seshu Reddy (1983) reported that C. partellus was most important in low altitude areas of Kenya while B. fusca was prevalent in the higher altitude areas.

1.3 Busseola fusca as a constraint to maize production

The maize stalk borer B. fusca is a major pest throughout the maize and sorghum growing areas of Africa (Hill, 1975) and to avert losses application of insecticides for its control is called for (Walker, 1981 ; Ogunwolu et al., 1981 ; Mlambo, 1983). It is particularly notorious in the cool highland areas of East Africa where the bulk of the maize crop is grown (Nye, 1960 ; Bohlen, 1973 ; Seshu Reddy, 1983).

There is a controversy with respect to the exact distribution of the maize stalk borer in Kenya. According to an earlier survey by Nye (1960) and later on by Mohyuddin and Greathead (1970), the pest was found to occur in areas above 460 m above sea level. Recent studies in Kenya and Ethiopia have showed that the occurrence of the pest was rare at altitudes below 1200 m (Tassema, 1982) and was dominant at higher and cooler altitudes (1,140 - 2,500 m) (Seshu Reddy, 1983). These are also, incidentally, the areas (1,200 - 2,000 m) known for high productivity of maize in Kenya (Allan, 1972).

1.4 Crop infestation and injury due to the maize stalk borer Busseola fusca attack

Maize is susceptible to stalk borer attack when plants are between 26 - 45 cm tall (Khaemba, 1985 ; Barrow, 1989), with the damage being caused by the larval stage. Damage is as a result of feeding activities of the larvae which begin after hatching (de Pury, 1968 ; Schmutterer, 1969 ; Bohlen, 1973).

The eggs which are laid within the leaf sheaths hatch in 7 - 12 days (Barrow, 1989) into young larvae which migrate up to the stem and down into the funnel to feed on the tender, rolled up young leaves or whorl by scraping the leaf tissue (Hill, 1975; Walters *et al*., 1980). When damaged young leaves grow out of the funnel and unfold, they exhibit characteristic lines of "windows" (fine holes) which run across the leaves at right angles to the main vein (Plate 1) which is typical of early

Plate 1. Typical symptoms of maize stalk borer _Busseola_ _fusca_ damage to maize plants

stages of stalk borer infestation (de Pury, 1968 ; Bohlen, 1973 ; De Lima, 1976 ; Khaemba, 1985 ; Schmutterer, 1969).

When the larvae are overcrowded in the funnel of a plant, they may be dispersed to adjacent plants by being blown away on silken threads from which they hang suspended during their upward migration (Taylor, 1952 ; Swaine, 1957 ; Walters et al. 1980). Some of the larvae which become established cause extensive foliar damage leading to the production of many holes on the leaves of infested plants. They also penetrate downwards destroying the growing point leading to death of the shoot to create a "dead heart" condition (de Pury, 1968 ; Schmutterer, 1969 ; Bohlen, 1973).

In case the plant dies, the larvae move to the adjacent plants. On the other hand, if the plant survives, the mature larvae bore down into the centre of stalk where they feed until pupation (de Pury, 1968 ; De Lima, 1976). It has also been reported that migration occurs in later larval instars until pupation (Walters et al. 1980 ; Kaufmann, 1983) resulting in a wider distribution of the pest within the crop habitat.

Feeding by tunnelling of stems of growing plants by larvae weaken plants resulting into lodging (Swaine, 1957). Damaged plants often die through the reduction of translocation of water and minerals (Blaire, 1971 ; Hodson and Walker, 1975). When infestation coincides with the tasselling and silking stages, the moths usually lay eggs on sheaths of older leaves or on ear husk leaves (Walters et al. 1980). The emerging larvae damage tassels resulting in reduced pollination and also damage the developing seeds in cobs (Jepson, 1954 ; Swaine, 1957 ; Walters et al. 1980). In late planted maize, maturing cobs may be ruined by the larvae which feed on the seeds (Blaire, 1971 ; Hodson and Walker, 1975 ; Gebre-Amlak, 1988).

1.5 Justification of the current investigations

One of the major objectives in Kenya's agricultural development policies is to meet the increasing demand for food and attain self sufficiency to feed the rapidly expanding population (Anon., 1979b ; Anon., 1984 ; Anon., 1986). Therefore, any factors such as insect pests that reduce yields in maize make the achievement of the above goal elusive. There is therefore need to minimize losses due to stalk borer damage in order to achieve the already stated goal.

Although numerous studies on some aspects of the biology of *B. fusca* have been conducted elsewhere (Usua, 1968a ; 1968b ; 1970a ; 1970b ; 1973 ; Van Rensburg et al. 1985 ; 1987 ; 1988a ; 1988b ; Gebre-Amlek, 1988) similar studies on the biology and ecology of the pest in Kenya are lacking. Such studies would generate valuable information that would be used to design effective control strategies against the pest to minimize its losses. It therefore became necessary to conduct studies to gain information on some aspects of the biology and ecology of this pest so as to achieve the foregoing goal.

Despite the fact that *B. fusca* is recognized as the most widespread and destructive pest of maize in Africa (Jepson, 1954;

Nye, 1960 ; Walters, 1979), quick and reliable techniques have not, as yet, been developed for rapid assessment of crop losses that the pest causes. Such techniques, once developed would be of immense value in the development of sound pest management practices to minimize yield losses due to its attack.

Before accurate crop loss assessment studies could be undertaken, it became necessary to determine the residual larval population of the maize stalk borer carry-over from season to season. Seasonal fluctuations of adult moths were also determined. Such information once available on the magnitude as well as on the sources of infestation and periods of the peak pest activities could greatly assist in designing improved pest management strategies to reduce its damage.

Not available also is the quantitative data on yield loss due to B. fusca incurred by crops in farmers fields in Kenya, particularly in the high altitude maize growing areas. It therefore became necessary to conduct field studies in farmers' fields to estimate crop losses caused by this pest. The other objective of the study was to generate information on B. fusca infestation levels in farmers' maize crops and the magnitude of the damage caused to them.

Finally, it was considered that it was essential to understand the relationship between the levels of infestation by B. fusca and its effects on vegetative growth and grain yield of maize. Such information once acquired, would be valuable in the formulation of economic injury levels related to the growth stage of maize when the attack commenced. This would also lead to the identification of the most vulnerable stage during which damage by _B_. _fusca_ should be controlled.

The summary of the main objectives of the studies reported here is as follows:

(a) To study the biology and ecology of the maize stalk borer _B_. _fusca_ ;

(b) To study the population patterns of _B_. _fusca_ in relation to crop phenology in early and late planted maize crops ; and,

(c) To assess crop losses caused by _B_. _fusca_ using several methods.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Pest status of Busseola fusca

The pest status of B. fusca which is an endemic pest in Africa was recognized at the beginning of this century (Mally, 1920 ; Jepson, 1954). Since its description by Fuller (1900), the pest has received considerable attention (Mally, 1920 ; Jepson, 1954 ; Usua, 1968a ; Walters, 1979 ; Kaufmann, 1983 ; Gebre-Amlak, 1988).

The present review of literature was undertaken with a view to bring together available information pertinent to the objectives of the studies reported here. The review would also indicate the existing gaps in the available information which when filled could lead to a better understanding of the pest.

2.2 The biology of the maize stalk borer Busseola fusca

There is no reported information on the biology of B. fusca in Kenya's high altitude maize growing areas. From studies conducted in South Africa, the female moth prefers to lay eggs in batches beneath the leaf sheath on the youngest fully unfolded leaf (Van Rensburg, 1980). Maize plants that are 3 - 5 weeks old after germination are the most preferred for oviposition (Walters et al. 1980).

The number of eggs laid by the female moth under uncontrolled conditions ranges from 360 - 723 (Smithers, 1960a ; Usua, 1968b ; Unnithan, 1987). The eggs which are globular and measure about 1.0 mm in diameter are whitish when newly laid but turn black just before hatching (Tams and Bowden, 1953 ; Hill, 1975 ; Schmutterer, 1969). The incubation period is 6 - 11 days depending on temperature and relative humidity (Ingram, 1958 ; Smithers, 1960a ; de Pury, 1968).

The newly hatched larvae remain at the site of oviposition for 1 - 2 days and then migrate up to stem and down into plant funnel (Walters _et al_. 1980 ; Barrow, 1989). There appears to be variations in the durations of the larval stage of _B_. _fusca_. For example, in Nigeria, Kaufmann (1983) recorded a larval period of 32 days while in Uganda the pest had larval duration of 50 days (Ingram, 1958). Usua (1968b) considered that among the factors that led to variations in larval durations were ambient temperature, relative humidity and age of the plant at the stage of infestation.

Newly hatched larvae are about 2 mm long and when mature measure about 30 - 40 mm (Mally, 1920 ; de Pury, 1968 ; De Lima, 1976). Larvae vary in colour from light to pink (Schmutterer, 1969). However those which undergo diapause become pure white (Usua, 1970a ; Hodson and Walker, 1975). Larvae are identified by brown to black heads with brown prothoracic plates (Smit, 1964). In addition, black spots along the sides and dark warts arranged segmentally from which fine hairs arise are diagnostic characteristics of the larvae (Hodson and Walker, 1975 ; Hill, 1975 ; Khaemba, 1985).

The biology of B. fusca is characterised by larval diapause occurring during periods of unfavourable conditions (Swaine, 1957 ; Smithers, 1960b ; Harris, 1962 ; Usua, 1970a). This adaptation enables the pest to synchronize its activities to favourable conditions and also to enhance its survival during unfavourable periods (Tauber and Tauber, 1976).

Not all larvae of B. fusca pupate on attaining full growth; a portion of the larvae enter diapause (Kaufmann, 1983). Both Usua (1973) and later on Unnithan (1987) considered that among the factors responsible for diapause induction in B. fusca is the composition of food plants.

Diapause may last 6 - 7 months and its termination has been associated with increasing rainfall and lower temperatures (Harris, 1962). In addition, pupation of diapausing larvae appear to be influenced by the amount of rainfall received during the post-diapause period (Gebre-Amlak, 1988). However, the factors involved in maintenance and termination of diapause in the field have not been well established.

The morphological characteristics of the pupae were described by Mally (1920). Average duration of pupal stage is 10 - 14 days depending on temperature (Ingram, 1958 ; De lima, 1976). The pupae are obtect in form and brown measuring about 25 mm in length (Hill, 1975).

The adult moth, with a wingspan of about 30 - 40 mm is nocturnal (de Pury, 1968 ; Schmutterer, 1969). Its forewings are dull coppery brown with inconspicous markings and the hind wings are pale smokey-brown and unmarked (Fuller, 1900 ; Taylor, 1982). The body of the moth is greyish brown with the front of thorax being tinged with red (Fuller, 1900). Sexes of the moth are recognized by shape of antennae, the female having filiform antennae while those in males being pectinate (Jepson, 1954).

Fecundity rate and survival of _B_. _fusca_ moths varies depending on whether they emerged from diapause or non-diapause generations. Female moths from non-diapause generations laid more eggs and survived longer (Unnithan, 1987 ; Gebre-Amlak, 1988). These authors (Unnithan, 1987 ; Gebre-Amlak, 1988) attributed this variation to better quality of nutrition derived from young maize during their development.

The number of generations the pest undergoes per year varies from 2 - 3 in most areas in Africa (Graham, 1947 ; Schmutterer, 1969 ; Hill, 1975). The variation in the number of generations completed per year is probably due to the different climatic conditions and vegetation and cropping patterns found in different regions (Gebre-Amlak, 1988).

2.3 Incidence and carry-over of the maize stalk borer _Busseola_ _fusca_ during the dry season

At the close of the growing season, the larvae of _B_. _fusca_ often enter into diapause and remain in dry stalks and stubble left in the field after crop harvest (Nye, 1960 ; Mohyuddin and Greathead, 1970 ; Unnithan and Seshu Reddy, 1989). As a result, the diapausing larvae are a potential innoculum source which perpetuates infestation from season to season. For this reason, the extent to which crops are attacked at the beginning of a new growing season is partly determined by the number of diapausing larvae surviving during the dry season (Warui and Kuria, 1983).

According to the report of Jepson (1954), serious infestations by stalk borers could develop in two main ways:

(a) the initial population may be in stubble left from a previous crop and within two generations, this population could increase sufficiently to cause serious damage; and,

(b) the emergence of adults of stalk borer population on alternate host-grasses coincides with young maize crops in the field.

Harris (1962) observed that the survival of *B. fusca* in Nigeria depended on the presence of crop residues of the previous season throughout the dry season. In the same country, where the climate permits the planting of two maize crops, the intervening dry periods are bridged by diapausing larvae so that two similar patterns of attack are experienced each year (Adeyemi, 1969). In addition, Adeyemi (1969) found that the maize stubble left after the early season's harvest had an average of 27.0 stalk borers per 100 stubbles while the late season crop had 15.0 stalk borers per 100 stubbles. From these data, Adeyemi (1969) concluded that the stalk borer population in the stubble of both early and late crops was sufficiently large to cause initial infestation of the succeeding crop.

In Ethiopia, Gebre-Amlak (1988) demonstrated the potential of B. fusca larvae population to survive the dry season in crop residues left on peasant farms.

Very little information is available on the role of maize residues left in fields after harvesting in the carry-over and survival of B. fusca in Kenya. Unnithan and Seshu Reddy (1989) observed high numbers of mature diapausing larvae surviving in sorghum crop residues left after harvest. These authors recorded an average population of 13.3 stalk borers per 50 sq.m in February when land preparation and planting of long rain crop had started. They concluded that moths emerging from the diapausing larvae at this time could cause heavy infestation of the newly planted crops.

There is overwhelming evidence in literature which indicates that apart from Sorghum bicolor (L.) Moench and maize, the pest has many other alternative hosts (Jepson, 1954 ; Swaine, 1957 ; Ingram, 1958 ; Harris, 1962 ; Le Pelley, 1959 ; Seshu Reddy, 1983 ; Gebre-Amlak, 1988).

2.4 Biotic mortality factors influencing populations of diapausing larvae of the maize stalk borer Busseola fusca during the dry season

As yet, in Kenya's highland maize growing areas, the role of mortality factors especially parasitic insects that reduce the stalk borer population diapausing in maize crop residues is undetermined. In South Africa, Mally (1920) and recently Kfir (1988) and Van Rensburg et al. (1988b) observed that hymenoptera parasites Apanteles sesamiae Cameron and Bracon spp were important biological mortality factors of the diapausing larvae. Similar observations were reported by Mohyuddin (1971) in Ethiopia. Additionally, ants especially Pheidole spp , Dorylus spp (Kfir, 1988) and Camponotus spp (Seshu Reddy, 1983) have been reported as being important predators of the larvae of the maize stalk borer. Other mortality factors include fungus and dessication (Jepson, 1954).

2.5 Monitoring of seasonal populations of adult Busseola fusca moths

Various types of light traps have been used to monitor populations of lepidopterous moths, for survey purposes to indicate periods of peak activity in timing of pest outbreaks and to provide clues for improvement of control strategies (Southwood, 1978). Light traps have been used in monitoring of B. fusca in Africa on a limited scale.

Harris (1962) using a mercury-vapour light trap (model unspecified) established that three generations of B. fusca were completed during the growing season in Nigeria. Van Rensburg et al. (1985) used Robinson light traps to monitor seasonal abundance of the maize stalk borer moths in the maize producing areas of South Africa. He (Van Rensburg et al. 1985) established that geographical variation existed between localities and that there were three seasonal flight periods. It would be extremely useful to find out similar information with regard to seasonal flight periods of B. fusca in Kenya's highlands. This would indicate whether there is any relationship between crop attack and flight activities of the pest.

Thanh Ho and Seshu Reddy (1983) investigated the possibility of using light traps (using pressure lamps) for monitoring field populations of cereal stalk borers in Western Kenya. B. fusca moths were the least attracted. The reasons why the moths were the least attracted to the light traps were not immediately established.

However, it is known that light traps are generally inefficient at low levels of pest populations (Oloumi-Saghedi et al. 1975). In addition, light trap catches are also influenced by the phases of the moon and weather (Bowden and Church, 1973 ; Robertson, 1977 ; Thanh Ho and Seshu Reddy, 1983).

2.6 Effect of maize stubble disposal practices on the survival of the maize stalk borer Busseola fusca

It has already been noted that a number of researchers have reported that B. fusca larvae survived as diapausing larvae in crop residues after harvesting (See Section 2.3). From their observations these researchers concluded that diapausing larvae in crop residues were an important potential source of infestation to young maize crops and recommended complete destruction of such residues.

Duerden (1953) and Swaine (1957) discussed the relative potential of destruction of stubble in managing population of stalk borers through burning, grazing and ploughing under. They argued that such practices would not be adopted as they would conflict with farmers requirements for fuel, thatch and soil conservation measures.

Complete burning of the stalks after crop harvest or spreading them thinly on the ground to expose larvae to full effects of weather conditions was recommended by Harris (1962) as a cultural way of controlling stalk borers. However, Adesiyun and Ajayi (1980) noted that such a practice though capable of achieving 100% mortality of B. fusca was not accepted by farmers in Nigeria, since these crop residues were kept for use as fuel apart from being fed to livestock and for construction purposes. They (Adesiyun and Ajayi, 1980) recommended partial burning of stalks immediately after harvest when the stems still contained some moisture. This practice achieved 95% mortality of B. fusca with no damage to the stalks which farmers used for other purposes.

In addition, Gebre-Amlak (1988) observed that the practice of placing infested maize stalks horizontally on the ground in the sun for about four weeks was effective in reducing carry-over populations of B. fusca. It achieved 97% mortality of the larvae and thereafter the stalks could still be used for building or fuel. It was conluded from Lawani's (1982) review on cultural control measures applied against stalk borers, that though cultural methods seldomly gave spectacular results, they could readily be adopted by farmers when such methods also had desirable agronomic advantages.

2.7 Population patterns of the maize stalk borer Busseola fusca in relation to crop phenology in early and late season crops of maize

According to available literature, there are conflicting reports regarding the relationship between B. fusca infestations and planting dates. In Kenya early planting of maize has always been recommended to avoid the late population build-up of B. fusca in maturing plants (Jepson, 1954). The late plantings of maize could escape the first generation and not the second generation known to cause heavier damage on such crops (Graham, 1951 ; Taylor, 1982). Warui and Kuria (1983) in Coast Province of Kenya observed that early plantings of maize had lower infestations of stalk borers per plant. Similar observations have been reported by Gebre-Amlak (1988) in Ethiopia. These researchers (Warui and Kuria, 1983 ; Gebre-Amlak, 1988) also noted that in the case of late plantings the levels of infestations by stalk borers were significantly higher and caused heavier damage.

On the other hand, observations of Duerden (1953) working in Tanzania indicated that there existed very little effect of planting dates of maize on the infestation pattern by B. fusca. From field studies, Swaine (1957) reported that late plantings escaped the first generation emerging from diapause larvae of B. fusca after the onset of rains. Both workers (Duerden, 1953 ; Swaine, 1957) discussed the relative potential of adjusting times of sowing as a way of reducing stalk borer damage. They both ruled out this practice as being unfeasible because farmers staggered planting dates and could not effect synchronized planting over large areas in order to escape damaging population of stalk borers.

In the highland areas of Kenya the exact infestation pattern of _B_. _fusca_ in relation to the phenology of the crop has not been carefully determined. It is not known whether the infestation pattern of the pest is comparable throughout the maize growing areas of Kenya. Part of the studies reported here were aimed at obtaining this information.

2.8 Crop loss assessment methods used in estimation of yield losses caused by the maize stalk borer _Busseola fusca_

Crop loss is the reduction in either quantity and / or quality of yield and in quantitive terms , it is the difference between actual yield and attainable yield (Zadoks and Schein, 1979). Crop loss data have been gathered by several methods listed by Teng (1981) as being :

(a) expert testimony ;
(b) inquiries ;
(c) literature review ;
(d) remote sensing ; and
(e) field experiments / surveys.

The value for crop loss data need not be emphasized since assessment of crop losses due to pests is a pre-requisite for any planned programme of crop protection for the purpose of getting higher returns (James and Teng, 1979).

Crop loss data for B. fusca has not been calculated in the case of highland areas of Kenya. In order to design and achieve optimal control of the pest, it became necessary to seek through field experiments for the information. Although many estimates of insect losses have been made, some of them have been controversial because they have depended on personal opinion, with most of them not being backed by adequate data (Ridway, 1980).

Additionally, estimates have been converted to quantitive monetary losses without considering price changes associated with changes in supply and demand that was likely to occur if the losses were prevented (Veeresh, 1980). According to one estimate, Africa loses no less than 42% of potential harvest with 13% caused by insects, 13% by plant diseases and the remaining 16% by weeds (Singh, 1977).

It is clearly evident from literature that suitable techniques for assessment of crop losses due to insect damage including, B. fusca are available (Pradhan, 1964 ; Veeresh, 1980; Khosla, 1980 ; Singh and Khosla, 1983 ; Leuschner and Sharma, 1983). The extent of quantitative crop losses caused by insect pests could be obtained through the following methods :

(a) estimation of damage through visual scores (Leuschner and Sharma, 1983) ;

(b) comparing the yields from a mechanically protected pest-free crop with a naturally pest infested crop (Veeresh, 1980 ; Khosla, 1980 ; Singh and Khosla,

1983) ;

(c) comparing the yields from a chemically protected pest-free crop with a naturally pest-infested crop (Veeresh, 1980 ; Khosla, 1980 ; Singh and Khosla, 1983 ; Leuschner and Sharma, 1983) ;

(d) comparing the yields in different fields having different degrees of pest infestation (Singh and Khosla, 1983 ; Leuschner and Sharma, 1983) ;

(e) comparing the average yields of individual plants free from pest infestation with that of infested plants (Veeresh, 1980 ; Khosla, 1980 ; Singh and Khosla, 1983) ;

(f) comparing the yields with the degree of incidence brought about by artificial infestation (Leuschner and Sharma, 1983) ; and ,

(g) by knowing the average amount of damage caused by one individual insect (Veeresh, 1980 ; Khosla, 1980 ; Singh and Khosla, (1983).

In these studies the techniques outlined in (c), (e) and (f) above were employed in working out maize yield losses due to B. fusca.

2.9 Crop losses caused by the maize stalk borer Busseola fusca

Of all the stalk borers B. fusca probably has the greatest potential to damage cereals in Africa due to its wide distribution and voracious feeding habits (Barry and Andrews, 1974 ; Hill, 1975). The pest causes particularly serious damage when it infests maize at an early age and in large numbers (Ingram, 1958 ; Usua, 1968a). In earlier studies, damage to the leaves and whorls had been reported as being more economically important in expressing crop losses (Ingram, 1958 ; Walker, 1960b). However, recent studies indicated that injury to the stem was more economically important than whorl damage (Van Rensburg _et al_. 1988a).

