THE BIOLOGY AND CONTROL
OF
RED TEF WORM,
<u>Mentaxya</u> <u>ignicollis</u> (Walker) (LEPIDOPTERA: NOCTUIDAE)
IN ETHIOPIA

By

TADESSE GEBREMEDHIN

B Sc (HSIU, Ethiopia)
M Sc (Univ. of Arizona, USA)

A thesis submitted for the degree of

Doctor of Philosophy of the University of London

and for the Diploma of Imperial College

Department of Pure and Applied Biology
Imperial College of Science and Technology
Silwood Park
Ascot
Berkshire
United Kingdom

January 1986

Dedicated to my beloved wife, Zewdi and my beloved children without whose support and encouragement this would have been impossible to achieve, and for their enduring patience, love and courage during my absence from home while studying in the United Kingdom.

ABSTRACT

The life cycle of red tef worm, Mentaxya ignicollis (Walker) was studied at Holetta, Ethiopia. In the laboratory an average of over 1000 eggs were laid by each female. The larval period with six instars extended over a mean period of 32.9 ± 2.5 days. The full-grown larvae, about 3.5 cm long, are reddish-brown or light green in colour with greenish head and true legs. The pupae are shiny, light or dark brown in colour and about 13.5 ± 0.7 mm long. The adult stage is a greyish (female) or brownish (male) night-flying moth with wing span of about 3.4 cm; the forewings have three conspicuous black and dark brown patches on the leading edge of each wing in both sexes.

Four generations were possible over a year, with economic damage to tef (Eragrostis tef) in the period between September and November. High trap catches indicated peak moth populations in September with most larvae in October. The larvae feed at night and most larvae hide under shade and in soil cracks during the day. The major infestation areas are Becho, Serbo and Dejen. Larval populations increased on tef, particularly in the Becho area, over the four seasons studied. Most red tef worm populations survive the dry season as pupae.

Survey of natural enemies revealed only one parasitoid wasp (Enicospilus rudiensis Bischoff) and one pathogenic bacterium (Bacillus thuringiensis Berl.). Birds, ants, carabid beetles, spiders

and mites were important predators.

Larvae will feed on two wild grasses, Phalaris paradoxa and Digitaria scalarum, thus providing alternative hosts which allow survival of the red tef worm when the tef crop is not available.

Field trials indicated that the economic threshold level of red tef worm was 25 larvae per square metre for the Becho area. Crop losses ranged between 4 - 19 per cent grain yield.

Biological or natural control was inadequate, so chemical control was assessed using insecticide spray treatments. Cypermethrin, fenitrothion, endosulfan, diazinon, and trichlorphon as well as Bacillus thuringiensis (Bt) increased yields significantly over an untreated check. Cypermethrin gave the highest yield while trichlorphon and Bt were considered to be too slow in action. Work rate was increased by ULV sprays, assessed with hand-held, battery-operated sprayers, a 6m swath being optimum. One correctly timed insecticide spray can reduce larval populations in the field below economic levels. Thus one spray increased tef yields by 36 to 58 per cent.

CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

a.i.	active ingredient
ARC	Agricultural Research Council
Bt	Bacillus thuringiensis
BCPC	British Crop Protection Council
°c	degree(s) Celcius (Centigrade)
CAB	Commonwealth Agricultural Bureaux
CIE	Commonwealth Institute of Entomology
COPR	Centre for Overseas Pest Research
CRC	The Chemical Rubber Company
cm	centimetre
cm^2	square centimetre
c.v.	coefficient of variation
d.f.	degrees of freedom
e.c.	emulsifiable concentrate
fig.	figure
FAO	Food and Agriculture Organization
g, gm	gram
h	hour
ha	hectare
H.S.I.U.	Haile Selassie first University (now A.A.U., Addis Abeba University)
I.A.R.	Institute of Agricultural Research
ITU	International toxic unit
kg	Kilogram
km	kilometre
l	litre
LD	lethal dose
LD_{50}	the amount of active ingredient (lethal dose) that would kill 50 per cent of the test animals
m	metre
m^2	square metre
m/s	metre(s) per second
max.	maximum
mg	milligram
ml	millilitre
mm	millimetre
MS	mean square
min.	minimum
min.	minute
NAS	National Academic Science
OP	Organo-phosphorus
OSMC	Overseas Spraying Machinery Centre
PANS	Pest Articles and News Summaries

ppm	parts per million
S.E.	Standard Error
SPL	Scientific Phytopathological Laboratory
SS	Sum of squares
Tech	Technical
temp.	temperature
ULV	ultra-low volume
U.S.D.A.	United States Department of Agriculture
w.p.	wettable powder

CHAPTER 1

GENERAL INTRODUCTION

The biology and control of red tef worm (*Mentaxya ignicollis* Walker) was studied in Ethiopia, in the horn of Africa, bordering the Sudan, Red Sea, Djibouti, Somalia and Kenya (Fig. 1). It lies entirely within the tropics between latitudes 3° and 18° North and longitudes 33° and 48° East. The country is divided into 14 administrative regions (Fig. 1). The climate ranges from tropical semi-desert and desert to a permanently humid condition with a hot summer. Altitudinal differences affect the climate and in consequence the biological system in the environment. Thus, three broad climatic zones based on the relationship of elevation and temperature are recognised: (1) *Kola* - a hot lowland zone below 1600m and with mean temperature of 22°- 28°c, (2) *Weina Dega* - between 1600 and 2100m and mean temperatures of 18°- 24°c and (3) *Dega* - highland zones above 2100m and with average temperatures of 14°- 20°c (Bogale, 1982).

Ethiopia has a total land area of 122 million hectares out of which 84 million hectares are considered to be suitable for agricultural production (Beyene, 1984). Currently only 13 million hectares are cultivated and of the total area under cultivation, cereals occupy about 83 per cent.

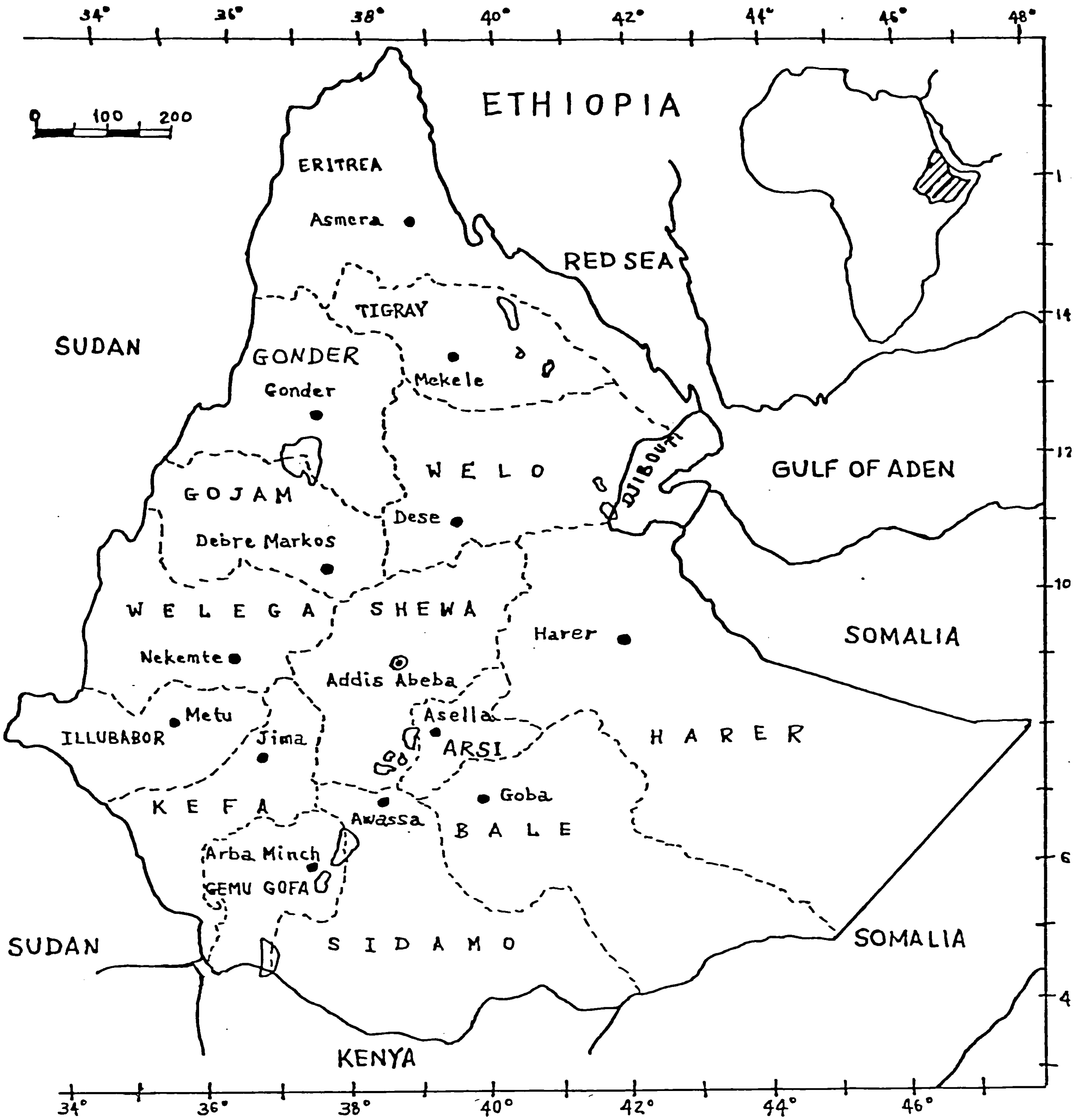


Fig. 1 The borders of Ethiopia and its 14 administrative regions with their capital cities or towns.

Agriculture is the mainstay of the Ethiopian economy providing approximately 56 per cent of the gross national product, but most farmers practice traditional production methods. As a result grain yields of most field crops are very low and consequently the national economy is still at a subsistence level (Central Statistics Office, 1978).

1.1 Tef (*Eragrostis tef* (Zucc.) Trotter)