Warui _et al_. (1986) reported that the seriousness of damage caused by infestation of _B_. _fusca_ was influenced by factors such as rainfall, ambient temperature, age of plant, infestation pressure and other agro-ecological conditions. This had been demonstrated earlier by Coaker (1956) in East Africa where maize is grown under adverse conditions such as unpredictable rainfall and poor soils. He (Coaker, 1956) observed that maize grown under adequate rainfall was unaffected by stalk borer damage. Additionally, small weak plants suffered more from stalk borer attack than healthy ones (Coaker, 1956).

Several workers have reported yield loss estimates due to _B_. _fusca_ in several countries in Africa (Walker, 1960b ; Harris, 1962 ; Usua, 1968a ; Gebre-Amlak, 1988). Apparently, these losses in yields have been attributed to the damage caused in the form of loss of plant stands, extensive leaf feeding, cob feeding and stem tunnelling (Jepson, 1954 ; Swaine, 1957).

In Tanzania, Duerden (1953) observed that maize not protected from _B_. _fusca_ yielded 44% less grain than maize protected with DDT. In the same country, Swaine (1957) recorded 14% loss in yield when plots of small holder farmers were not treated with DDT for stalk borer control. He (Swaine, 1957) found that insecticide applications for stalk borers increased grain yields by 73 - 83%. Additionally, Walker (1960a) reported that total crop loss due to the same pest was not uncommon in Tanzania.

Harris (1962) working in Nigeria recorded an increase in yield of about 26% when maize crops were protected from attack by B. fusca by application of insecticides. Usua (1968a) determined that the presence of 1 or 2 larvae per plant reduced yield by 25% in the same country.

Rose (1962) and Taylor (1982) recorded variable crop losses in maize due to B. fusca ranging from 0 - 100% in Zimbabwe. The first generation of larvae was important in terms of causing yield loss than the second generation larvae which attacked the crop when it was already well established unless the crop was very late planted (Taylor, 1982). Walters et al. (1980) working in South Africa and Gebre-Amlak (1988) working in Ethiopia reported similar findings.

In Kenya, Walker (1967) in his surveys estimated losses in maize due to stalk borer infestation to be 18% for the whole country. Walker and Hodson (1976) reported further that about 1.2% yield reduction occurred when 1% of the plants were attacked. Reliability of these estimates is questionable since the technique used was based on visual scores backed with inadequate data.

CHAPTER 3

SOME ASPECTS OF THE BIOLOGY OF THE MAIZE STALK BORER BUSSEOLA FUSCA

3.1 INTRODUCTION

The maize stalk borer B. fusca has been recognized as the most destructive pest of maize throughout most of the tropical areas of Africa (See Chapter 2). In the Rift Valley Province of Kenya, the pest causes much damage and is responsible for considerable losses in yield (Bullock, 1958).

Some aspects of the biology and life cycle of B. fusca have been studied in other parts of Africa (See Chapter 2, Section 2.2). No information is available on the biology and life cycle of the pest in Kenya's high altitude (1,000 - 2,400 m) maize growing areas. Since it was difficult to ascertain as to whether the information gathered elsewhere on the biology of the pest was applicable to Kenya, the present studies were undertaken to provide information for a better understanding of the pest. The aspects of the biology of the pest studied were durations of different life stages, longevity, fecundity and sex ratio using moths derived from diapause and non-diapause generations.

The experimental work reported here was conducted at the Plant Breeding Research Centre (PBRC), Njoro (2165 m, 0^{o} 20' S, 35^{o} 56' E). The rearing of B. fusca larvae was accomplished in controlled environmental chambers (Conviron Model 123L) set at

23.5 °C, 50 - 70% relative humidity and 12 hours of light : 12 hours of darkness photoperiod.

3.2 MATERIALS AND METHODS

3.2.1 Development of Busseola fusca

Cultures of B. fusca were initiated by collecting pupae from the field, and kept in glass vials (75 X 25 mm) in the laboratory.

Genital characteristics were used to sex pupae into males and females. In the case of the female pupa the genitalia scar was situated on the 8th sternum while in the male pupa it was situated on the 9th sternum. The male and female pupae were then retained separately until adult moth emergence. Moths were paired by sex and kept for oviposition.

In order to determine the duration of developmental stages, a batch of 188 eggs from one female which were laid at the same time (0 - 12 hrs) were placed in plastic petri dishes (15 X 85 mm) lined with moistened filter paper. The petri dishes were then placed in the controlled environmental chamber. The eggs were observed daily until they hatched.

The newly hatched larvae were then introduced by the use of a camel hair brush into leaf whorls of terminal funnels of maize variety H625 aged four weeks. The larvae were transferred to fresh stems within leaf whorls at three-day intervals. When the larvae started dispersing fom leaf whorls to stems, they were each transferred to a portion of maize stem measuring 16 cm long. The infested stems were then placed into perspex cages (40 X 25 X 25 cm) and held in the controlled environmental chamber.

As <u>B</u>. <u>fusca</u> larvae fed and increased in size, they were transferred to maturer portions of maize stems. Introduction of the larvae into the stems was accomplished by punching holes into them with a nail (10 cm size) before the larvae were placed into each hole. The larvae were allowed to tunnel through the stem until they attained maturity. The larvae on reaching maturity, which was detected when they started chewing small perforated "windows" (exit holes) in the outer stem tissue, were allowed to complete pupation inside the stems. Incubation period, durations of larval and pupal stages were determined.

3.2.2 Longevity, fecundity and sex ratio of <u>Busseola</u> <u>fusca</u> obtained from different seasons

Comparative studies on longevity, fecundity and sex ratio of <u>B</u>. <u>fusca</u> were conducted after separately establishing laboratory colonies with larvae collected fom the field during two different seasons :

(a) the dry season (March) for recovery of diapausing larvae from the dry stalks of maize ; and ,

(b) the wet season (July) for recovery of non-diapausing larvae from fresh stalks of maize.

The pupae derived from larvae from these seasons were confined singly in plastic petri dishes (15 X 85 mm) after sexing until adult emergence. After eclosion, moths that emerged on the same day were paired by sex and kept for oviposition after mating in perspex cages (40 X 25 X 25 cm).

No food was provided to adult moths since in view of the findings of Kaufmann (1983) and Unnithan (1987) that it neither affected their survival nor fecundity. The moths were however provided with tap water soaked in cotton wool pads before being placed in the rearing cages.

Maize seedlings (variety H625) aged four weeks were introduced into the rearing perspex cages for oviposition. Fresh seedlings were introduced everyday for the same purpose. The eggs laid were collected every morning and counted prior to being incubated in petri dishes lined with moistened filter papers. Adult longevity, pre-oviposition period, oviposition period, post-oviposition period and fecundity per female moth were determined. The data were subjected to analysis of variance in order to find out if there were significant differences between moths from the two seasons.

In order to establish the sex ratio for diapause and non-diapause generations, 106 sixth instar larvae were retained in rearing perspex cages. The diapause larvae were retained in dry stems while the non-diapause larvae were retained in fresh stems, with a single larva in its own portion of stem. Emerging moths were then counted and sexed. In order to establish whether there were differences in survival and sex ratio between the moths derived from diapause or non-diapause larvae, the data was analysed using a Chi-square test.

3.3 RESULTS

3.3.1 Development of Busseola fusca

The developmental periods of various stages of B. fusca are summarised in table 1. Of the total of 188 eggs incubated 135 eggs or 71.8% hatched into viable larvae. Incubation period of eggs lasted between 7 - 9 days (mean 7.5 ± 0.5 days). Out of a total of 135 larvae reared, 41 of them or 30.4% underwent diapause, while the rest (94 larvae or 69.6%) underwent normal development without experiencing an intervening diapause. The larval period of non-diapause larvae lasted between 31 - 60 days (mean 40.9 ± 0.5 days). On the other hand, the duration of larval period of diapause larvae was much longer ranging between 221 - 256 days (mean 238.5 ± 13.1 days). The pupation period ranged from 14 - 21 days (mean 19.5 ± 2.1 days). The average longevities of males and females were 5.8 ± 3.1 days and 5.3 ± 2.2 days respectively (Table 1).

3.3.2 Longevity, fecundity and sex ratio of Busseola fusca

The life history of B. fusca moths arising from larvae derived from the dry and wet seasons indicating durations of pre-oviposition period, oviposition period and post-oviposition period, longevity and fecundity is given in table 2. It is

Table 1. Mean duration (±S.E.) in days of the developmental stages of the maize stalk borer <u>Busseola</u> <u>fusca</u>

Developmental stages	Mean duration ± S.E.	Range (days)	Number (n)
Egg	7.5±0.5	7-9	188
Non-diapause larvae	40.9±0.5	31-60	94
Diapause larvae	238.5±13.1	221-256	41
Pupae	19.5±2.1	14-21	23
Adult			
Male	5.8±3.1	2-9	10
Female	5.3±2.2	3-8	10

Table 2. Pre-oviposition, oviposition, post-oviposition periods, longevity and fecundity of *Busseola fusca* derived from the wet and dry seasons.

	Diapause female moths		Non-diapause female moths		F
Parameter of oviposition	Mean (±S.E.)	Range	Mean (±S.E).	Range	value
Pre-oviposition period (days)	1.2±0.4	1-2	1.2±0.4	1-2	0.01ns
Oviposition period (days)	3.4±1.1	3-5	2.8±2.2	2-6	0.3ns
Post-oviposition period (days)	1.2±1.3	0-3	1.2±0.4	1-2	0.01ns
Total longevity (days)	5.6±2.5	3-8	5.2±1.8	4-8	0.24ns
Mean number of eggs / female	570.2±173.9	372-818	318.4±278.0	111-747	2.95ns

ns = nonsignificant (P>0.05)

shown in table 2 that both female moths from diapause and non-diapause generations had similar pre-oviposition periods lasting between 1 - 2 days (mean 1.2 ± 0.4 days). Diapause female moths had a longer mean oviposition period of 3.4 ± 1.1 days (range 3 - 5 days) as compared to that of non-diapause female moths which was shorter being 2.8 ± 2.2 days (range 2 - 6 days. This difference was however not significant ($P > 0.05$).

As shown in table 2 , post-oviposition period lasted an average of 1.2 ± 1.3 days (range 0 - 3 days) in diapause moths whereas that of non-diapause females lasted 1.2 ± 0.4 days (range 1 - 2 days). The post-oviposition period did not also differ significantly ($P > 0.05$) between diapause and non-diapause moths. The average longevity for diapause and non-diapause moths was 5.6 ± 2.5 days (range 3 - 8 days) and 5.2 ± 1.8 days (range 4 - 8 days), respectively. There was no significant ($P > 0.05$) difference between the two generations in longevity.

The mean fecundity (eggs / female) between diapause and non-diapause female moths was not significantly ($P > 0.05$) different as shown in table 2. However, the fecundity of diapause moths was higher and ranged between 372 - 818 (mean 570.2 ± 173.9 eggs / female) whereas that of the non-diapause moths ranged between 111 - 747 (mean 318.4 ± 278 eggs / female).

Data on sex ratio of B. fusca sampled from different generations of diapause and non-diapause larvae is given in table 3. The female to male sex ratio was almost identical in diapause and non-diapause moths being 0.52 : 0.48 and 0.51 : 0.49, respectively. There was no significant difference

Table 3. Sex ratios of the maize stalk borer <u>Busseola</u> <u>fusca</u> derived from different seasons.

	No. of larvae	No. of larvae	Survival	No. of emerged		Sex ratio
Source of larvae	infested	that survived	ratio	females	males	
Diapause larvae	106	88	4.9	46	42	0.52 :0.48
Non-diapause larvae	106	103	34.3	53	50	0.51 :0.49

Chi-square (sex ratio) = 0.0127ns ($P>0.05$).

Chi-square (survival ratio) = 11.8922** ($P<0.01$).

in sex ratio between diapause and non-diapause moths (Chi-square = 0.013, P > 0.05). Non-diapause larvae showed a significantly higher survival ratio of 34.3 as compared to diapause larvae which had a survival ratio of 4.9 (Chi-square = 11.892, P < 0.01).

3.4 DISCUSSION

From the results obtained in the present study, the average developmental period of B. fusca from egg to adult for non-diapause larvae was shorter (67.9 ± 4.03 days) than that of the diapause larvae (265.5 ± 5.2 days) which was about four times as long. Additionally, 30.4% of the larvae from the same egg batch entered diapause. Similar observations were reported by Unnithan (1987). In his work (Unnithan, 1987) recorded a higher percentage of 72.0 of the larvae which entered diapause after being fed on mature stems. It is evident that this is a common feature in the biology of B. fusca to ensure its survival.

Diapause, was in the present studies, probably caused by deterioration in the quality of nutritional factors in the host plant. Both Usua (1973) and Unnithan (1987) in their studies suggested that maturity of the host plants were responsible for the onset of diapause. In addition, Usua (1970a) earlier on reported that there was probably an intrinsic genetic mechanism that was responsible for the onset of diapause in B. fusca.

Pre-oviposition period is of considerable importance as its duration has some implications on how far the moth could disperse before egg oviposition starts. In the current studies the pre-oviposition was similar and quite short in both generations implying that its role in pest dispersal was minimal.

Results obtained in these studies also indicated that the female moths from diapause and non-diapause generations had similar adult longevity. This finding was of interest because some of the earlier researchers (Unnithan, 1987 ; Gebre-Amlak, 1988) reported that female moths from non-diapause generation lived significantly longer than diapause generation moths. The disparity in observations on the longevity of moths was probably caused by the different environmental conditions under which the studies were performed.

Fecundity studies showed that there were no significant differences in the mean number of eggs laid per female between diapause and non-diapause moths. This finding is also contrary to earlier observations on B. fusca by Smithers (1960a), Usua (1968b), Unnithan (1987) and Gebre-Amlak (1988). In their studies they found that female moths from non-diapause generations laid significantly more eggs.

It was observed that diapause larvae suffered higher mortality as compared to non-diapause larvae. This was in conformity with Usua's (1970b) observations who attributed the higher survival of non-diapause larvae to a better nutrition as they fed on more nutritious stems of young plants.

From the results obtained in these studies, it was found that the sex ratio between the females and males of the pest was almost identical for diapause and non-diapause generations.

Unnithan (1987) reported similar findings, with males and females emerging in about equal numbers. The results gathered in these studies suggested that the normal sex ratio was approximately 1 : 1 . As males mate more frequently than the females (Chapter 6) it would appear that many of the former must be deprived of the opportunity to copulate. This might have the advantage of increasing sexual competition to ensure a higher rate of successful and viable matings.

CHAPTER 4

INCIDENCE AND CARRY-OVER OF THE MAIZE STALK BORER BUSSEOLA FUSCA DURING THE DRY SEASON

4.1 INTRODUCTION

B. fusca causes serious damage to maize in the cool high altitude areas of East Africa (Chapter 2). The pest passes the dry season as full grown diapausing larvae in maize crop residues as a dry season survival mechanism (Graham, 1951 ; Swaine, 1957 ; Smithers, 1960b). This mechanism of adaptation to survive adverse drought conditions has important implications for control purposes.

Despite the seriousness of this pest, information on population levels in stalk borer incidence during the off-season period is not available in Kenya. The role of maize crop residues in the carry-over of the pest is also not clearly understood. Studies reported here were designed to obtain this information.

Also known is the fact that B. fusca has several alternate grass hosts besides maize (Schmutterer, 1969). Since weed control in maize crops in farmers' fields is not thorough, especially in high altitude areas where these studies were conducted, it is not unusual to find alternate host plants growing in maize fields especially during the off-season and could thus serve as a reservoir.

Although diapausing larvae are the main source of innoculum that causes initial infestation of crops every season, adequate information on the role of crop residues and alternative host plants is lacking. Availability of such information would be of immense value in designing better control strategies for the pest.

4.2 MATERIALS AND METHODS

Studies to determine the incidence and carry-over of B. fusca in maize crop residues were conducted in Nakuru District at two sites : Kiroboni (1954 msl) and Njoro (2165 msl) during 1987 and 1988 off-seasons. Both areas are in Lower Highland 3 (LH 3) agro-ecological zone having a bimodal pattern of rainfall of over 875 mm (Jaetzold and Schmidt, 1983).

The investigations were conducted using stubbles of maize variety H625 left in the field immediately after crop harvest. The stubbles were taken from a predetermined area measuring 2.5 ha. The area was divided into four plots each measuring approximately 0.625 ha (75 X 83.4 m). From each plot one random sample of stalks found in an area of 12.5 sq. m (2 m radius) was removed at each sampling date. B. fusca population present in stubbles were determined by repeated removal of four samples at two weekly intervals in the four randomly selected 12.5 sq.m plots. Thus in total 50 sq.m area of stubble was removed on every sampling date.

In each of the four randomly selected 12.5 sq.m plots, all the standing stalks and broken pieces of stalks lying on the ground were gathered together in a bundle and taken to the laboratory for dissection to recover the larvae and pupae of B. fusca . The bundles from different plots were kept separately to avoid mixing up.

Monitoring of B. fusca populations surviving in maize stubbles was started in January and terminated after the onset of the long rains in April of each year. Additionally, the presence of peak numbers of pupae was taken as being the termination point of diapause of the surviving B. fusca larvae in the maize stubble. Statistical analysis of data was undertaken using one way analysis of variance to establish whether there were significant differences between the two study areas. Also tested for significance was the variation in B.fusca larval population in each of the sites between 1987 and 1988 seasons.

To identify alternate hosts of B. fusca, grasses growing in the fields of PBRC,Njoro and in adjacent farmers' fields were examined for any infestation by B. fusca larvae during 1987 and 1988 dry seasons. Observations commenced after the completion of harvesting maize in January and were discontinued at the beginning of the long rains in April.

Four random samples of plants each obtained from an area of 12.5 sq.m of the grass species observed to be infested by B. fusca were taken once every month. These plants were carefully dissected to recover any larvae and pupae present in them. These were then counted and recorded. Statistical assessment using a two way analysis technique of the data collected was performed to ascertain as to whether significant variation of the pest population existed from month to month and among the different alternative hosts.

4.3 RESULTS

Data obtained on the incidence of carry-over of the population of B. fusca during the off-season at Kiroboni and Njoro are presented in table 4. Significant ($P < 0.01$) differences in larval population existed between the two sites for the season of 1987 and not for that of 1988 . At Kiroboni an average of 52.5% stalks were infested with larvae and / or pupae of stalk borers. At this level of stalk infestation it was revealed by these studies that there was a density of 2.9 insects / sq.m as carry-over population. During the following year (1988) infestation level decreased to 34.7% or 2.1 insects / sq.m. No significant ($P > 0.05$) differences existed between 1987 and 1988 in percentage stalk infestation and density of carry-over population of B. fusca.

At Njoro, stalk infestation rate by B. fusca was much lower being 39.7% or 0.6 insects / sq.m for the season of 1987. During the following year (1988), the level of stalk infestation became drastically low being 12.6% stalks infested or 0.3 insects / sq.m. There were significant ($P < 0.01$) differences in stalk infestation between 1987 and 1988 at Njoro (Table 4). However no such significance was established between insect

Table 4. Carry-over of <u>Busseola</u> <u>fusca</u> larvae and pupae population in maize crop residues per 50 sq. m at two localities in Nakuru District during 1987 and 1988 off-seasons.

		KIROBONI AREA (1954 msl)					NJORO AREA (2185 msl)				
Year	Sampling dates	No.of stalks assessed	% stalks with larvae	No.of live larvae	% larvae below ground	No.of live pupae	No.of stalks assessed	% stalks with larvae	No.of live larvae	% larvae below ground	No.of live pupae
1987	22.1.87	180	80.0	301	28.3	0	68	51.4	42	46.0	0
	4.2.87	186	78.0	296	26.0	2	62	54.8	35	45.0	0
	18.2.87	154	53.9	125	20.9	3	68	36.8	26	38.5	0
	4.3.87	144	54.9	104	25.4	0	64	39.1	33	45.5	0
	18.3.87	120	46.7	81	16.1	1	62	48.4	37	21.6	2
	1.4.87	120	38.3	70	12.9	2	55	36.4	18	33.3	8
	15.4.87	174	35.6	89	22.5	13	52	17.3	3	0.0	15
	29.4.87	133	32.3	23	30.4	32	45	33.3	1	0.0	14
	Mean	151.4	52.5	136.1	22.8	6.6	59.5	39.7	24.4	28.7	4.3
988	21.1.88	182	44.5	240	4.6	0	83	19.3	17	11.8	0
	3.2.88	160	44.4	118	5.9	3	102	19.6	18	16.7	1
	17.2.88	141	64.5	170	12.9	2	81	19.8	15	13.3	3
	1.3.88	145	55.2	174	7.1	5	97	9.3	9	22.2	1
	14.3.88	123	35.0	63	15.9	12	86	11.6	12	8.3	4
	28.3.88	143	15.4	23	13.0	15	68	14.7	11	9.1	14
	11.4.88	60	15.0	7	0.0	14	61	3.3	6	0.0	6
	25.4.88	60	3.3	0	0.0	2	61	3.3	5	0.0	4
	Mean	126.8	34.7	99.4	7.4	6.6	79.9	12.6	11.6	10.2	4.1
test years			3.4ns	1.6ns	16.6**	0.2ns		28.9**	0.5ns	2.4ns	0.3ns
test sites (1987)			2.8ns	11.5**	0.2ns	0.3ns					
test sites (1988)			6.7*	3.8ns	0.3ns	0.6ns					

Significant at 5%level, ** =significant at 1% level and ns = nonsignificant.

densities recorded for the two years.

Data presented in table 4 also showed that diapausing larvae penetrated into the base of stalks below ground level during the dry season at both study sites. No significant ($P > 0.05$) differences occurred in percentage numbers of larvae that survived below the ground level between the two sites for both years. At Kiroboni an average of 22.8% (1987) and 7.4% (1988) larvae were found in stalks below ground level. The difference in infestation was significant ($P < 0.01$) between the two seasons.

On the other hand, at Njoro an average of 2.4% (1987) and 10.2% (1988) of larvae survived below the ground in stalks (Table 4). The difference in stalk infestation between the two seasons was not significant ($P > 0.05$).

Investigations in both localities revealed that the carry-over population within the stalks declined as the season advanced (Table 4). This was demonstrated by the fact that at the beginning of the season (January) at Kiroboni the population density was 6.0 insects / sq.m and declined to 1.0 insects / sq.m at the end of the season (April). During the following season (1988), the carry-over population declined from 4.8 insects / sq.m at the commencement of dry season (January) to 0.04 insects / sq.m at the end of the season (April).

A similar trend in the decline of the diapausing population of the pest was recorded at Njoro (Table 4). At Njoro the carry-over population declined in 1987 from 0.84 insects / sq.m at the start of dry season (January) to 0.30 insects / sq.m at the end of the season (April). During the following season (1988), the carry-over population declined from 0.34 to 0.18 individuals / sq.m at the end of the season (April).

Peak pupation period of the diapausing larvae occurred slightly earlier in 1987 as compared to 1988 season at both sites that were studied (Table 4). At Kiroboni and Njoro, peak pupation occurred towards the end of April in 1987 off-season. During the following year (1988), peak pupation occurred towards the end of March at both sites.

Results presented in table 5 showed that alternate grass hosts played a role in the carry-over of B. fusca during the dry season. The results (Table 5) confirmed that B. fusca survived in alternate grass hosts until the next cropping season in April / May. Columbus grass, S. almum harboured a significantly (P < 0.05) higher carry-over population as compared to other hosts. On the other hand, napier grass, P. purpureum carried the lowest carry-over population (P < 0.05).

There were no significant (P > 0.05) differences in the carry-over population between sudan grass, S sudanensis and grain sorghum, S. bicolor. Columbus grass carried the highest diapausing population of 1.4 individuals / sq.m throughout the observations lasting five months (January - May). It was followed in a descending order by sudan grass (0.9 insects), grain sorghum (0.9 insects) and napier grass (0.1 insects). There were significant (P < 0.05) variations in the carry-over population of B. fusca among grass hosts for each month of the dry season.

Table 5. Carry-over of *Busseola fusca* larvae and pupae population per 50 sq. m on alternate grass hosts during 1987 and 1988 off-seasons.

	B. fusca	Sampling months					
Alternate hosts	population	January	February	March	April	May	Mean
1.Columbus grass	No.of larvae	10.6(112)	9.2(84)	8.0(63)	6.2(37)	4.9(23)	7.8a (63.8)
(*Sorghum almum*)	No.of pupae	1.0(0)	1.7(2)	1.7(2)	4.0(15)	3.9(14)	2.5a (6.6)
2.Sudan grass	NO.of larvae	8.4(70)	7.4(53)	6.9(46)	5.7(32)	3.6(12)	6.4b (42.6)
(*Sorghum sudanensis*)	No.of pupae	1.0(0)	1.0(0)	1.7(2)	2.7(6)	2.0(3)	1.7b (2.2)
3.Grain sorghum	No.of larvae	8.8(76)	7.6(57)	5.9(34)	4.6(20)	2.7(6)	5.9b (38.6)
(*Sorghum bicolor*)	No.of pupae	1.4(1)	2.2(4)	2.5(5)	3.6(12)	3.0(8)	2.5a (6.0)
4.Napier grass	No.of larvae	3.7(13)	2.5(5)	2.8(7)	2.2(4)	2.0(3)	2.7c (6.4)
(*Pennisetum purpureum*)	No.of pupae	1.0(0)	1.0(0)	1.4(1)	1.4(1)	1.7(2)	1.3b (0.8)
Criterion	F test	LSD (5%)	C.V.				
Larvae (hosts)	29.8**	1.23	15.7%				
Larvae (months)	15.94**	1.37	15.7%				
Pupae (hosts)	6.78**	0.71	25.9%				
Pupae (months)	8.78**	0.80	25.9%				

* = Significant at 5% level, ** = significant at 1% level.

Figures in parentheses are means of original values.

Means followed by the same letter are not significantly different at P<0.05 by the LSD test.

Among the alternate grass hosts, peak pupation of _B_. _fusca_ occurred in April (Table 5). During this particular month, columbus grass had a carry-over population of about 1.04 insects / sq.m. Sudan grass had a carry-over population of 0.8 while grain sorghum and napier grasses harboured, respectively, 0.6 and 0.1 insects / sq.m.

4.4 DISCUSSION

The evidence gathered in these investigations confirmed that maize crop residues in the highland areas enabled _B_. _fusca_ to survive over the dry season until the next cropping season. It was revealed that the estimated carry-over population density was different between the sites that were studied. This suggested that infestation levels could be variable depending on the locality in the highlands.

The carry-over population of _B_. _fusca_ in maize crop residues declined as the season advanced. This was probably attributable to mortalities through dessication by adverse climatic conditions, predation and parasitism. Similar mortality factors were reported by Jepson (1954) and Harris (1964).

Diapausing _B_. _fusca_ larvae usually penetrated into root stalks below the ground level. The probable reason for this type of behaviour was to avoid dessication in order to survive the dry season conditions. Similar observations were reported by Smithers (1960a) and Unnithan and Seshu Reddy (1989). According to Unnithan and Seshu Reddy (1989), it was considered that diapausing larvae that had penetrated the underground parts of the stems had the best chances of survival.

Peak pupation period occurred slightly earlier in 1988 (end of March), as compared to 1987 (end of April). The difference was probably attributable to delays in the onset of rains and the amounts of rainfall falling prior to peak pupation. Preceding total rainfall before peak pupation was 60 mm and 149.3 mm for 1987 and 1988 respectively. Pupation of diapausing larvae was reported to be hastened by abundant early rains (Jepson, 1954). On the other hand, pupation could be delayed due to insufficient rainfall during post-diapause period (Gebre-Amlak, 1988). According to Gebre-Amlak's (1988) work, a cummulative rainfall of about 80 mm or more was necessary to induce pupation in B. fusca.

B. fusca was observed to survive on alternate grass hosts during the dry off-season. The alternate grass hosts were identical to the types reported earlier by Ingram (1958) , Nye (1960) and Harris (1962) as being important hosts of the pest. However, although these hosts played some role in the carry-over of B. fusca it was probably of little consequence in the overall incidence of the carry-over of the pest in the highland areas. The reason for this is that there is limited cultivation of the pasture grasses identified as alternative hosts of B. fusca for dry season supplementary grazing in the highlands. Besides, the grass hosts when cultivated are also frequently cut short at various intervals during the dry off-season for feeding livestock thereby reducing the chances of B. fusca larvae being harboured in them.

The high population levels of B. fusca found in maize crop residues left in the fields represented an important carry-over population from one season to the other. This is because farmers commonly leave harvested maize crop residues in abundance in the fields undisturbed and in this way, they enable the diapause larvae in them to survive the dry off-season. It is evident from these studies that to avoid any carry-over of diapausing B. fusca larvae, appropriate control measures should be directed against the reservoir population of the pest in the harvested maize crop residues.

CHAPTER 5

MORTALITY FACTORS AND INFLUENCE OF WEATHER ON DIAPAUSING POPULATION OF MAIZE STALK BORER *BUSSEOLA FUSCA* DURING THE DRY SEASON

5.1 INTRODUCTION

Parasitism by a braconid hymenopterous parasitoid *A. sesamiae* is an important cause of mortality of diapausing *B. fusca* larvae (Mally, 1920 ; Du Plessis and Lea, 1943 ; Mohyuddin, 1971 ; Kfir, 1988 ; Van Rensburg *et al.* 1988b). However, no information is available in the highland areas of Kenya on the relative importance of parasitoids and other natural control factors in general as causes of mortality during the dry season. These studies were conducted to generate information to fill the existing gap.

No clear information is available on weather factors responsible for diapause termination in the highland areas where these studies were conducted. A better understanding of the natural mortality of *B. fusca* due to parasitoids and other natural causes including weather factors responsible for its diapause termination could form the background for a sound pest management programme to minimize its destructiveness.

5.2 MATERIALS AND METHODS

Investigations on the factors affecting the survival of diapausing larvae during the dry season were conducted at PBRC, Njoro during 1987 and 1988 dry seasons. The investigations were conducted using harvested maize stalks obtained from the previous season's crop.

Harvested maize stalks which were used in these studies were uprooted from the field and brought to PBRC. Maize stalks were then kept in a huge pile on a raised bed made of barbed fencing wire. The raised bed was about 1.5m above ground surface. This ensured that the stalks were not damaged by rodents and termites apart from the arrangement permitting free air circulation within the stalks.

Population of diapausing _B_. _fusca_ were monitored to determine if any fluctuations existed by removing random samples of 50 stalks (mean length 239.5 ± 34.6 cm) once weekly for 6 - 7 months until all larvae had emerged from diapause. The stalks were then dissected open and the number of larvae (live or dead), pupae and pupal cases found recorded.

The effect of parasitism as a factor was separated from other mortality factors by the presence of larvae or cocoons of _A_. _sesamiae_ on or near the diapausing larvae. The incidence of mortality due to _A_. _sesamiae_ and other mortality causes was determined throughout the season by calculating the percentage of total number of live and dead larvae on a monthly basis. In addition the rate of pupal formation and adult moth emergence (as evidenced by the number of pupal cases) was calculated as a percentage from the total number of borers on monthly basis throughout the season. Rainfall and temperature were recorded throughout the study period to assess their influence, if any, on the diapausing larvae of *B. fusca*.

The data collected was subjected to a one-way analysis of variance to find out whether there were significant seasonal variation between 1987 and 1988. The influence of weather elements on diapausing larvae was assessed by the use of multiple regression analysis.

5.3 RESULTS

Data on the mortality of *B. fusca* during 1987 and 1988 dry seasons is presented in table 6. No significant ($P > 0.05$) differences existed in mortality due to *A. sesamiae* and other causes between the two seasons. The incidence of mortality due to *A. sesamiae* was observed in the months of February, March and April during both years. Larval mortality due to *A. sesamiae* throughout the experimental period was 12.3% (Table 6) which was quite low.

Mortality due to other causes other than *A. sesamiae* generally declined as the dry season advanced after crop harvest (Table 6). Mortality due to other causes was quite high being on the average 87.7% throughout the experimental period.

From the results presented in table 7, it is evident that the number of diapausing *B. fusca* larvae declined during both 1987 and 1988 dry seasons. Pupation began in April reaching its peak in June during 1987. Peak adult emergence occurred in July

Table 6. Distribution of mortality due to *Apanteles sesamiae* and other causes of mortality of diapausing *Busseola fusca* larvae during 1987 and 1988 off-seasons.

		Larval mortality of *B. fusca*				Total mortality	Total number of larvae (dead & live)	Percentage total mortality
		Mortality due to *Apanteles sesamiae*		Mortality due to other causes				
Year	Sampling period	Number of dead larvae	Percentage mortality	Number of dead larvae	Percentage mortality			
1987	January	0	0.0	66	22.0	66	300	22.0
	February	21	8.9	48	20.4	69	235	29.3
	March	6	3.1	31	15.8	37	196	18.9
	April	6	4.8	27	21.6	33	125	26.4
	May	0	0.0	9	14.8	9	61	14.8
	June	0	0.0	0	0.0	0	14	0.0
	July	0	0.0	0	0.0	0	5	0.0
Total / Average		33	15.4	181	84.6	214	936	-
1988	January	0	0.0	58	21.8	58	266	21.8
	February	2	0.8	29	11.4	31	255	12.2
	March	4	4.2	14	14.6	18	96	18.8
	April	5	16.1	6	19.4	11	31	35.5
	May	0	0.0	1	11.1	1	9	11.1
	June	0	0.0	0	0.0	0	2	0.0
Total / Average		11	9.2	108	90.8	119	659	-
F value (seasons)			0.001ns		0.117ns			0.056ns

Table 7. Weather factors and mean number of diapausing larvae, pupae and pupal cases of <u>Busseola fusca</u> per 50 dry maize stalks during 1987 and 1988 off-seasons.

		Weather factors		Stage of life cycle			Percentage of total		
Year	Sampling period	Total rainfall (mm)	Mean temperature (°C)	Mean no.of larvae	Mean no.of pupae	Mean no. of pupal cases	Larvae	Pupae	Pupal cases
1987	January	14.1	17.2	58.5	0.0	0.3	99.5	0.0	0.5
	February	19.4	18.2	41.5	0.5	0.8	97.0	1.2	1.8
	March	36.5	18.9	31.8	0.0	0.0	100.0	0.0	0.0
	April	84.6	18.2	23.0	4.8	0.3	81.8	17.1	1.1
	May	16.0	17.1	13.0	7.3	2.0	58.3	32.7	9.0
	June	115.5	16.5	2.8	10.0	5.4	15.4	55.0	29.6
	July	48.9	15.5	1.3	2.5	7.5	11.5	22.1	66.4
1988	January	95.5	17.7	52.0	1.8	0.8	95.2	3.3	1.5
	February	8.5	18.0	44.8	0.8	0.0	98.2	1.8	0.0
	March	45.3	18.7	19.5	0.5	1.0	92.8	2.4	4.8
	April	273.9	18.4	5.0	1.3	2.3	58.1	15.1	26.8
	May	156.4	16.2	1.6	3.2	4.8	16.7	33.3	50.0
	June	116.9	14.6	0.5	1.3	7.5	5.4	14.0	80.6
F - test (years)				0.71ns	0.81ns	0.01ns	0.64ns	0.28ns	0.16ns

ns = nonsignificant.

Table 8. Multiple regression analysis of the effect of weather factors on the diapausing <u>Busseola</u> <u>fusca</u> larvae during 1987 and 1988 off-seasons.

Year	Variable	Partial regression coefficient	S.E.	t	Correlation coefficient (r)
1987	X_1 Total rainfall (mm)	-0.4944	0.1927	-2.57**	-0.45*
	X_2 Mean temperature (°C)	6.9485	3.4501	2.01ns	0.48*
	F value =	8.2066**			
	R^2 =	0.3781			
	a =	-89.5487			
	Y =	$-89.5487 - 0.4944\ X_1 + 6.9485\ X_2$			
1988	X_1 Total rainfall (mm)	-0.1119	3.035	-0.034ns	-0.25ns
	X_2 Mean temperature (°C)	5.462	2.5445	2.1134ns	0.41*
	F value =	3.1512ns			
	R^2 =	0.2151			
	a =	-70.7305			
	Y =	$-70.7305 - 0.1119\ X_1 + 5.462\ X_2$			

* = Significant at 5% level, ** = significant at 1% level and ns = nonsignificant.

of the same year. In the following year (1988), a similar trend was observed except that in this case peak pupation occurred in May and peak adult emergence in June. Both peaks coincided with increased rainfall intensity and reduced mean temperatures (Table 7). No significant ($P > 0.05$) variation existed in the population of immature stages of the pest between the two dry seasons of both years.

Rainfall was significantly negatively correlated ($r = -0.45$, $P < 0.05$) with the number of larvae in 1987 (Table 8). Table 8 also shows that for every unit increase in rainfall, the number of larvae was reduced by a factor of 0.49. However, during 1988, rainfall was not significantly negatively correlated ($r = -0.25$, $P > 0.05$) with the number of larvae. On the other hand, mean temperature was significantly positively correlated with the number of larvae ($r = 0.47$, $P < 0.05$) observed during the dry season of 1987 and that of the following year ($r = 0.41$, $P < 0.05$). It is further shown in table 8 that the weather factors studied adversely influenced the larvae population to the extent of 37.81% in 1987 and 21.51% in 1988.

5.4 DISCUSSION

From the results obtained in this study, it was evident that larval mortality due to _A_. _sesamiae_ was somewhat low (12.3%). However in dealing with a large population of the pest such as _B_. _fusca_, the level of parasitism recorded should not be regarded as being negligible. In recent studies, Van Rensburg _et_ _al_.

(1988b) recorded A. sesamiae as being an important cause of mortality of diapausing B. fusca larvae in South Africa with its action accounting for about 36.0% of the total mortality.

It was also shown in these studies that mortality due to other causes was quite high (87.7%). This observation suggested that mortality of diapausing larvae due to other causes was the most important during the dry season. Mortality was quite high at the start of the dry season and declined as the season progressed for reasons which were not immediately established. Jepson (1954) attributed the high degree of mortality at the commencement of the dry season to the mechanical impact of the harvesting operations, as well as to increased exposure of larvae to mortality factors. Additionally, Smithers (1960a) reported that in regions where weather conditions were severe only those B. fusca larvae that hid in suitable diapausing places survived. The same was probably the case in these studies.

The results obtained also showed that diapausing larvae survived in the stalks for as long as 6 - 7 months before emerging from diapause. This is not peculiar in view of the work of Harris (1962) who reported similar observations. In addition, pupation was observed to occur over a prolonged period. This feature appears to be common in this pest and was also recently reported by Unnithan and Seshu Reddy (1989).

Rainfall was significantly negatively associated with larval population. This indicated that an increase in rainfall was probably a major and critical factor responsible for the timing of diapause termination. Mean temperature was on the other hand significantly positively associated with larval population. This indicated that a decline in mean temperature was also responsible for diapause termination. Previous studies by Harris (1962) showed that termination of diapause was associated with increasing rainfall and decreasing temperatures. According to Usua's (1970b) work, rainfall did not terminate larval diapause but only enhanced adult moth emergence. In their studies, Unnithan and Seshu Reddy (1989) reported that heavy rains did not result in synchronous pupation indicating that rainfall was not the most important critical factor responsible for diapause termination. In his studies, Van Rensburg _et_ _al_. (1987) observed similar variabilities as reported above and concluded that it was uncertain as to which factors were responsible for diapause termination.

CHAPTER 6

STUDIES ON MONITORING OF SEASONAL POPULATIONS OF ADULT BUSSEOLA FUSCA MOTHS USING A LIGHT TRAP

6.1 INTRODUCTION

Information is not available on the seasonal abundance of adult B. fusca moths in Kenya's highland maize growing areas. Thanh Ho and Seshu Reddy (1983) monitored field populations of stalk borers in Western Kenya and recorded fluctuations in trap catches of B. fusca from season to season. They (Thanh Ho and Seshu Reddy, 1983) also observed that adult moths occurred at about five weeks after planting maize and sorghum crops. However, their studies were only confined to periods when there were crops in the field during the long rains and short rains seasons.

In the present studies, investigations were conducted to identify periods of peak moth activity throughout the year using a light trap. Identification of periods of when peak catches occurred could indicate the main wave of oviposition on young crops in the fields. Such information would be useful for timely application of control measures against the pest to minimize its damage and subsequent crop losses.

6.2 MATERIALS AND METHODS

Investigations reported here were conducted at PBRC, Njoro, Kenya (0° 20′ S ; 35° 56′ E ; 2165 msl) throughout 1987 and 1988 (January - December) in order to gain knowledge on the occurrence of adult moths under local conditions. Seasonal abundance of stalk borer moths is determined through continuous trapping by use of 'Muguga trap' which was a modification of the Robinson light trap (Brown et al. 1969 ; Siddorn and Brown, 1971) (Plate 2).

The light trap was fitted with a 125 W mercury-vapour discharge bulb and placed at a height of 1.5 m above the ground level 10 m away from the nearest building. A killing agent (dichlorvos 50% e.c.) impregnated on cardboards (10 X 10 cm) at the rate of 10 ml at monthly intervals was used within the trap. The trap was operated daily from 1900 to 0600 hours.

Daily catches of moths were sexed into males and females and counted to record their numbers. To gain information about their mating habits, the freshly caught female moths which were preserved in 70% alcohol were later dissected under water and the number of spermatophores counted and recorded. This would give a cummulative measure of copulation as described by Waloff (1958).

To determine the general distribution of B. fusca moths throughout the year, monthly light trap catches were presented in graphical form after grouping the data obtained for the same months of the two years. In addition, to investigate the effect

Plate 2. The Muguga light trap used for trapping adult <u>Busseola</u> <u>fusca</u> moths.

of weather on the catches , rainfall and temperature (maximum and minimum) recorded in an adjacent weather station was plotted against the number of moths caught on a monthly basis. The influence of the weather elements on catches (total moths, male and female moths) was assessed by the use of multiple regression analysis.

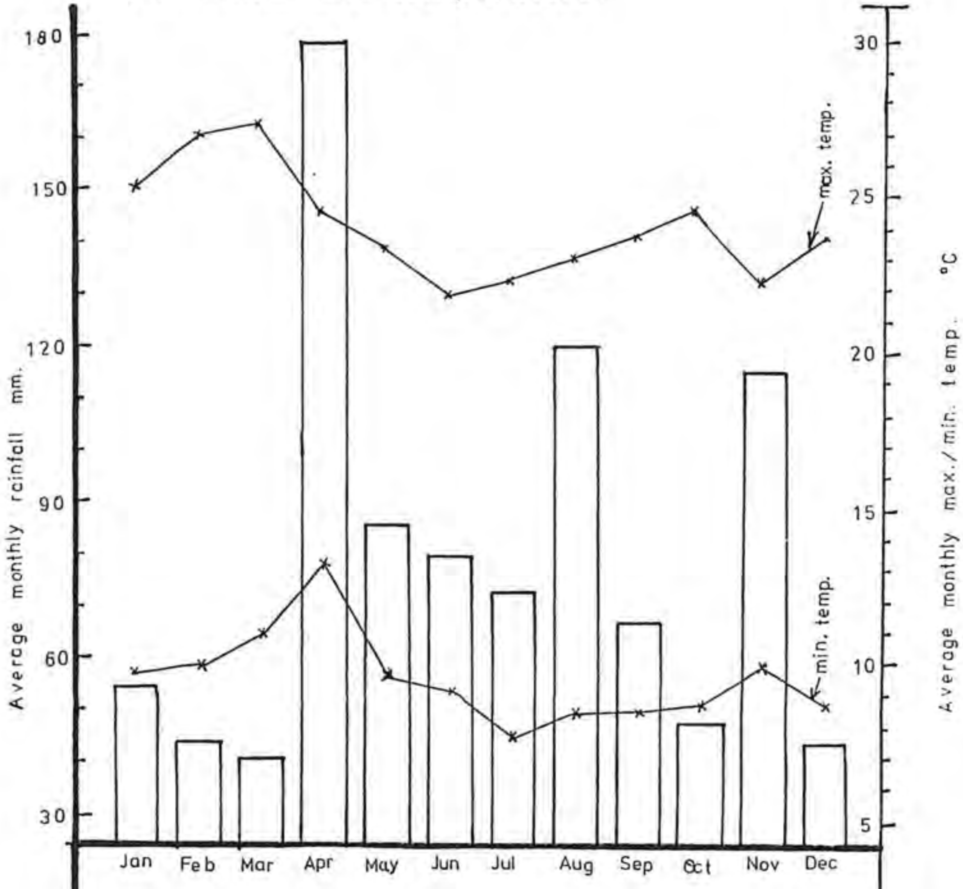
In order to ascertain the effect of moonlight on the catches and sex ratios, the distribution of moths over the study period was assessed. This was achieved by grouping together the data obtained for the same periods of the four lunar phases (i.e. first quarter, full moon, last quarter and new moon) in accordance with the calendar dates of the lunar phases provided by the Kenya Meteorological Department. To find out whether there were significant differences in total number of moths caught and their sex ratios for the different lunar phases, the data was analysed using the Chi-square criterion.