Tef is a very popular small-grain cereal crop grown for local consumption in Ethiopia, especially in the urban areas. The crop commands a high price and in consequence it is regarded as a cash crop by most farmers. Where it was first cultivated is not exactly known, but Ciferari and Baldrati (1939) stated that the domestication of tef took place somewhere in the northern highlands of Ethiopia. They suggested that it probably originated in the Axumite dominion called Shire and elsewhere in the Tigray Administrative Region where it still is an important food crop. The theory that tef originated in Ethiopia (Vavilov, 1935) is supported by the presence of numerous cultivars there today (Ebba, 1975)

A discovery of tef seeds in the pyramid of Dassur built in 3349 B.C. in Egypt was reported by Unger (1866). In the bricks of this pyramid he found a small quantity of tef seed which must have been pressed in the bricks where straw was added to the clay for reinforcement. Tef seeds could have easily been carried to Egypt by the Blue Nile or they could have been taken to Egypt by merchants or messengers (Ebba, 1975).

Many authors share the opinion that tef (Eragrostis tef) originated from the wild species E. pilosa (L.) Beauv. (Braun, 1841, 1848). The characters of E.pilosa and E. tef are in many respects so similar that it is sometimes claimed that tef should be considered a subspecies or a variety of E. pilosa, rather than a separate species. (Braun, 1841, 1848).

In periods of famine, the seeds of E. pilosa are collected as food by people in many parts of Africa other than Ethiopia (Ciferari and Baldrati, 1939). This may suggest that the selection and domestication of tef for food might have originally commenced during years of food scarcity.

The binomial Eragrostis tef (based on the specific epithet used by Zuccagni) was proposed by Trotter (1918). The scientific name Eragrostis tef (Zucc.) Trotter is now accepted by most botanists (Ebba, 1975).

Some authors say that the name tef is derived from the Amharic (the official language in Ethiopia) word ´teffa´ meaning lost (Rouk and Mengesha, 1963). This no doubt refers to the small size of the tef grain which is hard to find if it falls to the ground.