6.3 RESULTS

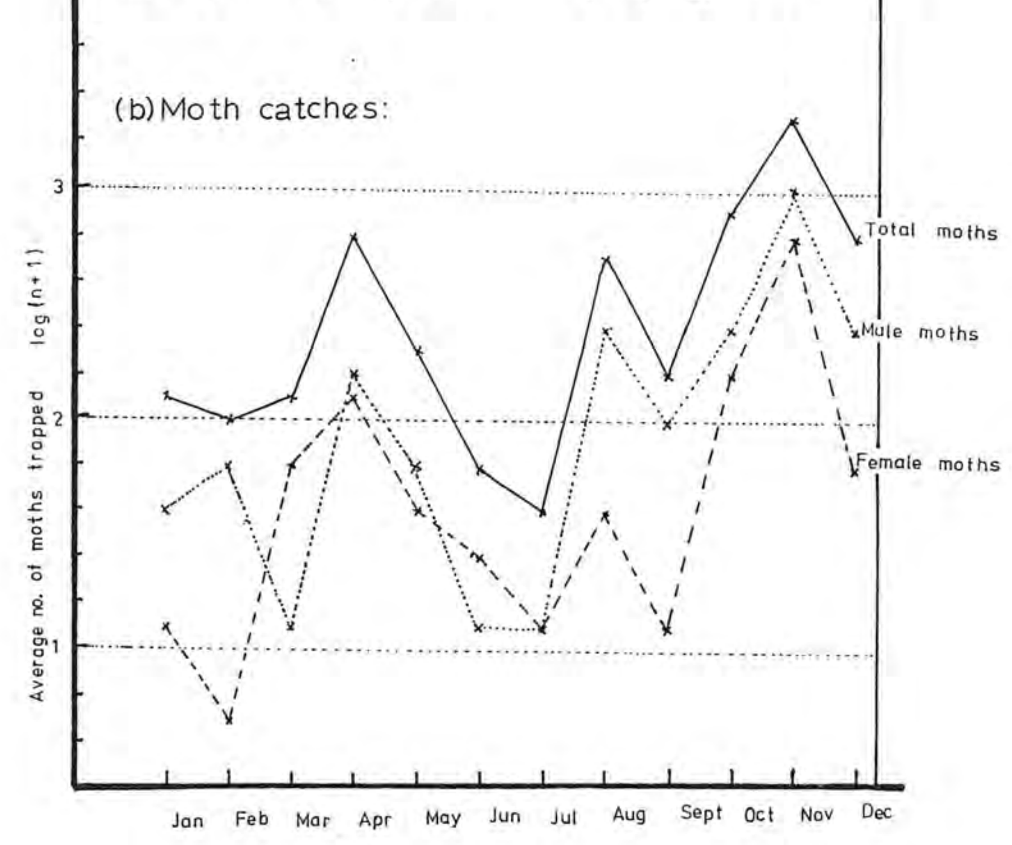
Data presented in figure 1 shows that there were well defined peak periods of <u>B</u>. <u>fusca</u> moth activities. There were three peak periods of moth flight activities per year corresponding with peak periods of effective rainfall (Figure 1). The first peak in the season occurred in April, the second in August and the third in November. Catches of male and female moths showed similar pattern of peak occurrence. However, the male moths were always more abundant than female moths throughout

Figure 1. Average monthly records of rainfall and temperature at Plant Breeding Research Centre, Njoro, and average light trap catches of <u>Busseola</u> <u>fusca</u> moths over the period 1987/88.

(a) Rainfall and temperature:



(b) Moth catches:



the year except in the months of March and June. Figure 1 also indicates that B. fusca moths were intercepted by the light trap throughout the study period. This pointed to the fact that the pest was present throughout the year.

Regression and correlation coefficients of weather factors on the number of moths caught are presented in table 9. Weather elements, rainfall and minimum temperature, were both positively correlated ($r = + 0.40$ and $r = + 0.24$, respectively) with the moth catches. On the other hand, maximum temperature was negatively correlated ($r = - 0.24$) with the moth catches. Thus data summarised in table 9 showed that maximum temperature was the main factor influencing the catches of both male and female B. fusca moths.

Data presented in table 10 shows that the lunar phases of the moon significantly influenced the number of B. fusca moths caught by the light trap (Chi-square = 67.76, $P < 0.01$). The moths were more abundant during the last quarter phase (85.0) of the moon, followed in descending order by full moon phase (47.0), new moon phase (22.0), and the first quarter phase (18.0). No significant (Chi-square = 0.85, $P > 0.05$) differences were attributed to the effect of moonlight on the male and female moths as the sex ratio was about 1 : 1 throughout all the four lunar phases.

Results obtained from dissection studies of the freshly caught female moths showed that all the moths had copulated by the time they were caught in the light trap. Out of 86 females caught, 18 females (20.9%) had each 2 spermatophores while the

Table 9. Regression coefficients of weather factors on <u>Busseola</u> <u>fusca</u> moths caught by the light trap.

Weather factors	Regression coefficient	Correlation coefficient
<u>(a) Males + females</u>		
Rainfall	+0.07	+0.40
Temperature (max.)	-0.91	-0.24
Temperature (min.)	+1.12	+0.24
<u>(b) female moths</u>		
Rainfall	+0.04	+0.39
Temperature (max.)	-0.55	-0.24
Temperature (min)	+0.67	+0.33
<u>(c) Male moths</u>		
Rainfall	+0.03	+0.33
Temperature (max.)	-0.46	-0.18
Temperature (min.)	+0.57	+0.08

Table 10. Total number of Busseola fusca moths trapped during each lunar phase of the moon over the period 1987/88 at Plant Breeding Research Centre, Njoro.

Number of moths trapped	First quarter	Full moon	Last quarter	New moon
Total number of moths	18	47	85	22
Number of male moths	9	23	41	13
Number of female moths	9	24	44	9
Ratio of males : females	1:1	0.96:1	0.93:1	1:0.7

Chi-square test (lunar phases) = 67.76**

Chi-square test (sex ratio) = 0.85ns

** = Significant at 1% level, ns = nonsignificant.

remaining 68 females (79.1%) had each 1 spermatophore. This indicated that double and single copulations occurred in this pest.

6.4 DISCUSSION

Results obtained in these studies indicated that B. fusca was present throughout the year. Its presence throughout the year could be attributed to continuous breeding on alternate hosts and the emergence of moths from the diapause population in crop residues. This finding has important implications on the control of the pest since in order to reduce the pest population, complete destruction of all forms of crop residues and alternate host plants is called for. Similar views were expressed by Ingram (1958).

The data collected confirmed that there were three seasonal peaks in April, August and November. This suggested that the pest had three generations annually. Elsewhere similar observations depicting that the pest had three generations per year have been reported (Graham, 1951). These peak activity periods could largely be attributed to successful breeding of resident populations of B. fusca in the months prior to peak catches. The first peak in April occurred probably due to the emergence of moths from the diapause generations. The second peak in August occurred due to the emergence of first generation pupae at the flowering / silking stage of maize crops while the third peak was due to the emergence of the second generation pupae in November.

A positive relationship between moth catches and rainfall was observed. With increase in rainfall in the months of April, August and November there was a corresponding increase in moth population resulting in three annual peaks. This observation was not peculiar in view of the work of notably, Bowden and Gibbs (1973) and Robertson (1977) who also identified a positive correlation between moth catches and rainfall.

Results obtained indicated that single and double copulations occurred in B. fusca. This is probably a new finding as its mention is absent in available reports on B. fusca (Chapters 1 and 2).

The influence of lunar phases on noctuid moth catches is still a matter of controversy. The results obtained in these studies showed that lunar phases significantly influenced B. fusca moth catches with more moths being trapped during the last quarter phase. However the lunar phases did not affect the sex ratio. These results are in agreement with Brown and Taylor's (1971) work which showed that Agrotis segetum Dennis & Shiff. was more abundant in light traps during the last quarter phase. However, Thanh Ho and Seshu Reddy (1983) showed that catches of B. fusca were higher during the new moon phase. On the other hand, Hardwick (1972) and Blair (1982) observed no difference on the effect of lunar phases on noctuid moth catches.

CHAPTER 7

EFFECT OF DIFFERENT MAIZE STUBBLE DISPOSAL PRACTICES ON THE SURVIVAL OF THE MAIZE STALK BORER *BUSSEOLA FUSCA*

7.1 INTRODUCTION

The maize stalk borer *B. fusca* has been reported as surviving inside the dry stalks or stubble and maize cobs after crop harvest during the dry season as mature diapausing larvae in either the last 5th or 6th larval instars (See Chapter 1 and 2). The diapause period lasts until the onset of rains at the commencement of the subsequent cropping season (Harris, 1962 ; Unnithan and Seshu Reddy, 1989). The few larvae which survive the harvest operations and the dry season complete development and the emerging moths escape into the subsequent season's maize crop to perpetuate pest infestation (Graham, 1951 ; Jepson,1954).

Cultural control measures for stalk borer control have been directed at the diapausing larvae (Jepson, 1954 ; Egwuatu and Ita, 1982). One of the cultural control measures that has been emphasized as being effective for reducing larvae is the complete destruction of stubble in which the stalk borer larvae diapause (Unnithan and Seshu Reddy, 1989). Complete destruction of crop residues after crop harvest through such practices as uprooting, burning and ploughing are practised (Mally, 1920 ; Wahl, 1930 ; Du Plessis and Lea, 1943 ; Duerden, 1953 ; Ingram, 1958 ;

Bullock, 1958 ; Harris, 1962 ; Adesiyun and Ajayi, 1980).

So far no quantitative data is available on the impact of different maize stubble disposal practices on _B_. _fusca_ in Kenya. The objective of the studies reported here was to examine the effects of different maize stubble disposal practices on the survival of diapausing _B_. _fusca_ during the dry season. Information gained from the studies could be of immense value in developing integrated control strategies against the pest.

7.2 MATERIALS AND METHODS

In this experiment the commonly observed stubble disposal practices carried out by farmers in Nakuru area on the remaining crop residues after crop harvest were evaluated. There were five treatments of different disposal practices as described below :

(a) Treatment 1 - Standing stalks : harvested stalks left standing undisturbed in the field until the onset of rains when ploughing commences followed by maize planting ;

(b) Treatment II - Cut stumps of maize stems : in this type of disposal practice, top parts of stalks are cut, and then burnt ; the stumps are left standing in the field ;

(c) Treatment III - Burning of maize stubble _in situ_ : the burning destroys almost all the stubble, but still leaves some stalks partially burnt in the field ;

(d) Treatment IV - Deep ploughing : in this practice, there is complete burial of all the crop residues which is achieved by ploughing under using a tractor ; and,

(e) Treatment V - Harrowing : in this practice the maize stubble is chopped into small pieces using the harrow ; stumps are uprooted and spread thinly on the ground.

The effect of the above treatments on the survival of the pest were compared using a randomized block design during the dry seasons in 1987 and 1988. Each treatment was replicated four times. The treatments were usually applied in February and taking of samples at fortnightly intervals commenced immediately and were terminated at the onset of long rains in April.

Individual plots sited at PBRC, Njoro each measuring 40 X 50 m (0.2 ha) were marked out in harvested maize fields. The treatments of different stubble disposal practices were randomly assigned to the marked plots.

The population of B. fusca was monitored by repeated removal of samples of stubble at two weeks intervals from each plot assigned to a particular stubble disposal practice. The population of B. fusca larvae was determined on every sampling date in four randomly selected plots measuring 12.5 sq.m. A simple technique of obtaining samples of stubble involved using a looped rope of known radius (2.0 m) to obtain a plot of required area (12.5 sq.m). The stalks collected in each sample area were kept separately and later dissected in the laboratory to reveal larvae and pupae (dead or alive) which were counted and recorded.

The incidence of mortality was determined by calculating the percentage of total number of the live and dead larvae and pupae at each sampling date. Comparison of the effect of different stubble disposal practices was calculated as a percentage of the total number of live larvae and pupae reduction relative to harvested standing stalks treatment which is the common practice.

Data for the number of dead larvae, live larvae and pupae per treatment was transformed using the square root transformation (X + 1) before analysis of variance . Data on percentage mortality and percentage reduction (live larvae and pupae) relative to standing stalks was transformed using arcsine square root transformation (X + 1) before analysis. Transformation of the data was carried out in order to stablize and homogenize the variance (Steele and Torrie, 1980). Mean separation was done using least significant difference (LSD) ($P = 0.05$) (Steele and Torrie, 1980).

7.3 RESULTS

Data presented in table 11 on the mean number of live larvae and pupae indicated that during both years there were significant ($P < 0.05$) differences between the treatments applied. The mean number of live larvae and pupae was significantly ($P < 0.05$) higher in the treatment involving standing stalks as compared to all the others. The population of live larvae and pupae was

Table 11. Comparison of the influence of different maize stubble disposal practices on the survival and mortality of <u>Busseola fusca.</u>

(a)		1987		
Treatments	Number of live larvae and pupae.	Number of dead larvae.	Percent mortality	% larvae and pupae reduction relative to standing stalks.
Standing stalks	2.70d (6.7)	2.05b (2.6)	25.3a (23.9)	1.0a (0.0)
Cut stumps	2.02c (3.3)	1.77a (1.3)	23.5a (24.1)	31.8b (40.2)
Burning	1.70b (2.3)	2.20b (3.1)	49.9a (56.8)	48.1b (57.2)
Deep ploughing	1.29a (0.8)	1.79a (1.5)	57.8b (65.1)	76.6c (89.5)
Harrowing	1.21a (0.6)	1.96ab (2.2)	69.7b (77.4)	80.8c (91.9)
<u>Criterion</u>				
F test	44.8**	4.36**	14.32**	78.27**
LSD at 5%	0.25	0.25	33.9	23.7
S.E. ±	0.09	0.09	5.4	3.7
C.V.	22.6%	19.9%	53.0%	34.6%
(b)		1988		
Standing stalks	1.99d (3.3)	1.69a (1.0)	21.6a (22.5)	1.0a (0.0)
Cut stumps	1.62c (1.9)	1.71a (1.0)	34.1a (36.7)	38.9b (43.6)
Burning	1.35b (1.0)	1.81a (1.4)	58.8b (65.5)	65.1c (73.3)
Deep ploughing	1.15a (0.4)	1.70a (1.0)	77.5c (86.7)	80.7d (91.8)
Harrowing	1.04a (0.1)	1.68a (1.0)	86.3c (96.3)	86.7d (97.1)
<u>Criterion</u>				
F test	32.9**	0.74ns	22.19**	61.41**
LSD at 5%	0.19	0.17	16.6	12.6
S.E. ±	0.07	0.06	5.9	4.5
C.V.	20.8%	15.7%	47.1%	37.4%
F test (years)	1.64ns	28.9**	8.09**	5.08*

* = Significant at 5% level.

** = Significant at 1% level.

ns = Nonsignificant.

Figures in parentheses are means of original values.

The same letter besides figures indicates no significant difference at P<0.05 by the LSD test.

significantly ($P < 0.05$) lower in treatments involving deep ploughing and harrowing than in any of the other treatments.

The mean number of dead larvae of B. *fusca* recovered in all the treatments is presented in table 11. Significant ($P < 0.05$) differences in larval mortalities were observed among the treatments. Both treatments involving standing stalks and burning of stalks yielded significantly ($P < 0.05$) more dead larvae as compared to the other treatments during the dry season of 1987. During 1988 dry season, there were no significant ($P > 0.05$) differences among the treatments on the numerical quantity of dead larvae recovered.

The percentage mortality of stalk borers in the different maize stubble disposal treatments is summarized in table 11. During both 1987 and 1988 seasons, harrowing and deep ploughing treatments consistently achieved high mortality detected at $P = 0.05$ level of significance as compared to the other treatments. On average over both years, the treatments involving harrowing and deep ploughing practices achieved 86.9% and 75.9% mortality, respectively. On the other hand, treatments involving burning of stalks, cut stumps and standing stalks achieved on the average 61.2%, 30.4% and 23.2% mortality, respectively.

Since treatment one involving standing stalks is the common practice by farmers in Nakuru District, it became necessary to report in details its exact effects on the survival of the pest. Effective reduction of B. *fusca* of the other treatments involving burning of stalks, cut stumps, deep ploughing and harrowing as compared to standing stalks treatment which was considered as the control is presented in table 11. All stubble disposal treatments significantly ($P < 0.05$) reduced the stalk borer population relative to standing stalks treatment in both seasons. Harrowing and deep ploughing treatments consistently achieved high percentage reduction ($P < 0.05$) of stalk borer population relative to standing stalks treatment (control) and all other treatments. On average over both years of study, treatment V involving harrowing and treatment IV involving deep ploughing achieved 94.5% and 90.7% reduction, respectively. Treatment III involving burning achieved 65.3% while treatment II of cut stumps achieved 41.9% reduction of the stalk borer population.

7.4 DISCUSSION

The soil tillage practices of disposing stubble namely, harrowing and deep ploughing achieved the highest mortality and reduction of <u>B</u>. <u>fusca</u> larvae in these investigations. The harrrowing operation achieved reduction of diapausing larvae probably through mechanical injury. Besides it also probably predisposed the diapausing larvae population to lethal dessication. The deep ploughing operation achieved reduction of stalk borer population probably also through mechanical injury and by burrying the larvae deeper in the soil, thereby preventing moth emergence. The larvae were probably also exposed onto the the surface to adverse weather factors. Other workers have attributed larval mortality to similar factors in their studies (Omolo and Seshu Reddy,1983 ; Lawani, 1982). A technique such as ploughing under as a means of destruction of crop residues which may harbour diapausing larvae numbers among the earliest recommendations for control of the pest (Mally ,1920 ; Jepson, 1954).

The results obtained from these studies have clearly shown that harrowing and deep ploughing practices were more effective in reducing stalk borer population. It is clear that adoption of both of these practices by farmers would not only be advantageous agronomically (Anon., 1985) but also beneficial in destroying diapausing larval population of _B_. _fusca_.

CHAPTER 8

POPULATION PATTERNS OF THE MAIZE STALK BORER BUSSEOLA FUSCA IN RELATION TO CROP PHENOLOGY IN EARLY AND LATE SEASON CROPS OF MAIZE

8.1 INTRODUCTION

Damage by maize stalk borer B. fusca is one of the factors limiting maize production in Kenya (Chapters 1 and 2). Kuria and Oile (1982) reported a loss of about 21.1% due to the pest in Nakuru area of the Rift Valley Province.

Although the relationship of B. fusca to the cropping period has received some attention (Van Rensburg et al. 1987 ; Gebre-Amlak, 1988), there are conflicting reports on the relationship between planting time and pest infestation levels. Duerden (1953) reported that there was little effect of planting dates on infestation of maize by stalk borers. On the other hand, Walters (1979) reported that late plantings, exposed to oviposition by moths originating from earlier plantings suffered severe damage and in some cases resulted in complete crop failure. Van Rensburg et al. (1987) reported that variation in planting date had a marked influence on levels of infestation due to the occurrence of distinct periods of moth flights.

Information relating to infestation of maize in Kenya by B. fusca when the crop is growing under varying planting dates is not available. There is need to obtain this information on the effect of early and late plantings on population patterns of B. fusca to facilitate fashioning of suitable techniques for its control.

8.2 MATERIALS AND METHODS

Investigations to establish the population pattern of B. fusca in early and late planted maize crops were conducted during 1987 and 1988 cropping seasons at PBRC, Njoro. Two plots of 50 X 100 m (0.5 ha) were planted with maize variety H625. The crop was planted on the 15th of April of every season. This date was chosen because it was the earliest possible planting date for the area at the onset of the long rains. Late planting was done one month later on the 15th of May of every season. Recommended agronomic practices including spacing, fertilization and weed control were followed in both early and late plantings to promote normal growth of plants.

Experimental plots were planted using a two row conventional maize planter drawn by a tractor. Spacing of 30 cm between plants and 75 cm between rows was used. At sowing, Diammonium phosphate (DAP) (18 : 46: 0) fertilizer was applied at the rate of 200 kg / ha. A pre-emergence herbicide, Primargram 500 FW, was applied after sowing at the rate of 5 l / ha to ensure complete weed control.

The crop was left to natural infestation by B. fusca. The infestation was monitored every two weeks after crop germination until crop maturity 30 weeks after emergence (WAE).

Samples of 50 consecutive plants were taken per row selected at random in both early and late planted experimental plots.

The samples were on every occasion brought to the laboratory and the number of damaged plants determined. The growth stages of the sampled plants were also determined. Each plant was then dissected to reveal the number of larvae and pupae which was recorded. The results obtained were expressed as the number of borers per plant. Other records taken included the number of bored internodes per plant which was expressed as a percentage of the total internodes and as well as a percentage of the stem tunnelled. Detailed information on early and late planted crops was also gathered on the distribution and location of the larvae of _B_. _fusca_ within the different plant tissues : whorl, leaf sheath, stem, tassel, and cob. Analysis of variance was undertaken of the data collected to establish whether there were siginificant differences in borer population, plant damage, stem and internode damage between the early and late planted maize crops.

8.3 RESULTS

Comparative data from early and late grown maize plants on the mean number of _B_. _fusca_ larvae and pupae observed at different growth stages is presented in table 12. There were no significant ($P > 0.05$) differences between the early and late planted maize crops in terms of the magnitude of the larval and pupal populations recorded.

Table 12. Population distribution of the number of larvae and pupae of *Busseola fusca* per plant in early and late planted maize crops at different growth stages after crop emergence

		Early planted		Late planted	
Weeks after germination	Maize plant growth stages	No. of larvae	No. of pupae	No. of larvae	No. of pupae
2	2 leaf	0.0	0.0	0.0	0.0
4	4 leaf	0.0	0.0	0.0	0.0
6	6 leaf	4.6	0.0	0.0	0.0
8	8 leaf	9.6	0.0	0.0	0.0
10	10 leaf	4.9	0.0	0.0	0.0
12	12 leaf	5.6	0.0	0.0	0.0
14	14 leaf	2.4	0.4	0.9	0.0
16	Tasselling	0.9	1.1	12.2	0.0
18	Silking	0.4	0.9	12.9	0.0
20	Blister	0.6	0.4	5.3	0.1
22	Dough	8.8	0.0	4.7	0.5
24	Early dent	2.8	0.0	3.2	0.1
26	Mid dent	3.8	0.1	5.5	0.7
28	Hard grain	8.9	0.2	4.4	0.5
30	Hard dry grain	4.3	0.0	4.9	0.3

B. fusca population (larvae + pupae) between planting dates F = 1.88ns

In the early crop (Table 12), the initial infestation started from 6 WAE when the crop was at 6 leaf stage. Three population peaks were identified in the crop of maize planted early. The first peak (9.6 larvae / plant) occurred 8 WAE at the 8 leaf stage. The second peak (8.8 larvae / plant) occurred 22 WAE at dough stage. The third peak (8.9 larvae / plant) occurred 28 WAE at the hard grain stage when the crop had reached physiological maturity in the early crop (Table 12).

Two peak pupation periods were observed in the early crop (Table 12). Pupation started at 14 leaf stage (14 WAE) and declined from the blister stage (20 WAE). A minor pupation period occurred at the hard grain stage (28 WAE) in the crop of maize planted early. At harvest (30 WAE) the population declined to 4.3 larvae / plant in the early crop (Table 12).

In the case of the late crop, the data presented in table 12 shows that the plants were not attacked until after 14 WAE when the crop was at 14 leaf stage. This coincided with the pupation period of B. fusca in the early crop. Two population peaks were observed in the late crop (Table 12). The first peak (12.9 larvae / plant) occurred at silking stage (18 WAE). The second peak (5.5 larvae / plant) occurred at mid dent stage (26 WAE).

One long pupation period was noticed in the late crop (Table 12). Pupation period started at 20 WAE when the crop was at blister stage and continued until the hard grain stage. At harvest, the population of stalk borers declined to 4.9 larvae / plant in the late planted crop (Table 12).

The infestation levels, stem damage and internode damage as a result of B. fusca attack in early and late crops is shown in table 13. Percentage plant infestation by B. fusca was significantly ($P < 0.05$) higher in the late planted crop as compared to its infestation in the early planted crop. However, there were no significant ($P > 0.05$) differences in stem and internode damage between the early and late planted crops (Table 13).

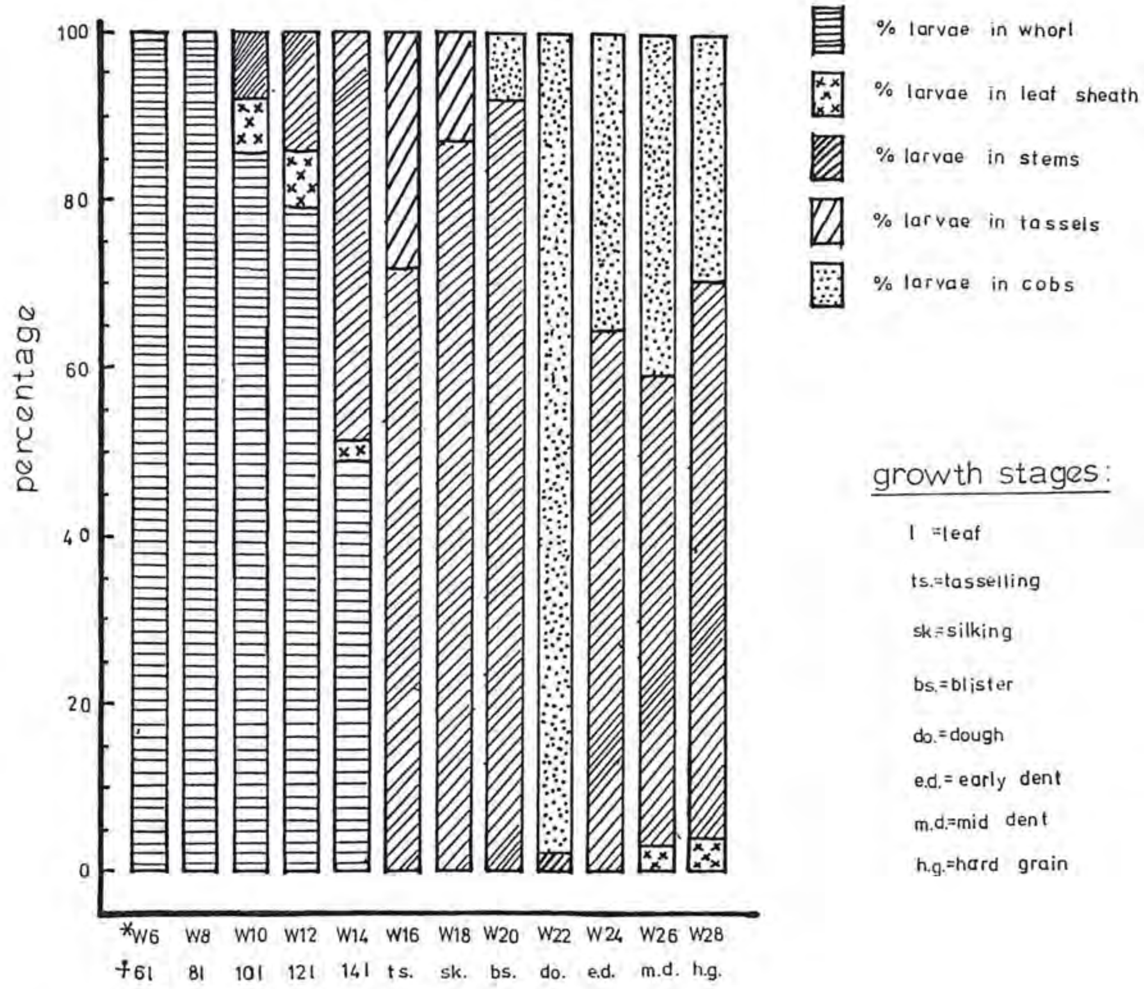
In the early crop initial plant infestation (3.0%) was noticed at 6 leaf stage (6 WAE) reaching a peak at the hard grain stage (37.4%). In the case of the late crop, initial plant infestation of 1.7% was observed at 12 leaf stage (12 WAE). Thereafter it rose steeply to 100% infestation at silking stage when the crop was 18 WAE (Table 13). Generally, plants in late crop suffered more damage from the pest attack than those in the early planted crop. The late planted crop had a high plant infestation rate of 70.9%. Damage to stems and internodes was 48.6 and 77.6%, respectively. In the case of the early planted crop, the infestation rate was low being 9.5%. Damage to stems and internodes was 9.2% and 25.1%, respectively, (Table 13).

The distribution of B. fusca larvae to different parts of the plants at different growth stages after crop emergence in early planted crop is presented in figure 2. In the early crop, all the larvae found at the 6 - 8 leaf stages were located in the whorls of plants. The majority of the larvae remained in the whorls even during the 10 - 12 leaf stages, with very few being found in the leaf sheaths and stems. At 14 leaf stage (14 WAE), ble 13. Distribution of plant damage as a result of *Busseola fusca* attack in early and late planted maize crops at different growth stages after crop emergence.

		Early	planted		Late	planted	
eks after mination	Maize plant growth stages	Mean % plant infestation	Mean % stem tunnelling	Mean % internode damage	Mean % plant infestation	Mean % stem tunnelling	Mean % internode damage
	2 leaf	0.0	0.0	0.0	0.0	0.0	0.0
	4 leaf	0.0	0.0	0.0	0.0	0.0	0.0
	6 leaf	3.0	0.0	0.0	0.0	0.0	0.0
	8 leaf	9.5	2.0	4.3	0.0	0.0	0.0
	10 leaf	6.9	4.0	11.7	0.0	0.0	0.0
	12 leaf	5.7	4.5	26.0	0.0	0.0	0.0
	14 leaf	2.6	4.7	18.5	3.1	0.0	0.0
	Tasselling	2.2	5.4	31.7	4.9	3.8	14.1
	Silking	4.5	10.1	23.8	100	13.5	51.2
	Blister	2.8	10.5	19.5	100	19.4	55.6
	Dough	1.5	6.1	12.9	100	22.7	100
	Early dent	2.1	3.5	22.4	100	51.6	100
	Mid dent	9.3	10.7	33.2	100	77.5	100
	Hard grain	35.9	22.6	56.8	100	100	100
	Hard dry grain	37.4	25.7	40.2	100	100	100
	Mean	9.5	9.2	25.1	70.9	48.6	77.6

% plant infestation between planting dates F test = 6.17*
% stem tunnelling between planting dates F test = 1.82ns
% internode damage between planting dates F test = 1.60ns

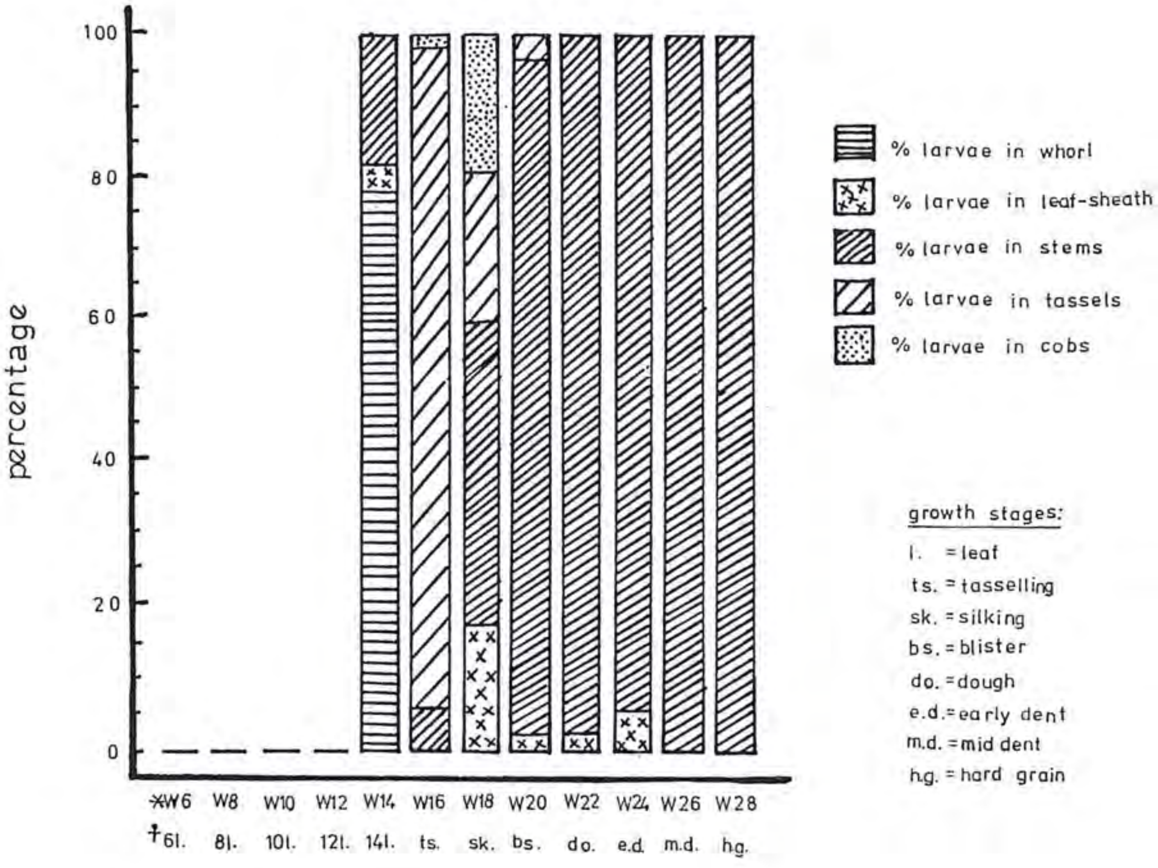
Figure 2. Distribution of Busseola fusca larvae in early crop at different growth stages after crop emergence.



* weeks after crop emergence

† crop growth stages after crop emergence

Figure 3. Distribution of Busseola fusca larvae in late crop at different growth stages after crop emergence.



* weeks after crop emergence

† crop growth stages after crop emergence

48.9% of the larvae were found in the whorls, 2.4% in the leaf sheaths, while 48.8% of them had penetrated into the stems in the early planted crop (Figure 2). At tasselling (16 WAE) and silking stage (18 WAE) the majority of the larvae had penetrated in the stems with very few larvae being found in the tassels. At dough stage (22 WAE) nearly all the larvae were located in the cobs in the early planted crop. However, at hard grain stage (28 WAE), 74.5% of the larvae were in the stems, while 25.5% of them infested the cobs in the early planted crop (Figure 2).

In the case of the late crop (Figure 3), where the initial infestation was noticed at 14 leaf stage (14 WAE), 77.7% of the larvae were recorded in whorls, 18.4% of the larvae in the stems, and 3.9% of them in the leaf sheaths. At tasselling stage (16 WAE), 92.6% of the larvae were found in tassels. A further 5.8% and 1.6% of the larvae were found infesting the stems and cobs, respectively. At silking stage (18 WAE), 17.8%, 41.7%, 21.2% and 19.3% of the larvae infested the leaf sheaths, stems, tassels and cobs, respectively, in the late crop. From blister stage (20 WAE) to the early dent stage (24 WAE) nearly all the larvae had penetrated into stems. At near harvest (28 WAE), no larvae were recovered from the cobs (Figure 3).

8.4 DISCUSSION

From the results obtained in these studies, it was evident that there were three population peaks of _B_. _fusca_ in early crop.

These results confirmed that the pest had three seasonal peaks as identified earlier (See Chapter 6).

Two complete generations rather than one as in the late planted crop were completed by B. fusca in the early planted crop. This was expected as the pest in the late planted crop was subject to adverse environmental conditions towards the end of the first rains season. Graham (1951) and Harris (1962) reported similar findings. Additionally, Khaemba (1985) further reported that there are usually two generations of B. fusca before the maize crop ripened.

In both early and late planted crops, a residual population of B. fusca larvae remained inside the stalks at harvest. This confirmed the importance of the stalks as harbouring sites of diapausing larvae of B. fusca to ensure its survival after crop harvest. This is a commonly known adaptation utilized by the pest to survive during adverse conditions (Swaine, 1957 ; Mohyuddin and Greathead, 1970).

Late planted maize sustained significantly higher plant attack than the early planted crop. This was probably due to the fact that the yield reducing factors identified earlier in these studies became severer with the advancement of the season. In his studies Bullock (1958) reported that early planted maize carried little infestation (10 - 15%) of B. fusca. He (Bullock, 1958) observed that the infestation intensified on late planted crops. More recently, Khaemba (1985) reported further that late crops were often heavily infested and yield losses up to 60% have been recorded in such crops.

Results obtained in these studies confirmed that there was a gradual distribution of B. fusca larvae from the whorl to other plant tissues as they differentiated. Although initially high populations occurred in the whorl, tassel appearance apparently forced them to move to other parts of the plant.

The presence of larvae in leaf sheath could be considered as being transitional, as the larvae moved through the leaf sheath so as to reach the stems. These results suggested that plant growth characteristics were probably the major factor influencing larval distribution within a plant. The fact that a large proportion of larvae remained in whorls from 6 - 14 leaf stages could be exploited for efficient chemical control, and thereby reduce pest damage.

CHAPTER 9

DETERMINATION OF ECONOMIC INJURY LEVELS FOR NEONATE BUSSEOLA FUSCA LARVAE AT DIFFERENT CROP GROWTH STAGES OF INFESTATION

9.1 INTRODUCTION

The maize stalk borer B. fusca damages maize in at least five ways : young plants are killed by larvae as a result of extensive foliar and whorl damage producing "dead hearts" (Duerden, 1953 ; Usua, 1968a) ; feeding by larvae disrupts physiological processes and reduces plant growth (Duerden, 1953 ; Usua, 1968a) ; feeding by larvae destroys young cobs and kernels (Blaire, 1971 ; Gebre-Amlak, 1988) ; boring into stalks weakens plants and causes lodging (Duerden, 1953 ; Jepson, 1954) ; and, if attack coincides with tasselling, the tassels are destroyed resulting in reduced pollination (Jepson, 1954). Recorded yield losses generally range from 15% per larvae per plant as in Ethiopia (Tchekmenev, 1981) to 25% per larvae per plant as in Nigeria (Usua, 1968a) using artificial infestations.

Information is not yet available on the magnitude of crop losses to be expected when B. fusca larvae infest the crop at different infestation levels and different growth stages. Furthermore there have been no investigations to establish the economic injury levels of this pest when infesting maize crops. These studies were therefore designed to obtain this information.

The information obtained would be useful in the establishment of meaningful economic injury and threshhold levels.

9.2 MATERIALS AND METHODS

These studies were carried out during 1987 and 1988 cropping seasons in a large wire mesh cage (50 X 100 m) to eliminate the possibility of uncontrolled infestation and to prevent hail and bird damage. The experimental design was a randomized block design with a factorial arrangements replicated three times. Each plot (1.5 X 3.6 m) consisted of three rows with a spacing of 75 cm between rows and 30 cm between plants. Plots and replicates were separated by a corridor of 2.0 m thus leaving a vacant space for preventing larval migration from plot to plot.

Four seeds of maize variety H625 were planted per hill during the first week of April for both 1987 and 1988 cropping seasons. Thinning was done two weeks after emergence to leave one plant per hill. This ensured a reasonable uniformity of the plants used in the experiments. The plants were fertilized with Diammonium phosphate (DAP) (18:46:0) fertilizer which was applied at the rate of 200 kg/ha. A pre-emergence herbicide (Primargram 500 FW) was applied two days after sowing at the rate of 5 l/ha to control weeds.

Three growth stages of maize : 6 leaf stage (30 days old plants), 8 leaf stage (45 days old plants) and 10 leaf stage (60 days old plants), were evaluated. For each growth stage, five larval densites : 0 (control), 2, 4, 8, and 16 larvae per plant were artificially infested into the maize funnels using a camel hair brush. The first instar (neonate) larvae reared in the laboratory were used for the infestation of plants. Artificial infestation of the plants with the specified larvae density was done when the maize plants reached the designated stage of growth. Only the middle row per plot served as a basis for data collection after artificial infestation, with the rows on either side being used as guard rows.

The infested maize plants were checked once a week for the presence of exit holes. Whenever the exit holes were observed, they were blocked by taping using the insulating electrical tape to prevent adult moth emergence. This was done to eliminate the possibility of a second generation population build-up within the experimental plots.

Before the crop tasselled, plant damage was assessed by examining the whorl for injury. The modified index used for estimating the intensity of injury in maize whorls (Huise, 1981) is described in table 14.

At complete pollen shedding, the average leaf area (LA) per plant was estimated by measuring the length and maximum width of leaf number 8 (from the top of plant) on the five plants per plot. LA was calculated using the formula : length X maximum width X 9.38 sq.cm (Pearce _et_ _al_. 1975).

Cobs from the crop were hand harvested approximately 240 days after crop emergence. This was when the leaves and husks were dry. The cobs of all plants per plot were bagged separately and labelled. Measurements were taken of cob length and

Table 14. Visual index used for estimating the intensity of *Busseola fusca* larvae damage in maize whorls.

---

1 - No injury.
2 - Number of leaf lesions more than 1 and less than 7.
3 - More than 7 leaf lesions.
4 - Less than 3 holes smaller than 2 cm.
5 - More than 3 holes smaller than 2 cm.
6 - Less than 3 holes larger than 2 cm.
7 - More than 3 holes larger than 2 cm.
8 - Whorl almost completely eaten away.
9 - Whorl completely eaten away.

---

diameter. The cobs with grains were then dried in the sun for one week to a uniform moisture and shelled before weighing the grain.

After harvest, measurements were taken of the total plant height and the percentage of stem tunnelled (length tunnelled divided by total length of stem of infested plants per plot X 100 - Mahadevan and Chelliah, 1986). The lengths of tunnelled portions of the stem were taken after the stalks had been split.

Percentage reductions of plant height, leaf area, cob length, cob width and grain yield were calculated as a percentage by considering that the healthy control (uninfested plots) were completely free from pest damage. This was done in order to evaluate the effect of B. fusca larval activity on plant development.

Before statistical analysis was undertaken data for 1987 and 1988 were pooled. Additionally, a square root (X + 1) transformation was applied to the data for percentage reductions of plant height, leaf area, cob length, cob width, grain yield and percentage of stem tunnelling and the means later retransformed to actual values. The transformation was done in order to homogenize and stabilize the variance (Steele and Torrie, 1980). Analyses of variance for the data gathered was done using factorial in randomized design because both growth stages and larvae densities were being evaluated. Least significant difference (LSD) was used in separating the significant differences between the treatments. Correlation and regression analyses were also performed to establish how the plant development variables were affected by B. fusca larvae infestation.

The economic injury levels (EILs) for B. fusca in maize were determined according to the method outlined by Sharma and Sharma (1987). EILs were based on the use of Thiodan (endosulfan) 3% granules which is one of the commonest insecticide used against the stalk borer in the highlands.

9.3 RESULTS

Data on the effects of infesting varying densities (0 , 2 , 4 , 8 and 16 larvae / plant) of the first instar stage of B. fusca at different plant growth stages (6 , 8 and 10 leaf stages) are presented in tables 15 - 23.

Results on damage effects on foliage parts at varying pest population levels of B. fusca when infested onto the crop at different growth stages are presented in table 15. It is shown (Table 15) that damage on foliage parts decreased as the plant advanced in age regardless of the level of pest infestation used. For example, damage scores (1 - 9) on the leaves ranged from 5.7 (6 leaf) through 5.3 (8 leaf) to 4.7 (10 leaf stage). Nevertheless significant ($P < 0.05$) variation in foliar damage existed among the growth stages studied with the younger stage being the most susceptible (Table 15). Infact a significant ($P < 0.05$) interaction was detected between the growth stages and larval density.

On the other hand, it was evident that damage severity

Table 15. Mean plant leaf damage (1-9 scale) and percentage stem tunnelling as a result of attack by *Busseola fusca* larvae density infested at different growth stages of maize plants.