Tef is a very fruitful plant yielding from 1000 to 10,000 seeds per plant (Ebba, 1969), so it produces more grain per square unit of area than any of the other food grain crops. However, due to its minute seeds (1 -

1.7 mm long, 0.6 - 1 mm in diameter, thus 2500 - 3000 seeds in a gram), there is a great loss of seeds in the field during harvesting, carrying the bundles to be threshed and threshing (Ebba, 1969). Also as threshing is done by driving cattle over it, not all the grains are removed from the straw. Therefore, tef yields are usually low (500 - 2000 kg/ha). Short early maturing cultivars yield as low as 300 - 400 kg/ha, but late maturing cultivars can yield as much as 3000 kg/ha on good soil (Ebba, 1969). Yields vary with the fertility status of the soil, the cultivars used, altitude, pests and diseases and agronomic practices such as proper seedbed preparation and timely weeding.

Tef is the most commonly cultivated crop in Ethiopia and the area sown is increasing from year to year; for example in 1978/79 the area under tef cultivation increased by 14 per cent, so that over 30 per cent of the whole cereal area was used for tef (IAR,1980). In that year, tef production reached 1,083,000 metric tonnes (10,838,000 quintals) [1 quintal = 100kg] from 1,392,600 hectares; the national average yield was ,therefore, 800 kg/ha (IAR,1980). In addition to its small-sized seed, the wide distribution of the crop over the whole country, especially in the highland and medium altitudes, might have contributed to the low national average yield. In 1982/83, the yield had risen to an average of 986 kg/ha, but as this is still low, efforts are being made to improve the yields through an extensive research programme. In recent years tef yields on experimental plots have reached 3800 kg/ha (IAR,1984), so the scope for improvements in yield is considerable.

Tef is the principal cereal crop grown in Ethiopia (Ebba,1969), and is the staple food of the majority of the people, except nomadic groups and others, particularly in the lowland areas where grain sorghum is the main food. Tef is not exported.

Tef grain is mainly used for making different kinds of Injera (an Amharic name for a flat, very soft, circular, and slightly sour homemade bread made only in Ethiopia from tef, wheat, barley, maize, grain sorghum or from their mixtures). The best type of ´Injera´ is made from tef flour (Mengesha and Guard,1966), which is very nutritious and contains 11 per cent protein and has a very high iron content (Ethiopian Nutrition Survey,1959). Tef provides as much as two-thirds of the daily protein requirement in the Ethiopian diet (Anon, 1962). The grain is also used for preparing porridge, alcoholic drink (Arekie) and homemade beer (Tella).

Ethiopia is the only country in the world that uses tef as a cereal food crop (Mengesha,1966). The species is cultivated for its hay in several parts of the world such as Kenya, South Africa and Australia (Mengesha, 1966; IAR, 1980). Tef is not grown for hay in Ethiopia *per se*, but after the grain is threshed, the straw is used for livestock feed during the dry season. Tef straw is more expensive than any other straws because in addition to its use as animal feed, it is important for building purposes by mixing it with clay for reinforcement. The straw can also be used for mulching.

Another great advantage of tef grain is that it can be stored for many years in the traditional stores without being damaged by insects in the tropics (IAR,1980).

Of the three colour types of tef grain, namely white, red and mixed, white tef commands the highest price, particularly when marketed from the Adaa and Becho areas. The red type is the cheapest grain. When the demand for tef is very high compared to the supply, white tef would command a price somewhere between US $60-125 for a 100kg sack, so tef is considered to be a cash crop for the farmers who grow and sell their produce.

1.2 Pests and diseases of tef

Tef (E. tef) is vulnerable to attack by various sporadic insect pests in the different ecological regions of Ethiopia. The following general pests were recorded attacking tef in its different stages of growth: African armyworm (Spodoptera exempta Walker), desert locust (Schistocerca gregaria Forskal), Welo bush – cricket (Decticoides brevipennis), striped blister beetle (Epicauta albovittata Gestro), tef Epilachna (Epilachna similis Thumberg) (Jannone, 1941), tef fly (Delia arambourgi Seguy), African bollworm (Heliothis armigera Hubner), black tef beetle (Erlangerius niger Weise) and termites. Desert locust and Welo bush – cricket are more common in the river gorges of Gojam, in Welo, Shewa and Tigray Administrative Regions (Fig. 1). Striped blister beetle is mostly found in Kobo area of the Welo Region, while the black tef beetle is more common in the Debre Zeit and Holetta areas of the Shewa Region. Tef Epilachna, tef fly, African bollworm are widespread in their distribution and attack tef throughout many of the ecological regions where tef is grown. Termites are mostly found in the red soils of the undulating terrain of Welega Region in western Ethiopia. However, red tef worm specifically attacks tef and is mostly found on tef grown in the cracking, black soils in several parts of the country. Diseases such as rusts, damping off and smudge have been recorded on tef in several places.