	Mean plant leaf damage (1-9 scale)				Mean percentage stem tunnelling			
Larvae	Growth stages				Growth stages			
density	6leaf	8leaf	10leaf	Mean	6leaf	8leaf	10leaf	Mean
0 (control)	1.0	1.0	1.0	1.0a	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0a (0.0)
2	4.1	3.0	2.6	3.2b	3.4 (10.9)	3.4 (10.1)	3.0 (8.4)	3.2b (9.8)
4	6.5	6.0	4.4	5.6c	4.2 (16.9)	6.2 (20.4)	3.4 (11.7)	4.6c (16.3)
8	8.4	7.4	7.0	7.6d	6.5 (45.8)	4.5 (19.9)	5.2 (28.4)	5.4c (31.4)
16	8.8	8.9	8.4	8.7e	6.7 (46.3)	7.8 (62.2)	5.6 (32.0)	6.7d (46.8)
Mean	5.7a	5.3b	4.7c		4.4a(24.0)	4.6a(22.5)	3.6a(16.1)	
Criterion		LSD (5%)	S.E.+	F test		L.S.D. (5%)	S.E.+	F test
Larvae density(Ld)		0.18	0.06	2363.8**		1.1	0.4	32.1**
Growth stages(Gs)		0.14	0.05	125.4**		ns	0.3	2.3ns
Ld X Gs		0.32	0.11	19.7**		ns	0.7	1.8ns
C.V.		2.2%				15.9%		

* = Significant at 5% level, ** = Significant at 1% level and ns = Nonsignificant.

Figures in parentheses are means of original values.

The same letter besides figures indicates no significant difference at P<0.05 by the LSD test.

increased irrespective of the plant growth stages with increasing levels of pest infestation. This was demonstrated by the fact that 2 , 4 , 8 and 16 larvae / plant caused leaf damage (1 - 9 scale) in the order of 3.2 , 5.6 , 7.6 , and 8.7 , respectively as compared to the control (1.0) (Table 15). Significant ($P < 0.05$) damage effects were also observed when the intensity of the larval infestation was varied with the damage increasing with increased levels of infestation (Table 15).

When data collected for the following parameters was statistically assessed, it confirmed to the pattern already described above :

(a) stem tunnelling (Table 15) ;
(b) plant height reduction (Table 16) ;
(c) plant leaf area reduction (Table 17) ;
(d) cob length reduction (Table 18) ;
(e) cob width reduction (Table 19) ; and
(f) grain yield loss (Table 20).

Generally, plant height (Table 16), plant leaf area (Table 17), cob length (Table 18), cob width (Table 19) and grain yield, significantly ($P < 0.05$) decreased with increasing levels of larval density while on the other hand the same parameters significantly ($P < 0.05$) increased with the increasing age at which the plants were infested.

It was observed that except for stem tunnelling (Table 15), cob width (Table 19), cob width reduction (Table 19), grain yield / plant (Table 20) and grain yield loss (Table 20), all the other parameters assessed exhibited a significant ($P < 0.05$)

Table 16. Mean plant height (cm) and percentage plant height reduction as influenced by <u>Busseola fusca</u> larvae density infested at different growth stages of maize plants.

	Mean plant height (cm)				Mean percentage plant height reduction			
Larvae	Growth stages				Growth stages			
density	6leaf	8leaf	10leaf	Mean	6leaf	8leaf	10leaf	Mean
0 (control	234.2	231.0	224.0	229.7d	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0a (0.0)
2	199.4	225.0	225.4	215.2d	4.0 (16.7)	2.2 (5.4)	1.7 (2.7)	2.6b (8.3)
4	152.0	189.2	218.8	186.7c	6.0 (35.4)	4.2 (18.1)	2.1 (5.0)	4.1c (19.5)
8	99.0	180.5	201.4	160.3b	7.4 (58.8)	4.3 (22.5)	3.1 (11.0)	4.9c (30.8)
16	64.8	75.4	169.3	103.2a	8.6 (72.7)	8.8 (67.9)	5.0 (23.8)	7.5d (54.8)
Mean	148.9a	180.4b	207.8c		5.4c(36.7)	4.1b(22.8)	2.6a(8.5)	
Criterion		LSD (5%)	S.E.+	F test		LSD (5%)	S.E.+	F test
Larvae density(Ld)		18.1	6.4	61.5**		0.8	0.3	77.2**
Growth stages(Gs)		14.0	4.9	35.4**		0.6	0.2	47.0**
Ld X Gs		31.3	11.1	6.9**		1.3	0.5	5.1**
C.V.		6.2%				11.7%		

* = Significant at 5% level, ** = Significant at 1% level.

Figures in parentheses are means of original values.

The same letter besides figures indicates no significant difference at P<0.05 by the LSD test.

Table 17. Mean plant leaf area (cm2) and percentage leaf area reduction as influenced by _Busseola fusca_ larvae density infested at different growth stages of maize plants.

Larvae density	Mean plant leaf area (cm2)				Mean percentage plant leaf area reduction			
	Growth stages				Growth stages			
	6leaf	8leaf	10leaf	Mean	6leaf	8leaf	10leaf	Mean
0 (control)	8718.7	9386.4	8723.3	8942.8d	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0a (0.0)
2	6486.2	8331.3	9331.4	8049.6c	4.8 (28.6)	3.4 (11.8)	1.9 (3.3)	3.4b (14.6)
4	5059.7	7654.3	7901.5	6871.8b	6.6 (43.9)	4.2 (18.8)	3.5 (12.6)	4.8c (25.1)
8	4766.7	8148.9	8817.3	7244.3b	6.3 (50.3)	3.5 (13.5)	2.1 (5.1)	4.0b (23.0)
16	2097.8	3088.3	7991.8	4392.6a	8.8 (77.9)	8.2 (68.5)	3.2 (12.3)	6.7d (52.9)
Mean	5425.8a	7321.8b	8553.1c		5.5c(40.1)	4.1b(22.5)	2.3a(6.7)	
Criterion		LSD (5%)	S.E.+	F test		LSD (5%	S.E.+	F test
Larvae density(Ld)		694.3	245.4	48.6**		0.7	0.3	65.2**
Growth stages(Gs)		537.8	190.1	68.7**		0.6	0.2	64.4**
Ld X Gs		1202.7	424.9	9.7**		1.3	0.5	7.9**
C.V.		6.0%				11.3%		

* = Significant at 5% level, ** = Significant at 1% level.

Figures in parentheses are means of original values.

The same letter besides figures indicates no significant difference at P<0.05 by the LSD test.

Table 18. Mean cob length (cm) and percentage cob length reduction as influenced by <u>Busseola fusca</u> larvae density infested at different growth stages of maize plants.

	Mean cob length (cm)				Percentage cob length reduction			
Larvae	Growth stages				Growth stages			
density	6leaf	8leaf	10leaf	Mean	6leaf	8leaf	10leaf	Mean
0 (control)	15.9	18.8	20.1	18.3d	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0a (0.0)
2	12.4	17.6	18.2	16.1c	4.3 (21.6)	2.8 (8.9)	3.0 (10.2)	3.4b (13.6)
4	13.4	15.4	15.9	14.9b	4.2 (21.2)	4.0 (17.6)	4.3 (21.2)	4.2b (20.0)
8	10.8	14.6	15.2	13.5b	5.7 (41.3)	3.9 (22.7)	4.9 (23.4)	4.8c (29.1)
16	7.2	5.1	14.1	8.8a	7.5 (59.9)	8.7 (77.3)	5.4 (30.8)	7.2d (56.0)
Mean	11.9a	14.3b	16.7c		4.5a(28.8)	4.1a(25.3)	3.7a(17.1)	
Criterion		LSD (5%)	S.E.+	F test		LSD (5%)	S.E.+	F test
Larvae density(Ld)		1.8	0.6	32.8**		0.9	0.3	46.2**
Growth stages(Gs)		1.4	0.5	23.1**		1.6	0.3	2.4ns
Ld X Gs		3.1	1.1	3.2**		2.3	0.6	2.7*
C.V.		7.6%				22.9%		

* = Significant at 5% level, ** = Significant at 1% level and ns = Nonsignificant.

Figures in parentheses are means of original values.

The same letter besides figures indicates no significant difference at P<0.05 by the LSD test.

Table 19. Mean cob width (cm2) and percentage cob width reduction as influenced by <u>Busseola fusca</u> larvae density infested at different growth stages of maize plants.

	Mean cob width (cm)				Percentage cob width reduction			
Larvae	Growth stages				Growth stages			
density	6leaf	8leaf	10leaf	Mean	6leaf	8leaf	10leaf	Mean
0 (control)	4.2	4.8	4.8	4.6c	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0a (0.0)
2	3.8	4.6	4.6	4.3bc	3.2 (13.5)	2.1 (3.8)	2.5 (6.6)	2.6b (8.0)
4	3.4	4.3	4.2	4.0bc	4.5 (24.5)	3.0 (11.5)	3.2 (14.2)	3.6c (16.7)
8	3.0	3.8	4.1	3.6b	5.1 (36.1)	4.3 (22.3)	3.6 (14.5)	4.3c (24.3)
16	2.2	1.7	3.7	2.5a	7.1 (55.4)	7.5 (66.1)	4.6 (23.6)	6.4d (48.4)
Mean	3.3a	3.8ab	4.3b		4.2b(25.9)	3.6a(20.7)	3.0a(11.8)	
Criterion		LSD (5%)	S.E.+	F test		LSD (5%)	S.E.+	F test
Larvae density(Ld)		0.9	0.3	6.7**		0.9	0.3	38.3**
Growth stages(Gs)		0.7	0.2	5.2**		0.7	0.3	5.6**
Ld X Gs		ns	0.5	0.7ns		ns	0.7	1.73ns
C.V.		14.3%				15.7%		

* = Significant at 5% level, ** = Significant at 1% level and ns = Nonsignificant.

Figures in parentheses are means of original values.

The same letter besides figures indicates no significant difference at P<0.05 by the LSD test.

interaction between larval density and growth stages.

It was apparent that damage on the vegetative parts (Tables 15 - 17) of the plant eventually influenced the grain yield obtained (Table 20). It was shown that grain yield per plant ranged from 80.6 gm (6 leaf stage) through 105.7 gm (8 leaf stage) to 117.1 gm (10 leaf stage). The variations between these yields were significant ($P < 0.05$).

Table 20 also showed that the levels of infestation influenced grain yields. The heaviest damage (42.0 gm) to yield was incurred when 16 larvae / plant were infested as compared to other levels of infestation (8 larvae / plant = 83.6 gm ; 4 larvae / plant = 101.2 gm ; 2 larvae / plant = 118.6 gm) and the control (160.4 gm) (Table 20). The variations of yield by different pest densities were significant ($P < 0.05$).

When mean percentage yield loss was calculated, it was observed that the loss decreased as the plant advanced in age. Yield losses ranged from 40.9% (6 leaf stage) through 37.9% (8 leaf stage) to 36.7% (10 leaf stage)(Table 20). However, no significant ($P > 0.05$) variation in yield losses existed among the growth stages studied.

On the other hand, it was revealed that percentage yield losses increased irrespective of the plant growth stage with increasing levels of pest infestation (Table 20). This was demonstrated by the fact that 2, 4, 8 and 16 larvae / plant caused yield losses in the order of 26.4%, 37.0%, 48.2% and 74.4%, respectively, as compared to the control. The variations of percentage yield losses by different pest densities were

Table 20. Mean grain yield per plant (g) and percentage yield loss as influenced by Busseola fusca larvae density infested at different growth stages of maize plants.

	Mean grain yield per plant (g)				Mean percentage grain yield loss			
Larvae	Growth stages				Growth stages			
density	6leaf	8leaf	10leaf	Mean	6leaf	8leaf	10leaf	Mean
0 (control)	136.5	170.4	174.3	160.4d	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0a (0.0)
2	93.8	132.4	129.6	118.6c	5.6 (31.2)	4.8 (22.3)	5.2 (25.6)	5.2b (26.4)
4	83.2	113.1	107.2	101.2bc	6.3 (39.0)	5.8 (33.6)	6.2 (38.5)	6.1bc (37.0)
8	63.0	93.3	94.5	83.6b	7.4 (53.8)	6.7 (45.2)	6.8 (45.7)	6.9c (48.2)
16	26.8	19.4	79.8	42.0a	9.0 (80.3)	9.5 (88.6)	7.4 (54.2)	8.6d (74.4)
Mean	80.6a	105.7b	117.1c		5.8a(40.9)	5.6a(37.9)	5.3a(36.7)	
Criterion		LSD (5%)	S.E.+	F test		LSD (5%)	S.E.+	F test
Larvae density(Ld)		23.4	8.3	27.9**		1.04	0.4	61.6**
Growth stages(Gs)		18.1	6.4	8.5**		ns	0.3	1.9ns
Ld X Gs		ns	14.4	0.9ns		ns	0.7	0.9ns
C.V.		14.2%				11.9%		

* = Significant at 5% level, ** = Significant at 1%level and ns = Nonsignificant.

Figures in parentheses are means of original values.

The same letter besides figures indicates no significant difference at $P<0.05$ by the LSD test

Table 21. Values of linear regression coeffients of variables at different growth stages of maize H625 on <u>Busseola</u> <u>fusca</u> larval density.

	Crop growth stages					
	6 leaf stage		8 leaf stage		10 leaf stage	
Variable	b	r^2	b	r^2	b	r^2
Plant height	-10.25**	0.61	-9.70**	0.72	-3.67**	0.59
% stem tunnelled	2.99**	0.35	3.62**	0.65	2.00**	0.54
Leaf damage	0.43**	0.61	0.46**	0.75	0.45**	0.83
Leaf area	-361.66**	0.36	-361.07**	0.60	-49.48ns	0.04
Cob width	-0.12*	0.16	-0.19**	0.48	-0.06*	0.17
Cob length	-0.50**	0.19	-0.84**	0.61	-0.34**	0.27
Grain yield	-6.04**	0.22	-8.74**	0.39	-4.95*	0.19
% yield loss	5.07*	0.65	5.35**	0.73	2.89	0.46

b = Coefficient of regression.

r2 =Coefficient of determination.

* =Significant at 5% level.

** = Significant at 1% level.

ns = Nonsignificant.

Table 22. Values of simple correlation coefficients of variables at different growth stages of maize H 625 with <u>Busseola</u> <u>fusca</u> larval density.

	Crop growth stages		
	6 leaf stage	8 leaf stage	10 leaf stage
Variable	r	r	r
Plant height	-0.78**	-0.85**	-0.77**
% stem tunnelled	0.59**	0.81**	0.74**
Leaf damage	0.78**	0.87**	0.81**
Leaf area	-0.59**	-0.77**	-0.21
Cob width	-0.40*	-0.70**	-0.41*
Cob length	-0.45**	-0.78**	-0.52**
Grain yield	-0.46**	-0.62**	-0.43*
% grain yield	0.81**	0.86**	0.68**

* = significant at 5% level.

** = significant at 1% level.

r = correlation coefficient.

Table 23. Economic injury levels for different growth stages of maize H 625 to <u>Busseola fusca</u>

Growth stages	$y = a + bx$	Mean yield	B [shs.]	Z [shs.]	EIL [x]
6 leaf	$y = 116.87 - 6.04x$	80.66	0.087	0.149	0.03
8 leaf	$y = 158.09 - 8.74x$	105.67	0.126	0.103	0.01
10 leaf	$y = 146.77 - 4.95x$	117.08	0.071	0.183	0.04

$$\text{Modified gain threshold } [Z] = \frac{\text{Cost of insecticidal application/plant } [A]}{\text{Market price of maize produced /plant } [B]}.$$

Where ,
B =[Expected yield - Mean yield at a particular growthstage] x Market price.

$$\text{EIL } [x] = \frac{\text{Modified gain threshold } [Z]}{b}$$

Where ,
b = Regression coefficient, y = Grain yield [g] / plant ,
a = Intercept on Y, x = Larval density / plant.

NB: Calculations were based on :

(a) Cost of insecticide [Thiodan 3G] applied at 15 kg /ha costing Kshs. 400.95

[B] Insecticide application 4 man days / ha costing Kshs. 120.00

[c] Market price of maize costing Kshs. 217.20 per 90 kgs.

(d) Plant density of 40000 plants / ha.

significant ($P < 0.05$).

The values of linear regression coefficients given in table 21 showed that regression of maize parameters assessed against larval densities were much heavier on 8 leaf stage plants, followed by 6 leaf and 10 leaf stages. It was apparent that the rate of increase in stem tunnelling, leaf damage, leaf area, cob width, cob length, grain yield and yield loss, with every unit increase in larval density were much higher in 8 leaf stage, as compared to 6 leaf and 10 leaf stages.

It was also evident from the values of simple correlation coefficients found between different variables (Table 22) that for all the maize parameters assessed, the highest correlation values were observed in 8 leaf stage followed in decreasing order by 6 and 10 leaf stages. Plant height, leaf area, cob width, cob length and grain yield were significantly ($P < 0.05$) negatively correlated with larval population of _B_. _fusca_ for all crop growth stages studied. However, stem tunnelling, leaf damage and yield loss were significantly ($P < 0.05$) positively correlated with larval population for all crop growth stages.

The economic injury levels (EILs) for _B_. _fusca_ calculated at three different growth stages are presented in table 23. These results showed that the plants were more sensitive to _B_. _fusca_ damage at 8 leaf stage but at later growth stages more larvae were needed to cause economic losses. EILs of 0.03 larvae, 0.01 larvae and 0.04 larvae per plant were calculated as being the densities to cause economic losses at the 6 leaf, 8 leaf and 10 leaf stages, respectively.

9.4 DISCUSSION

Incremental trends of damage to maize parameters studied by increasing levels of B. fusca larvae was evident in these investigations. This was probably due to feeding by higher populations of the larvae. Similar relationships were reported by Walker (1960b) and Usua (1968a) on this particular pest.

It was also evident that damage levels of the parameters studied were highest in the maize crop infested at the earlier growth stages, while the damage levels were the least in plants infested with varying larval densities at later crop growth stages. This suggested that as maize plants become older they become more tolerant to attack by B. fusca larvae. The fact that as growth proceeded, the plants become more tolerant was reported by Bardner and Fletcher (1974) and Sharma and Sharma (1987). According to Sharma and Chatterji (1971), the reasons for less damage at later growth stages was due to increased toughness of plant tissues so that it became difficult for the larvae to thrive on them, thereby causing less damage. Besides early infestations when the crop was still young enabled them to feed longer and caused more injury (Sharma and Sharma, 1987).

The simple regression and simple correlation coefficients indicated that the level of damage had a more pronounced effect on plants infested at 8 leaf stage than at later crop growth stages. This suggested that the 8 leaf stage was the most critical phase of growth sensitive to B. fusca attack. This finding could be exploited for the timely application of control measures against the pest.

From the results obtained in these studies, leaf damage and stem tunnelling due to the feeding activities of larvae resulted into reduced plant heights. Additionally, the feeding activities also led to reduced leaf area index with the consequence that less photosynthesis occurred. This probably led to the overall poor performance of the plants as manifested by the heavy yield loss sustained by such plants.

It was also shown that economic injury levels were lower at early growth stages and increased at later growth stages. This was attributed to the fact that as plants grew older, they became more tolerant to damage caused by *B. fusca*. In their studies on a closely related pest species *C. partellus*, Sharma and Sharma (1987) reported that economic injury levels to the pest increased as the crop became more advanced in maturity.

CHAPTER 10

ESTIMATION OF CROP LOSSES CAUSED BY THE MAIZE STALK BORER *BUSSEOLA FUSCA* USING TWO DIFFERENT CROP LOSS ASSESSMENT TECHNIQUES

10.1 INTRODUCTION

The purpose of studying yield losses is to identify suitable control strategies which could be used to reduce losses resulting from *B. fusca* damage. However, before yield loss can be estimated from pest damage in the field, suitable crop loss assessment methods have to be available. Several methods of assessment of losses have been described by a number of workers (Veerish, 1980 ; Khosla, 1980 ; Walker, 1981; 1983 ; Singh and Khosla, 1983 ; and Leuschner and Sharma, 1983).

However, the assessment of losses caused by *B. fusca* has largely been based on comparison of yields of plants protected and unprotected with chemicals. For example, Swaine (1957), Harris (1962), Walker (1960a), and Walker and Hodson (1976) assessed losses caused by maize stalk borer using this technique.

In addition, crop losses caused by *B. fusca* have been assessed by artificial infestation with known numbers of larvae per maize plant (Usua, 1968a ; Walker and Hodson, 1976 ; and Tchekmenev, 1981).

The objective of these investigations was to evaluate two commonly used crop loss assessment methods of estimating losses and plant damage caused by B. fusca. The information obtained would be valuable in the development of sound pest management practices against the pest to minimize yield losses it causes.

10.2 MATERIALS AND METHODS

Two techniques of assessment of crop losses in farmers' fields that have been proposed by Leuschner and Sharma (1983) were evaluated. These techniques were :

(a) comparing the yields of damaged and undamaged maize plants ; and,

(b) comparing the yields of chemically protected and unprotected maize plants.

The assessment of loss using the two techniques was conducted at three experimental sites, namely, Njoro, Kiamunyi and Olrongai during 1987 and 1988 cropping seasons. The three sites were chosen to ensure pest attack since B. fusca infestation to maize is known to be variable from place to place. Assessment was carried out in selected farmers' maize fields at each site. All agronomic practices were implemented by individual farmers. The experiments were intiated at the 8 leaf stage (45 days after germination). The farmers' fields were chosen when the initial symptoms of B. fusca were noticed. Overall field infestation was assessed from a sample of 1,000 plants.

(a) Comparing the yields of damaged and undamaged maize plants

Individual infested and uninfested maize plants were tagged to study the effect of B. fusca attack. In total, 50 infested and 50 adjacent uninfested maize plants in each plot (20 X 30 m) were marked. Four such plots were demarcated in a particular field. The damaged and undamaged plants were marked by tagging using red and yellow polythene plastic strips, respectively (Plate 3). Apart from the routine management practices, all marked plants were left to grow undisturbed until the period of harvesting. At maturity, all marked plants were recovered and harvested. Cobs from both damaged and undamaged plants were bagged separately for every replicate.

After manually shelling the cobs, the grains were weighed after measuring the moisture content. Dry grain yield was calculated at a standard 14% moisture content. The stalks of the sample plants which had been harvested earlier were then split to reveal the extent of internode damage and stem tunnelling caused by the pest. The number of pupal cases per stalk was also taken to give an estimate of the number of larvae that effectively infested the plants.

The coefficient of harmfulness was calculated as the direct loss of yield per plant expressed as a percentage of yield from the undamaged plants whereas percentage economic losses were assessed using Judenko's (1972) formula represented as below :

Plate 3. Damaged and undamaged maize plants marked by tagging using red and yellow polythene plastic strips respectively.

Extent of losses $= W - A$

Where W = is the expected yield

A = is the actual yield.

$$W = \frac{100 \times A}{100 - L}$$

Where L = is the percentage economic loss.

$$L = \frac{C\ P}{100}$$

Where C = is the coefficient of harmfulness

P = is the percentage of plants infested.

$$C = \frac{(a - b)\ 100}{a}$$

Where a = is the mean yield of undamaged plant

b = is the mean yield of damaged plant.

The economic losses were converted into kg / ha and monetary losses calculated at the cost of Kshs. 217.20 per 90 kg of maize which was the set price for the commercial seed maize for 1989.

(b) Comparing the yields of chemically protected and unprotected maize plants

The experiment consisted of 8 plots measuring 20 X 30 m each which were marked out in the farmers' maize fields. Four of the plots were given chemical protection while the other four were left unprotected.

Carbofuran 5% granules was applied at 8 leaf stage (45 days after germination) at the rate of 1.0 kg active ingredient / ha into the funnels to ensure complete control of stalk borers. Guard rows were dispensed with as the mode of application was regarded as sufficient enough to eliminate interplot effects.

Plant damage and losses from the treatments were assessed at harvest. The cobs from treated and control plots were harvested from 50 randomly selected plants from the four central rows of each plot. Grain weight at a moisture content of 14% was determined after shelling. Other observations recorded were number of pupal cases, internode damage and stem tunnelled which were assessed by splitting the stalks as in the previous experiment.

Coefficient of harmfulness and economic losses were assessed, using the method described by Judenko (1972). The economic losses were converted into kg / ha and monetary losses calculated as in the previous experiment.

The data on number of pupal cases, internode damage and stem tunnelling was transformed using square root (X + 1) transformation (Steele and Torrie, 1980) before the means were retransformed to original values. The calculated coefficient of harmfulness, percentage economic losses and net monetary losses resulting from the use of the two crop loss assessment techniques were compared using the F test.

10.3 RESULTS

Data on the number of pupal cases, internode damage, stem tunnelling and grain yield between infested and uninfested plants at Njoro, Kiamunyi and Olrongai based on the technique of damaged / undamaged plants is presented in table 24. High

Table 24. Mean plant damage and grain yield as influenced by *Busseola fusca* attack estimated by using two crop loss assessment methods.

		Crop loss assessment methods					
		Undamaged /damaged method			Protected /unprotected method		
Study area	Assessed variable	Undamaged plants	Damaged plants	F test	Protected plants	Unprotected plants	F test
Njoro	No. of pupal cases	0.0	1.5	144.3**	0.0	0.9	15.7*
	% internode damage	0.0	26.0	286.1**	0.0	16.0	45.6**
	% stem tunnelled	0.0	17.0	47.1**	0.0	12.5	27.4*
	Grain yield / plant (g)	213.1	159.8	17.4*	221.1	200.9	10.1ns
Kiamunyi	No. of pupal cases	0.0	1.0	9.6ns	0.0	0.2	6.0ns
	% internode damage	0.0	11.7	410.7**	0.0	9.2	22.6*
	% stem tunnelled	0.0	10.0	35.1**	0.0	7.8	10.5*
	Grain yield / plant (g)	225.6	168.1	17.7*	207.5	142.5	56.1**
Olrongai	No. of pupal cases	0.0	1.5	45.3**	0.0	0.2	3.6ns
	% internode damage	0.0	25.9	227.1**	0.0	14.7	21.7*
	% stem tunnelled	0.0	15.5	587.5**	0.0	9.9	25.6*
	Grain yield / plant (g)	206.5	164.1	12.3*	213.6	164.5	20.3*

* = significant at 5% level, ** = significant at 1% level and ns = nonsignificant.

quantities of pupal cases and severe stem and internode damage were observed in the infested plants at the three study areas. It was observed that on the overall uninfested plants outyielded the infested plants (Table 24). For example, at Njoro undamaged plants yielded 213.1 gm as compared to 159.8 gm / plant in damaged plants. At Kiamunyi, undamaged plants yielded 225.1 gm while damaged individuals produced 168.1 gm / plant. Undamaged plants at Olrongai gave 206.5 gm as compared to 164.1 gm / plant obtained from damaged plants (Table 24). Significant ($P < 0.05$) differences in the number of pupal cases, internode damage, stem damage and grain yield between infested and uninfested plants existed in the three study areas (Table 24) except at Kiamunyi where the difference of number of pupal cases recovered between the two treatments was not significant.

Data collected on the number of pupal cases, internode damage, stem tunnelled and grain yield between infested and uninfested plants assessed using the basis of protected / unprotected plants technique at Njoro, Kiamunyi and Olrongai is presented in table 24. In all the three study areas, a higher number of pupal cases and more stem and internode damage occurred in the unprotected plants as compared to the protected ones (Table 24). The yields obtained at harvest showed that infested plants produced lesser grain yield as compared to their uninfested counterparts. At Njoro protected plants produced 221.1 gm as compared to 200.9 gm / plant which was yielded by protected ones. In the case of Kiamunyi, protected plants produced 207.5 gm while unprotected individuals each yielded

142.5 gm. Unprotected plants yielded 164.5 gm while the protected ones gave higher yields of 213.6 gm / individual at Olrongai (Table 24). At Kiamunyi and Olrongai, significant ($P < 0.05$) differences existed in stem and internode damage and grain yield between protected and and unprotected plants. At Njoro, it was revealed by these studies that no significant ($P > 0.05$) differences in grain yield existed between the two applied treatments (Table 24).

The coefficients of harmfulness and percentage economic losses for each of the three study sites when the two crop loss assessment techniques were applied are presented in table 25. At Njoro, coefficients of harmfulness of 25.1% and 9.0% were obtained when the techniques based on damaged / undamaged and protected / unprotected plants, respectively, were used. Coefficients of harmfulness of 25.5% and 31.3% were obtained when the techniques of damaged / undamaged and protected / unprotected plants, respectively, were applied at Kiamunyi. In the case of Olrongai, coefficients of harmfulness of 20.5% and 22.9% were realized when the same techniques were used (Table 25). However, there were no significant ($P > 0.05$) differences in the degree of harmfulness between the two techniques (Table 25) indicating that they could be regarded as being identical.

The economic losses of 2.7% and 1.1% occurred when the techniques based on damaged / undamaged and protected / unprotected plants, respectively were applied at Njoro (Table 25). Table 25 also gives corresponding figures for economic losses for Kiamunyi and Olrongai when the two techniques were

Table 25. Summary of percentage economic yield losses and net monetary losses due to *Busseola fusca* attack on maize assessed by using two crop loss assessment methods.

Study Area	Crop loss assessment method	Percentage plant infestation	Grain yield/ unattacked plant(g)	Grain yield/ attacked plant(g)	Coefficient of harmfulness	Percentage economic loss	Economic loss (kg/ha)	Net loss (Sh/ha
Njoro	Dam./Undam.	12.2	213.1	159.8	25.0	2.7	166.1	400.85
	Prot./Unprot.	12.2	221.1	200.9	9.1	1.1	76.9	185.70
	F test				1.57ns	1.59ns	1.67ns	1.77ns
Kiamunyi	Dam./Undam.	12.7	225.6	168.1	25.1	2.9	190.3	459.30
	Prot./Unprot.	12.7	207.5	142.5	31.3	1.0	200.3	483.40
	F test				1.18ns	1.17ns	1.18ns	1.19ns
Olrongai	Dam./Undam.	12.8	206.5	164.1	20.5	2.6	146.3	353.10
	Prot./Unprot.	12.8	213.6	164.5	22.9	2.8	152.9	369.00
	F test				0.06ns	0.03ns	0.05ns	0.06ns

N.B. Dam. means Damaged, Undam. means Undamaged, Prot. means Protected, and Unprot. means Unprotected.

applied. It was also found that no significant ($P > 0.05$) differences of economic losses existed in the values obtained when the two techniques were applied (Table 25). This finding pointed further to the closeness in similarity of the techniques.

From the data presented in table 25, it is also shown that the values of the overall economic losses (kg / ha) and monetary losses calculated when the two techniques were applied did not differ significantly ($P > 0.05$) in all the study sites. This demonstrated further the close identity of the two techniques in assessing damage and yield loss caused by B. fusca.

10.4 DISCUSSION

In these investigations it was revealed by the calculated values of coefficients of harmfulness and percentage economic loss that no significant differences existed in the study sites. This could be attributed to the fact that pest infestation levels were uniform in all the study areas. The results obtained demonstrated that no significant differences in effectiveness existed between the two techniques studied. It was therefore concluded that any one of them, rather than both, could be used to assess maize yield losses due to B. fusca. However, the technique in which no chemicals were applied was more appealing in view of the fact that it has practically no side effects.

The other attribute for damaged / undamaged plants technique is that it could be used for generalised surveys to indicate the magnitude of losses. The technique becomes especially useful when normal experiments cannot be conducted and also when the studies are intended to cover as many farms as possible. Additionally, this technique allows for quantification of any comparison of compensation achieved by unifested plants adjacent to infested neighbouring plants as pointed out by Richardson (1981).

It must, however, be pointed out that the use of chemically protected and unprotected plants to evaluate yield losses , could be put to good use by farmers as it conformed closely to standard agronomic practices and reflected the actual infestation status of the pest in the field. However, the methodology does not take into account any kind of compensation that will be detected as in the previous technique (Richardson, 1981). Furthermore, some of the chemicals applied could have phytotonic effects on plants and thereby influence grain yields.

CHAPTER 11

ON-FARM CROP LOSS ASSESSMENT CAUSED BY THE MAIZE STALK BORER BUSSEOLA FUSCA USING THE DAMAGED / UNDAMAGED PLANTS TECHNIQUE IN NAKURU DISTRICT, RIFT VALLEY PROVINCE, KENYA

11.1 INTRODUCTION

Information is not available in Kenya on the extent of crop losses caused by B. fusca and their relative importance in limiting production in the different agro-ecological zone of Nakuru District where maize is grown. The primary objective of conducting a survey of on-farm crop losses due to the pest during these studies was to obtain information on the extent of pest infestation and to determine eventual yield loss as a result of the pest damage.

Despite the widespread occurrence of the pest in the highland areas, information is not available on crop losses due to the pest. This study was thus conducted to gain an insight into the actual on-farm losses caused by B. fusca in Nakuru District of Rift Valley Province.

Since integrated pest management of the maize stalk borer requires detailed knowledge of the significance of pest infestation on the farms, availability of such information could be of immense value in designing suitable control strategies for B. fusca.

11.2 MATERIALS AND METHODS

On-farm crop losses caused by the maize stalk borer were studied in Nakuru District in five agro-ecological zones, namely:

(a) Elburgon area in Low Highland zone 2 (LH 2) ;

(b) Njoro area in Low Highland zone 3 (LH 3) ;

(c) Olrongai area in Low Highland zone 4 (LH 4) ;

(d) Lanet area in Upper Midland zone 4 (UM 4) ; and

(e) Pwani area in Upper Midland zone 5 (UM 5) .

The survey was based on a sample of four farms in each zone during the harvest seasons (October to December 1987 and 1988). The farms were selected in the study areas using simple random sampling. Assessment of crop losses in each farm was estimated using the paired sample method (Leclerg, 1970). In order to make comparisons of incidence and crop loss, two types of maize plant samples were removed. One such sample comprised of 25 plants damaged by the pest ; the other sample comprised of a similar number of 25 plants which had not been damaged by the pest. The percentage of infested plants in the field was also estimated from a random sample of 500 plants per field.

Cobs from both types of samples were harvested and bagged separately after labelling . All the harvested stalks were examined to assess the extent of damage, if any, caused to them by B. fusca. Stem and internode damage was assessed as in the the previous experiments.

When the stalks had been split the pupal cases, found in the stalks were counted in order to estimate the number of larvae that survived and effectively damaged the plants. At harvest the weight of grains, at 14% moisture content, were determined as in the previous experiments.

The formula of Judenko (1972) was applied to determine economic loss. The net monetary loss attributed to stalk borer damage was calculated based on the cost of maize in 1989 at Kshs. 217.20 per 90 kg.

Before analysis of variance was performed a square root (X + 1) transformation was applied to the data on the number of pupal cases, percentage internode damage, percentage stem tunnelling and percentage yield loss. This was done in order to homogenize and stabilize the variance (Steele and Torrie, 1980). The means were later retransformed to actual values.

11.3 RESULTS

The field survey of on-farm losses in maize due to _B_. _fusca_ revealed that the pest was common in all the agro-ecological zones. This demonstrated the importance of the pest under a variety of environmental and climatic conditions. Data on the quantity of pupal cases recovered (Table 26) showed that the highest numbers were recovered at LH 3 (1.8) followed in decreasing order by UM 4 (1.5), UM 5 (1.4), LH 4 (1.3) and LH 2 (0.8). However, there were no significant ($P > 0.05$) differences among these areas in the quantities of pupal cases recovered. This indicated that infestation by _B_. _fusca_ was fairly uniform in all the five zones studied.

Table 26. Survival of Busseola fusca, internode damage and stem tunnelling in damaged plants in the five zones of Nakuru area of Rift Valley Province.

Zone	Surveyed area	Mean no. of pupal cases (±S.E.)	Mean % internode damage (±S.E.)	Mean % stem tunnelling (±S.E.)
LH2	Elburgon	0.8±0.5	25.0±7.7	17.8±8.2
LH3	Njoro	1.8±0.8	32.8±17.9	22.2±11.8
LH4	Olrongai	1.3±0.9	23.4±11.0	23.6±2.8
UM4	Lanet	1.5±0.5	32.5±9.4	25.1±8.6
UM5	Pwani	1.4±0.8	30.9±14.6	25.2±13.4
	F test	0.57ns	0.47ns	0.43ns

ns = nonsignificant (P>0.05)

Table 27. Percentage economic yield losses and net monetary losses due to *Busseola fusca* attack in the five zones of Nakuru area of Rift Valley Province.

Zone	Surveyed area	Percentage plant infestation	Grain yield / 25 undamaged plants(kg)	Grain yield / 25 damaged plants(kg)	Coefficient of harmfulness	Percentage economic loss	Economic loss (kg/ha)	Net losses (Kshs/ha)
LH2	Elburgon	11.1	5.30	4.09	22.8	2.5	146.0	352.35
LH3	Njoro	13.1	5.06	4.04	20.1	2.6	151.0	364.40
LH4	Olrongai	12.3	5.23	3.58	31.5	3.9	203.4	490.90
UM4	Lanet	9.5	5.45	4.22	22.6	2.2	132.9	320.70
UM5	Pwani	20.3	4.04	2.75	31.9	6.5	267.6	645.80
	F test	16.4*	10.1ns	9.7ns	10.6*	14.7*	13.2*	11.3*

* = significant at 5% level.

ns = nonsignificant.

The fact that B. fusca infestations caused severe damage to maize in the study areas is also shown in table 26. The results (Table 26) revealed that highest internode damage of 32.8% occurred at LH 3 followed in decreasing order of importance by UM 4 (32.5%), UM 5 (30.9), LH 2 (25.0%) and LH 4 (23.4%). Correponding figures for stem damage are also shown in table 26. When analysis of variance was performed it was revealed that no significant ($P > 0.05$) differences in terms of the magnitude of stem and internode damage existed among the five zones.

Data presented in table 27 showed that damage by B. fusca adversely affected grain yields, causing substantial reductions. The highest coefficient of harmfulness was observed at UM 5 (31.9%), followed in decreasing order of severity by LH 4 (31.5%), LH 2 (22.8%), UM 4 (22.6%) and LH 3 (20.1%). It was shown through statistical analysis that the coefficients of harmfulness varied significantly ($P < 0.05$) among the five zones.

The effect of B. fusca attack on grain yield (Table 27) led to economic losses of 6.5% at UM 5, 3.9% at LH 4, 2.6% at LH 3, 2.5% at LH 2 and 2.2% at UM 4. The corresponding estimated monetary losses (Kshs. / ha) due to B fusca attack were Kshs. 645.80, 490.90, 364.40, 352.35 and 320.70 at UM 5, LH 4, LH 3, LH 2 and UM 4 zones, respectively, (Table 27).

11.4 DISCUSSION

Results from these investigations revealed that there were definite differences among the zones in potential losses due to

_B_. _fusca_ attack. These could be attributed probably to the differences in infestation levels among the zones studied. These observations suggested further that the same pest under different climatic conditions had the potential of inflicting heavy differential economic losses.

Field surveys on crop losses of this nature conducted at crop harvest have limitations in their use. This is because it is not possible to determine at which stage critical damage was inflicted. Thus the results obtained cannot indicate the pest intensity levels at which control measures could be applied. This is in view of the work of Lynch (1980) who observed that the extent of physiological yield losses depended on the stage of plant development at which infestation occurred. This aspect deserved further investigations in order to accurately quantify factors such as climatic conditions, maize variety, pest intensity and growth stage of the crop at the time of attack, all of which may interact and affect yields.

12. REFERENCES

Acland, J.D. (1971) East African Crops. An introduction to the production of field and plantation crops in Kenya, Tanzania and Uganda. Longman Group Ltd., London. 252 p.

Adesiyun, A.A. and O. Ajayi. (1980) Control of sorghum stem borer Busseola fusca, by partial burning of the stalks. Tropical Pest Management 26 (2) : 113 - 117.

Adeyemi, S.A.O. (1969) The survival of stalk borer population in maize stubbles. Bull. Ent. Soc. Nigeria 2 (1) : 16 - 22.

Allan, A.Y. (1972) The influence of agronomic factors in maize yields in Western Kenya, with special reference to the time of planting. PhD thesis. University of East Africa, Makerere, Kampala, Uganda.

Allan, A.Y. (1974) The development of improved agronomic practice for maize production in Kenya under favourable rainfall conditions. In : Proceedings of the first FAO / SIDA seminar on improvement and production of field food crops for plant scientists from Africa and the Near East. FAO, Rome. pp 486 - 494.

Annonymous, (1967) Annual Report. Maize Research Section. National Agric. Res. Station, Kitale. Min. of Agric., Rep. of Kenya.

Annonymous, (1970) Annual Report. Maize Research Section. National Agric. Res. Station, Kitale. Min. of Agric., Rep. of Kenya.

Annonymous, (1979a) Maize handbook. Kenya Seed Co. publication. Rodwell Press, Mombasa. 69 p.

Annonymous, (1979b) Kenya Development Plan 1979 - 84. Government Printer, Nairobi, Rep. of Kenya.

Annonymous, (1983) Facts and Figures about Kenya's Agriculture. Min. of Agriculture, Rep. of Kenya.

Annonymous, (1984) Kenya Development Plan 1984 - 88. Government Printer, Nairobi, Rep. of Kenya.

Annonymous, (1985) Conservation Tillage - Helping you to reap the profits. Monsanto Newsletter No. 4 April 1985, 9p.

Annonymous, (1986) Kenya 1986. Sessional Paper No. 1. Economic Management for Renewed Growth. Government Printer, Nairobi, Rep. of Kenya.

Bardner, R. and K.E. Fletcher. (1974) Insect infestations and their effects on the growth and yield of field crops : a review. Bull. ent. Res. 64 : 141 - 160.

Barrow, M. (1989) Screening and breeding for resistance to Busseola fusca. In : CIMMYT 1989 Toward insect resistant maize for the Third World : Proceedings of the International Symposium on methodologies for developing host plant resistance to maize insects, held from 9 - 14th March 1987. pp 184 - 191.

Barry, B.D. and D.J. Andrews. (1974) A sprayer for control of Busseola fusca in leaf whorl of sorghum. J. econ. Ent. 67 : 310 - 311.

Blair, B.W. (1982) Seasonal abundance of Agrotis segetum (Denis & Schiff) and A. ipsilon (Hufn.) (Lepidoptera :

Noctuidae) in Zimbabwe and a method of forecasting post-winter population densities. J. ent. Soc. Sth. Afr., 45 (2) : 201 - 215.

Blaire, B.W. (1971) Recent research on the maize stalk borer, Busseola fusca Fuller : Influence on control methods. Rhodesia Agric. J. 67 - 68 : 111 - 112.

Bock, K.R., E.J. Guthrie and R.D. Woods. (1974) Purification of maize streak virus and its relationship to viruses associated with streak diseases of sugarcane and Panicum maximum. Ann. appl. Biol. 77 : 289 - 296.

Bohlen, E. (1973) Crop pests of Tanzania and their control. Edited by Federal Agency for Economic Cooperation. Paul Parly, Berlin. 142 p.

Bowden, J., and B.M. Church. (1973) The influence of moonlight on catches of insects in light traps in Africa. Part II. The effect of moon phase on light trap catches. Bull. ent. Res. 63 : 129 - 142.

Bowden, J., and D.G. Gibbs. (1973) Light trap and suction trap catches of insects in the northern Gezira, Sudan, in the season of Southward Movement of the Inter Tropical Front. Bull. ent. Res. 62 : 571 - 596.

Brady, N.C. (1984) A lifeline to the developing world : more and better maize through collaboration. In : Proceedings of the U.S. Universities - CIMMYT maize conference on collaboration toward mutual LDC production objectives. International Maize and Wheat Improvement Center, El Batan. Texcoco, Mexico, August 9 - 14 1984. pp 9 - 15.

Brown, E.S., E. Betts and R.C. Rainey. (1969) Seasonal changes in the distribution of the African armyworm, Spodoptera exempta (Wlk.) (Lep., Noctuidae) with special reference to eastern Africa. Bull. ent. Res. 58 : 661 - 729.

Brown, E.S., and L.R. Taylor. (1971) Lunar cycles in the distribution and abundance of air-borne insects in the equatorial highlands of East Africa. J. Animal Ecol. 40 : 767 - 779.

Bullock, J.A. (1958) Barley fly, Black wheat beetle and Maize stalk borer : Appraisal and control. Kenya Farmer, April 1958.

Coaker, T.H. (1956) An experiment on maize stalk borer control on maize. E. Afr. Agric. For. J. 21 : 220 - 221.

Darrah, L.L. (1976) Altitude and environmental responses of entries in the 1972 - 1973 East African Maize Variety Trial. E. Afr. Agric. For. J. 41 : 273 - 288.

De Lima, C.P.F. (1976) A guide to the biology and control of pests of field crops and stored produce in Kenya. Min. of Agric. Rep. of Kenya.

de Pury, J.M.S. (1968) Crop pests of East Africa. Oxford University Press. Nairobi. Kenya. 227 p.

Duerden, J.C. (1953) Stem borers of cereal crops at Kongwa, Tanganyika, 1950 - 52. E. Afr. Agric. For. J.19 : 105 - 106.

Du Plessis, C., and H.A.P. Lea. (1943) The maize stalk borer Calamistis fusca (Hmps). Dept. Agric. of S. Afr. Bulletin No. 238, 51 p.