1.3 Red tef worm (*Mentaxya ignicollis* Walker)

The red tef worm is a very important pest of tef. It was collected first in 1971 from the Becho area of Shewa Region (Fig. 1), which is famous for its tef production in Ethiopia, and it was identified as *Mentaxya ignicollis* (Walker) by the British Museum, London (CIE, 1971). Following identification, preliminary studies on methods of control were carried out by the entomology staff of the Holetta Research Station of the Institute of Agricultural Research (IAR) in Ethiopia. DDT and malathion e.c. sprays were assessed, having determined that the red tef worm was an economic pest. Further research was then diverted to pests of other crops until 1980 when heavier infestations were reported. A survey that year resulted in priority being given to study of the red tef worm.

An extensive search of the literature was made, but very little information is available. *Mentaxya ignicollis* was not mentioned in any publications except by Pinhey (1975), who describes the moths with wings green from dens speckling or irroration, thorax reddish-brown giving rise to the scientific name of ´fiery neck´; three purplish-brown fasciae, one sub-basal, one mid-costal above the pinkish reniform stigma and another on the costa before the apex; hind wing white and forewing 14-18mm. Some of the descriptions do not seem to fit the Ethiopian species, but the scientific name Mentaxya ignicollis was confirmed by Laporte of the Museum National d´Histoire Naturelle, Paris, and by Holloway of the Commonwealth Institute of Entomology, London, in 1983, by genitalia examination of specimens sent from Ethiopia (personal communication).

1.4 Problem

Red tef worm is a serious pest affecting tef grown on black or heavy deeply cracking clay soils (vertisols). Fat reddish/light green larvae are observed on plants in the early morning and evening feeding on leaves and developing grains in their milky stage (Crowe and Shitaye, 1977). In the hotter hours of the day, they hide in cracks in the soil. Attacks were only recorded in the dry period (September to November) following the main rainy season. Infestations have been reported from five administrative regions in Ethiopia, namely Shewa, Kefa, Gojam, Welega and Tigray (Crowe et al ,1977). The crop loss by red tef worm was estimated by the entomology research staff of the IAR working on cereal pests to be between 10 and 30 per cent. However, apart from its identification and some tentative control measures, there was no information on this pest, especially on its biology.

1.5 Aims

The aims of this study are:

1). To investigate the biology of red tef worm, and determine the fecundity, number of larval instars, number of generations per year and feeding habits of the insect.

2). To estimate yield losses due to this pest.

3). To determine its seasonal occurrence and distribution in the tef growing areas of the country.

4). To collect and identify alternative hosts and natural enemies of this pest.

5). To assess the effectiveness of different insecticides, swaths and spray applications on the control of red tef worm.

CHAPTER 2

THE BIOLOGY OF RED TEF WORM

2.1 Introduction

Knowledge of the biology of insect pests is of utmost importance in any control or pest management strategy. There is a direct relationship between the amount of information gathered on the total insect complex in an agroecosystem and the number of options available with which to implement insect pest management. Data on such important aspects as life and seasonal cycles, host plants, overwintering or diapausing stage and location, plant parts attacked, natural enemies and climatic and soil effects are some of the essential information needed to make wise decisions concerning pest management. Hence, the study of an insect pest may provide the crucial information needed for improved ways of coping with it.

Initially correct identification is vital, particularly in relation to searching for suitable predators and/or parasites for biological control (Sabrosky, 1955; Rosen and DeBach, 1973). Knowing the pest may also assist in the selection of an insecticide if immediate control of the pest is warranted (Watson et al ., 1975).