Eberhart, S.A., L.H. Penny and M.N. Harrison. (1973) Genotype by environment interactions in maize in Eastern Africa. E. Afr. Agric. For. J. 39 : 61 - 71.

Efron, Y., and S.K. Kim. (1984) Can the success story of hybrid maize in Kenya repeat itself in Nigeria ?. In : Proceedings of the U.S. Universities - CIMMYT maize conference on collaboration toward mutual production objectives. International Maize and Wheat Improvement Center, El Batan, Texcoco, Mexico. August 9 - 14 1984, pp 75 - 76.

Egwuatu, R.I., and C.B. Ita. (1982) Some effects of single and spilt applications of carbofuran on the incidence of and damage by Locris maculata, Busseola fusca and Sesamia calamistis on maize. Tropical Pest Management 28 (3) : 277 - 283.

Fuller, C. (1900) Life history and description of larva, pupa and adult. Natal Agric. Dept., 1st Ann. Rept., 45 p.

Gebre-Amlak, A. (1988) Ecology and management of maize stalk borer Busseola fusca Fuller (Lepidoptera : Noctuidae) in Southern Ethiopia. PhD Dissertation, Dept. of Plant and Forest Protection. Swedish University of Agricultural Sciences, Uppsala.

Graham, J.F. (1947) Annual Report. Dept. Agric. Kenya.

Graham, J.F. (1951) Annual Report. Dept. Agric. Kenya. 2 pp 2 - 3.

Hardwick, D.F. (1972) The influence of temperature and moon phases on the activity of noctuid moths. Can. Entomologist 104 : 1767 - 1770.

Harris, K.M. (1962) Lepidopterous stem borers of cereals in Nigeria. Bull. ent. Res. 53 : 139 - 171.

Harris, K.M. (1964) Annual variations of dry-season populations of larvae of <u>Busseola</u> <u>fusca</u> Fuller in Northern Nigeria. Bull. ent. Res. 54 : 643 - 647.

Hill, D.S. (1975) Agricultural insect pests of the tropics and their control. Cambridge University Press. 516 p.

Hodson, M.J., and P.T. Walker. (1975) Stalk borer in the main maize-growing areas of Kenya. Centre for Overseas Pest Research, London. 7 p.

Huise, A. Van. (1981) Integrated pest management in the small farmers' maize crop in Nicaragua. Meded. LandbHoougesch. Wageningen, 81 - 6. 221 p.

Ingram, W.R. (1958) The lepidopterous stalk borers associated with Graminae in Uganda. Bull. ent. Res. 49 : 367 - 383.

Ivens, G.W. (1967) East African weeds and their control. Oxford University Press. 250 p.

Jaetzold, R., and H. Schmidt. (1983) Nakuru District. In : Farm management handbook of Kenya. Vol. II B. Central Kenya (Rift Valley and Central Provinces). Min. of Agric. Rep. of Kenya. pp 384 - 396.

James, W.C., and P.S. Teng. (1979) The quantification of production constraints associated with plant diseases. In : Coaker T.H. (ed.) Applied Biology. Vol. III. Academic Press. New York, pp 201 - 267.

Jepson, W.F. (1954) A critical review of the world literature on lepidopterous stem borers of tropical graminaceous crops.

°Commonwealth Institute of Entomology. London. 127 p.

Judenko, E., (1972) The assessment of economic losses in yield of annual crops caused by pests, and the problems of economic threshold. PANS 18 : 186 - 191.

Kaufmann, T., (1983) Behavioural biology, feeding habits, and ecology of three species of maize stem borers : Eldana saccharina (Lepidoptera : Pyralidae), Sesamia calamistis and Busseola fusca (Noctuidae) in Ibadan, Nigeria, West Africa. J. Georgia Ent. Soc. 18 (2) : 259 - 272.

Kfir, R. (1988) Hibernation by the lepidoteran stalk borers, Busseola fusca and Chilo partellus on grain sorghum. Entomologia exp. appl. 48 : 31 - 36.

Khaemba, B.M. (1985) Maize stalk borer : A serious pest of maize. Kenya Farmer J. Agric. Soc. No. 45.

Khosla, R.K. (1980) Field experiment and survey techniques for the estimation of crop loss. In : Assessment of crop losses due to pests and diseases. Proceedings of the workshop held from Sept. 19 - 30 1977 at UAS, Bangalore UAS. Tech. Series No. 33, pp 66 - 72.

Kulkani, H.Y. (1973) Notes on East African plant virus diseases. 5. Identification and economic importance of sugarcane mosaic virus in maize in East Africa. E. Afr. Agric. For. J. 39 : 158 - 164.

Kuria, J.N., and F.G. Oile. (1982) Field evaluation of pyrethrum marc for control of maize stalk borer Busseola fusca Fuller in Nakuru District, Kenya. Unpublished Report. Pyrethrum Bureau, Nakuru, Kenya.

Lawani, S.M. (1982) A review of the effects of various agronomic practices on the cereal stem borer populations. Tropical Pest Management 28 (3) : 266 - 276.

Leclerg, E.L. (1970) Field experiments for assessment of crop loss : FAO mannual on the evaluation and observation of losses by pests, diseases and weeds. FAO, Rome, Italy.

Le Pelley, R.H. (1959) Agricultural insects of East Africa. East African High Commission, Nairobi, Kenya. 307 p.

Leuschner, K., and H.C. Sharma. (1983) Assessment of losses caused by sorghum panicle pests. Paper presented at the "All India Workshop on Crop Losses due to Insect Pests". Jan. 7 - 9 1983, APAU Rajendranagar, A.P. India.

Lynch, R .E. (1980) European corn borer : Yield losses in relation to hybrid and stage of corn development. J. econ. Ent. 73 : 159 - 164.

Mahadevan, N.R., and S. Chelliah. (1986) Influence of season and weather factors on the occurence of sorghum stem borer _Chilo partellus_ Swinhoe in Tamil Nadu. Tropical Pest Management 32 (3) : 212 - 214.

Mally, C.W. (1920) The maize stalk borer _Busseola fusca_ Fuller. Dept. Agric. of S. Afr., Bulletin No. 3, 111 p.

Mlambo, S.S. (1983) The status of cereal stem borer and legume pod borer research in Zimbabwe. Insect Sci. & applic. 4 (1/2) : 221 - 222.

Mohyuddin, A.I. (1971) Comparative biology and ecology of _Apanteles flavipes_ (Cam.) and _A. sesamiae_ (Cam.) as parasites of graminaceous borers. Bull. ent. Res. 61 :33-39.

Mohyuddin, A.I., and D.J. Greathead. (1970) An annotated list of parasites of graminaceous stem borers in East Africa, with a discussion of their potential in biological control. Entomophaga 15 : 241 - 274.

Muthoka, D.K. (1987) Maize improvement in Kenya. In : Improving food crop production on small farms in Africa. FAO, Rome, Italy. pp 444 - 449.

Njeru, N. (1974) Maize production in Kenya. In : Proceedings of the first FAO / SIDA seminar on improvement and production of field food crops for plant scientists from Africa and the Near East. FAO, Rome, Italy. pp 94 - 101.

Nye, I.W.B. (1960) The insect pests of graminaceous crops in East Africa. Colon. Res. Studies. No. 31. London. H.M.S.O.

Ogada, F.F. (1971) Maize in the agriculture of Kenya. World Crops 22 : 302 - 303.

Ogunwolu, E.O., K. Nwosu and S.O. Ogunyebi. (1981) Stem borer damage in maize as affected by host plant density. J. Agric. Sci. Cambridge 96 : 695 - 697.

Oloumi-Saghedi, H., W.B. Showers and G.L. Reed. (1975) European corn borer : Lack of synchrony of attraction to sex pheromone and capture in light traps. J. econ. Ent. 68 : 633 - 667.

Omolo, E.O. (1974) Maize improvement programme - Kitale, Kenya. In : Proceedings of the first FAO / SIDA seminar on improvement and production of field food crops for plant scientists from Africa and the Near East. FAO, Rome, Italy. pp 212 - 214.

OmoIo, E.O., and K.V. Seshu Reddy. (1983) An overview of cultural component of an integrated pest management systems in sorghum. In : Africa, seminar on the use and handling of agricultural and other pest control chemicals, held from 30th Oct. - 5th Nov. 1983, Duduville, Nairobi, Kenya.

Ottichilo, W.K., and R.K. Sinange. (1988) Long rains maize and wheat production in Kenya, 1987. Dept. of Resource Surveys and Remote Sensing (KREMU). Min. of Planning and National Dev. Rep. of Kenya. Tech. Rept. No. 130, May 1988. 12 p.

Pearce, R.B., J.J. Mock and T.B. Bailey. (1975) Rapid method for estimating leaf area per plant in maize. Crop Science 15 (5) : 691 - 694.

Pradham, S. (1964) Assessment of losses caused by insect pests pests of crops and estimation of insect population. In : Entomology in India. N.C. Pant (ed.). Entomol. Soc. of India, New Delhi. pp 17 - 58.

Purseglove, J.W. (1972) Tropical Crops. Monocotyledons 1. William Clowes and Sons Ltd., London, pp 300 - 334.

Richardson, M.J. (1981) The determination of yield-loss relationships by non-plot methods. In : L. Chiarappa (ed.) Crop loss assessment methods ,Supplement 3. FAO Slough, Commonwealth Agric. Bureaux.

Ridway, R.L. (1980) Assessing agricultural crop losses caused by insects. In : Crop Loss Assessment. Proceedings of E.C. Stakman Commemorative Symposium. Misc. Publ. No. 7. Agric. Expt. Station, University of Minnesota. pp 229 - 233.

Robertson, I.A.D. (1977) Records of insects taken at light traps in Tanzania. VII. Seasonal changes in catches and effect of the lunar cycle on the adults of several pest species of lepidoptera (Lepidoptera : Noctuidae). Centre for Overseas Pest Research, London. Misc. Rept. No. 38, 11p.

Rose, D.J.W. (1962) Pests of maize and other cereal crops in the Rhodesias. Bull. fed. Min. Agric. Rhod. Nyasaland, No. 2163, 23 p.

Rossel, H.W., and G. Thottappilly. (1985) Virus diseases of important food crops in tropical Africa. IITA, Ibadan, Nigeria. 61 p.

Schmutterer, F. (1969) Pests of crops in North-East and Central Africa with special reference to the Sudan. Gustav Fischer, Stuttgart. 296 p.

Seshu Reddy, K.V. (1983) Studies on the stem borer complex of sorghum in Kenya. Insect Sci. & applic. 4 (1/2) : 3 - 10.

Sharma, A.N., and V.K. Sharma. (1987) Studies on the economic injury level in maize, Zea mays L. to stem borer, Chilo partellus Swinhoe (Lepidoptera : Pyralidae) in India. Tropical Pest Management 33 (1) : 44 - 45.

Sharma, V.K., and S.M. Chatterji. (1971) Screening of some maize germplasms against Chilo zonellus Swinhoe and some varietal plant characters (physical) in relation to their differential susceptibility. Indian J. Ent. 33 (3) :279 - 290.

Siddorn, J.W., and E.S. Brown. (1971) A Robinson light trap modified for segregating samples at pre-determined time intervals, with notes on the effect of moonlight on the periodicity of catches of insects. J. appl. ecol. 8 : 69 - 75.

Singh,J.P. (1977) Crop protection in East Africa. Dept. Crop Science, University of Nairobi. Unpublished Report.

Singh, D., and R.K. Khosla. (1983) Assessment and collection of data on pre-harvest food grain losses due to pests and diseases. FAO, Rome. FAO economic and social development paper, No. 28, 25 p.

Smit, B. (1964) Insects in Southern Africa. How to control them. A handbook for students, health officers, gardeners and farmers. Oxford University Press, 399 p.

Smithers, C.N. (1960a) Some recent observations on Busseola fusca Fuller (Lep., Noctuidae) in Southern Rhodesia. Bull. ent. Res. 50 : 809 - 819.

Smithers, C.N. (1960b) Moisture and pupation in Busseola fusca Fuller (Lep., Noctuidae). J. ent. Soc. Sth. Afr. 23 : 225 - 227.

Southwood, T.R.E. (1978) Ecological methods with particular reference to the study of insect populations. Methuen, London. pp 253 - 261.

Steel, R.G.D., and J.H. Torrie. (1980) Principles and procedures of statistics. McGraw-Hill, New York.

Storey, H.H. (1928) The transmission studies of maize streak diseases. Ann. appl. Biol. 59 : 429 - 436.

Swaine, G. (1957) The maize and sorghum stalk borer Busseola fusca Fuller, in peasant agriculture in Tanganyika Territory

Bull. ent. Res. 48 : 711 - 722.

Tams, W.H.T., and J. Bowden. (1953) A revision of the African species of Sesamia Guenee and related genera (Lepidoptera : Agrotidae). Bull. ent. Res. 43 : 645 - 678.

Tassema, M. (1982) Insect pests of sorghum in Ethiopia. A paper presented at Regional Workshop on Sorghum Improvement in East Africa, held from 17- 21 Oct. 1982. Nazreth and D Zeit, Ethiopia.

Tauber, M.J., and C.A. Tauber. (1976) Insect seasonality : diapause maintenance, termination, and postdiapause development. Ann. Rev. Ent. 21 : 81 - 107.

Taylor, D.E. (1982) Entomology notes : The maize stalk borer. Zimbabwe agric. J. 79 (4) : 119 - 120.

Taylor, F. (1952) The maize stalk borer in the Eastern Orange Free State. Farming in South Africa. Oct. 1952. pp 450 -452.

Tchekmenev, S.V. (1981). The effect of maize stalk borer Busseola fusca on the growth, percentage of broken panicles and yield of maize. Beitrage zur tropischen, Landwirtschaft und Veterinarmedizen 19 : 91 - 95.

Teng, P.S. (1981) Crop loss data recording and processing. In: Crop loss assessment methods, Supplement 3. Chiarappa L.C. (ed.). FAO Slough, Commonwealth Agric. Bureaux. pp 103 -109.

Terry, P.J., and R.W. Michieka. (1987) Common weeds of East Africa. FAO, Rome, Italy. 180 p.

Thanh Ho, D., and K.V. Seshu Reddy. (1983) Monitoring of lepidopterous stem borer population by pheromone and light traps. Insect Sci. & applic. 4 (1/2) : 19 - 23.

Unnithan, G.C. (1987) Development and reproductive biology of the maize stem borer Busseola fusca Fuller (Lepidoptera : Noctuidae). Z. angew. Ent. 104 : 172 - 179.

Unnithan, G.C., and K.V. Seshu Reddy. (1989) Incidence, diapause and carry-over of the cereal stem borers on Rusinga Island, Kenya. Tropical Pest Management 33 (7) : 441 -445.

Usua, E.J. (1968a) Effect of varying populations of Busseola fusca larvae on the growth and yield of maize. J. econ. Ent. 61 : 375 - 376.

Usua, E.J. (1968b) The biology and ecology of Busseola fusca and Sesamia species in South-Western Nigeria. I. Distribution and population studies. J. econ. Ent. 61 (3) : 830 - 834.

Usua, E.J. (1970a) Some notes on maize stem borers in Nigeria. J. econ. Ent. 63 : 776 - 778.

Usua, E.J. (1970b) Diapause in the maize stem borer. J. econ. 63 : 1605 - 1610.

Usua, E.J. (1973) Induction of diapause in the maize stem borer Busseola fusca. Entomologia exp. appl. 16 : 322 - 328.

Van Hamburg, H. (1980) The grain sorghum stalk borer Chilo partellus Swinhoe (Lepidoptera : Pyralidae) : Survival and location of larvae at different infestation levels in plants of different ages. J. ent. Soc. Sth. Afr. 43 (1) : 71 -76.

Van Rensburg, J.B.J. (1980) Selective oviposition by the maize stalk borer Busseola fusca Fuller. Proc. Congr. ent. Soc. Sth. Afr. No. 3, pp 23 - 24.

Van Rensburg, J.B.J., M.C. Walters and J.H. Giliomee. (1985) Geographical variation in the seasonal moth flight activity of the maize stalk borer Busseola fusca Fuller, in South Africa. S. Afr. J. Plant Soil 2 (3) : 123 - 126.

Van Rensburg, J.B.J., M.C. Walters and J.H. Giliomee. (1987) Ecology of the maize stalk borer, Busseola fusca Fuller (Lepidoptera : Noctuidae). Bull. ent. Res. 77 : 255 - 269.

Van Rensburg, J.B.J., J.H. Giliomee and M.C. Walters. (1988a) Aspects of the injuriousness of the maize stalk borer, Busseola fusca Fuller (Lepidoptera : Noctuidae). Bull. ent. Res. 78 : 101 - 110.

Van Rensburg, J.B.J., M.C. Walters and J.H. Giliomee. (1988b) Mortality in natural populations of the maize stalk borer, Busseola fusca Fuller (Lepidoptera : Noctuidae) in South Africa. Phytophylactica 20 : 17 - 19.

Veeresh, G.K. (1980) Economic losses due to pests of major crops in India. In : Assessment of crop losses due to pests and diseases. Proceedings of the Workshop held from 19 - 30th Sept. 1977 at UAS, Bangalore, UAS Tech. Series No. 33, pp 31 - 48.

Wahl, R.O. (1930) The maize stalk borer. Fmg. S. Afric. 5, 205 - 206.

Walker, P.T. (1960a) Insecticide studies on the maize stalk borer, Busseola fusca in East Africa. Bull. ent. Res. 51 : 321 - 351.

Walker, P.T. (1960b) The relation between infestation by the stalk borer Busseola fusca, and yield of maize in East

Africa. Ann. appl. Biol. 48 (4) : 780 - 786.

Walker, P.T. (1967) Survey of losses of cereals to pests in Kenya and Tanzania. FAO Symposium on crop losses 2 : 79 -88.

Walker, P.T. (1981) The relation between infestation by lepidopterous stem borers and yield in maize : Methods and Results. EPPO Bull. 11 (2) : 101 - 106.

Walker, P.T. (1983) The assessment of crop losses in cereals. Insect Sci. & applic. 4 (1/2) : 97 - 104.

Walker, P.T., and M.J. Hodson. (1976) Developments in maize stem borer control in East Africa, including the use of insecticide granules. Ann. appl. Biol. 84 : 111 - 114.

Waloff, N. (1958) Some methods of interpreting trends in field populations. Proc. X int. Congr. Ent. 2 : 675 - 676.

Walters, M.C. (1979). Maize pests of sub-Saharan Africa. In : Maize Technical Monograph. Ciba-Geigy, Basle, Switzerland. pp 66 - 71.

Walters, M.C., T.W. Drinkwater, J.B.J. Van Rensburg and L. Boshoff. (1980) The maize stalk borer. Farming in South Africa, Maize D. 3 / 1980. 8 p.

Warui, C.M., and J.N. Kuria. (1983) Population incidence and the control of maize stalk borers Chilo partellus Swinhoe, C. orichalcociliellus Strand (Pyralidae), and Sesamia calamistis Hamps in Coast Province, Kenya. Insect Sci. & applic. 4 (1/2) : 11 - 18.

Warui, C.M., J.N. Kuria and G.M. Kamau. (1986) Pyrethrum formulations in the control of maize stalk borers Chilo partellus Swinhoe, C. orichalcociliellus Strand (Pyralidae), Sesamia calamistis Hamps and Busseola fusca Fuller (Noctuidae) in Kenya. Pyrethrum Post 16 (2) : 43 - 47.

Wheatley, P.E., and T.J. Crowe. (1967) Pest handbook. The recognition and control of the more important pests of agriculture in Kenya. Government Printer, Nairobi, Kenya. 32 p.

Zadoks, J.C., and R.D. Schein. (1979) Epidemiology and plant diseases management. Oxford University Press, New York, pp 427.

Appendix 1a. The estimated area under maize cultivation, production, pricing structure and income earned in Kenya between 1980 and 1988*.

Year	Area ('000 ha)	Production (million bags)	Producer price / 90 kg bag (Kshs.)	Income earned (K.£ M)
1980 - 81	1120	19.7	90.00	88.7
1981 - 82	1208	27.8	90.00	125.1
1982 - 83	1236	26.0	95.00	123.5
1983 - 84	1200	23.7	130.00	154.1
1984 - 85	1130	15.7	144.00	113.1
1985 - 86	1240	29.0	156.00	226.1
1986 - 87	1200	30.0	188.00	282.0
1987 - 88	1100	20.0	188.00	188.00

* Data supplied by Economic Planning Division, Ministry of Agriculture, Kenya.

Appendix 1b. Estimates of maize production in Kenya on a district basis for the years 1986 and 1987 (Ottichilo and Sinange, 1988).

District	Area planted ('000 ha)	Pre-harvest ('000 90 kg bags)	Area planted ('000 ha)	Pre-harvest ('000 90 kg bags)
	1986		1987	
Trans Nzoia	67.2	3467.5	73.1	1827.0
Bungoma	71.2	2187.0	70.0	1302.3
Uasin Gishu	77.0	3760.5	62.5	1249.9
Nakuru	55.2	2197.0	48.0	949.5
Kericho	73.3	3028.4	86.7	2992.5
Kisii	74.7	3509.2	80.4	3247.1
Kakamega	85.0	2652.0	77.0	2247.2
Baringo	7.9	281.7	24.4	694.1
Busia	17.7	533.5	16.1	246.3
Embu	21.0	384.4	29.7	544.2
Elgeyo Marakwet	14.2	599.0	13.9	417.0
Kajiado	7.0	225.9	5.5	175.5
Kilifi	18.5	427.4	21.3	361.3
Kisumu	33.7	606.6	30.2	660.5
Kirinyaga	22.1	613.0	30.8	852.2
Kiambu	13.9	280.8	23.5	512.1
Kitui	19.4	274.1	12.2	55.1
Kwale	14.8	419.3	11.4	193.5
Laikipia	10.8	483.3	10.7	343.3
Machakos	98.3	1425.7	60.4	446.8
Meru	9.8	188.2	51.1	767.1
Muranga	19.0	371.3	31.8	872.4
Narok	21.7	797.5	26.0	928.7
Nandi	41.6	2048.2	45.5	1534.7
Nyandarua	27.9	1151.4	40.4	1082.3
Nyeri	8.6	275.6	24.8	861.9
Siaya	29.7	920.7	32.6	680.5
South Nyanza	63.0	813.5	59.2	1515.9
Taita Taveta	5.2	118.0	8.3	187.1
West Pokot	5.5	228.8	6.5	216.0
Total	1034.8	35286.0	1114.0	27963.0