2.2 Materials and methods

2.2.1 Life cycle of *M. ignicollis*

Third, fourth and fifth larval instars were collected from the field in October 1983 and sorted into several sizes. Plastic bowls with top diameter 22.5 cm, bottom diameter 11.5 cm and height 13 cm were two-thirds filled with a mixture of fine sand and black or red soil. Each group of 30 - 50 larvae were placed on the top of the soil and covered by a transparent plastic cylinder measuring 14.5 cm in diameter and 30 cm in height.

Larvae in each cage were fed with tef plants brought in from the field or from the glasshouse. A piece of muslin cloth was held on the top of a plastic cylinder with a metal ring or rubber band to prevent larvae escaping and also to allow air circulation. Old, remaining food and excreta were removed and fresh food of tef plants provided every day. The soil in the rearing cage was kept moist towards the end of the larval rearing period to make it easier for larvae to pupate and for normal moth development. Pre-pupation and pupation periods and moth emergence dates were recorded.

Moths were obtained either by rearing larvae collected from the field as described above or from light traps. Moths from either source were placed in a small plastic container with top diameter 10 cm, bottom diameter 9 cm and height 4 cm. At the bottom of the cage a circular filter paper was placed before putting in one pair of male and female moths per cage, for mating, egg-laying, moth longevity and other biological studies. The cage had a lid with a circular hole covered with gauze to allow air circulation. Moths were provided with 10 per cent sugar solution in 6-dram vials plugged with cotton wool. Filter papers were changed and vials cleaned and refilled every three days or as needed. Pre-oviposition and duration of oviposition were recorded, eggs were counted using a binocular microscope and egg-hatch, hatching date and hatching percentage were recorded.

After hatching, first instar larvae were removed and transferred on to tef plants which had been grown in plastic bowls in the glasshouse and caged as described earlier for larval rearing. In the moth cages fecundity and moth longevity were also observed and recorded.

For the constant supply of food for larval growth, tef was planted almost every two weeks both in the glasshouse on plastic bowls and in the field on 1.5 x 3 metre plots. In the glasshouse the pots or bowls were watered once or twice a week while the field plots were irrigated in the dry season two to three times weekly. Tef plants reaching 20-30 cm in height and just before seed production were brought in to the laboratory to provide food for the young larvae. Tef plants just after seed production when the seeds were in their milky stage, were brought in for the older larvae, fourth to sixth larval instars. From the glasshouse tef plants were transferred to the laboratory in their original containers, plastic bowls in which they were planted. From the field, however, they had to be dug out with their roots and soil intact and placed in plastic bowls with more soil. Handled this way, the plants from the field stayed fresh and continued to grow until they were almost finished in three to four days by the feeding larvae. If too many larvae were feeding in one cage or older (larger) larvae were present, the food in one cage lasted only for about 24 hours. Tef plants were grown in the field due to lack of sufficient space in the glasshouse and an inadequate number of plastic bowls. However, tef grown in the field was better compared with that in the glasshouse. When the tef plants were brought into the laboratory, transparent plastic cylinders with a muslin top were placed over them to accommodate the height of the plants and prevent the escape of larvae placed in them. Observations of larvae were easier through the cylinder. Rearing red tef worm larvae was attempted using a simplified artificial diet (Bot,1966), but though several attempts were made no larvae could grow on the artificial diet. In all cases, larvae died after several days and no larval growth was observed because they failed to feed on the diet.

First instar larvae were transferred from the moth cage to the larval rearing cage by a small brush, and three observations were made daily on feeding, body changes (growth) and larval mortality. Dead larvae were removed as soon as detected. At each instar stage, measurements of the head capsule and body length were taken from a random sample of twenty larvae. Measurements of sample larvae were made after they had been killed with ethyl acetate.

The pre-pupation period, pupation date and later the emergence date were observed and recorded to calculate the generation time. This detailed insect rearing was continued for over a year. After the emergence of most moths from the rearing cages, the soil was examined for live pupae and pupation cells. The size and weight of random samples of live pupae were taken. Also the size and depth of random samples of pupation cells were measured. The live pupae were returned to the soil in cages but about half failed to produce moths.

A random sample of the moths were examined using a binocular microscope to determine characteristics which differentiated between male and female sexes and their forewings were measured. A large number of male and female moths were also dissected for mounting and examination of their genitalia to confirm the sexes.

2.2.2 Position of eggs on tef plants

Twenty pairs of male and female moths were transferred to planted tef in rearing cages to study the relative position and proportion of oviposition on tef plants. A 10 per cent sugar sulution was provided to feed the moths in vials as described earlier. Then oviposition was observed three times daily to determine the position on plant parts where eggs were laid, the number of eggs and moth mortality.

2.2.3 Feeding rate and weight increase studies

In the laboratory, the feeding rate and weight increase of third to sixth larval instars were observed. Twenty, third instar larvae of uniform size were individually weighed and then each was placed on a single tef plant selected for uniform height and an equal number of leaves. The dates when feeding started and leaves of each plant completely consumed were recorded. Then each larva was weighed and transferred to fresh food plant(s) in another cage. This activity continued until each larva reached the sixth instar, stopped feeding and when it was about ready to pupate. The number of food plants provided increased progressively with weight increase.

In another experiment, twenty healthy and of uniform size red tef worm, third instar larvae were weighed and placed in the small moth cages with filter papers underneath. Then five grams of chopped tef leaves were provided for each larva in each cage. Observations were made on feeding rate; dates on which feeding started and stopped at the end of the sixth instar larvae were recorded. Fresh food was provided (in 5, 10, 15 or 20 gram lots) and the old food removed every 24 hours. Weight of larvae was recorded at the beginning and end of each instar stage.

2.2.4 Feeding tests of cultivated, possible alternative hosts

Red tef worms were fed on possible alternative hosts in the laboratory at the Scientific Phytopathological Laboratory (SPL) at Ambo, about 125 km west of Addis Abeba. The cultivated crops used were maize, sorghum, barley, wheat and tef as a check, all grown in the glasshouse in large pots and wooden frames. Third instar larvae were produced on tef food and then ten larvae were placed in a petri-dish with filter paper underneath for each alternative host crop. Three replicates were used for each host plant which was cut into pieces and provided to the respective larvae. Observations were then made on feeding and mortality every day. The number of dead larvae, pupation date, number of pupae, emergence date and number of moths were recorded for each plant. Moths produced from each host were paired (male and female) and placed in small plastic cages. They were provided with 10 per cent sugar solution and oviposition and longevity were observed. The number of eggs laid by each group and moth mortality were recorded. Attempts were made to include a wild grass alternative host such as Phalaris paradoxa L. but without success because the germination of the field collected seeds of this host was very low (3-5%) in the glasshouse, so it was excluded.

2.2.5 Survival of M. ignicollis in the dry season

Field surveys were carried out to determine the survival of red tef larvae in the dry season in the Becho area about 60 km west or south-west of Addis Abeba, Serbo area some 310 km in the same direction and Dejen area about 230 km north-west of Addis Abeba. In the Becho area of Shewa Region, the survey was conducted for four seasons while in the other two areas it was conducted for two seasons because of their relative distance. In each case three or four surveys were made for each season in every survey area. In the survey, areas dug for pupae on harvested tef fields were selected at random by throwing metal quadrats. Each quadrat sample measuring 0.5 x 0.5 m was dug using a pick-axe/crowbar. Soil particles and clods were examined carefully. Bigger clods were broken to smaller pieces for pupal examination. Each sample was dug to a depth of 20 - 40 cm depending on the depth of the cracks in the black soils. In each season 40 to 150 samples were dug in every area of the survey. During the survey live pupae found in the soil were collected, recorded and taken to the laboratory for adult emergence. Pupal skins (exuviae), pupae damaged by predators, the predators, the depth in which the pupae were found and the depth dug were recorded.

2.3 Results

2.3.1 Life cycle

2.3.1.1 Egg

The eggs are light pinkish in colour, spherical in shape but slightly flattened on both ends (top and bottom) and measuring 0.5 - 0.6 mm wide and 0.4 mm long in size. They have, on average, about 37 longitudinal ridges or stripes. As observed both in the laboratory and in the field, eggs are laid singly or in batches ranging from two to over 300 per batch, sometimes in two or three layers (Plate 1). A few days after oviposition, the eggs turn brown and almost dark just before hatching.

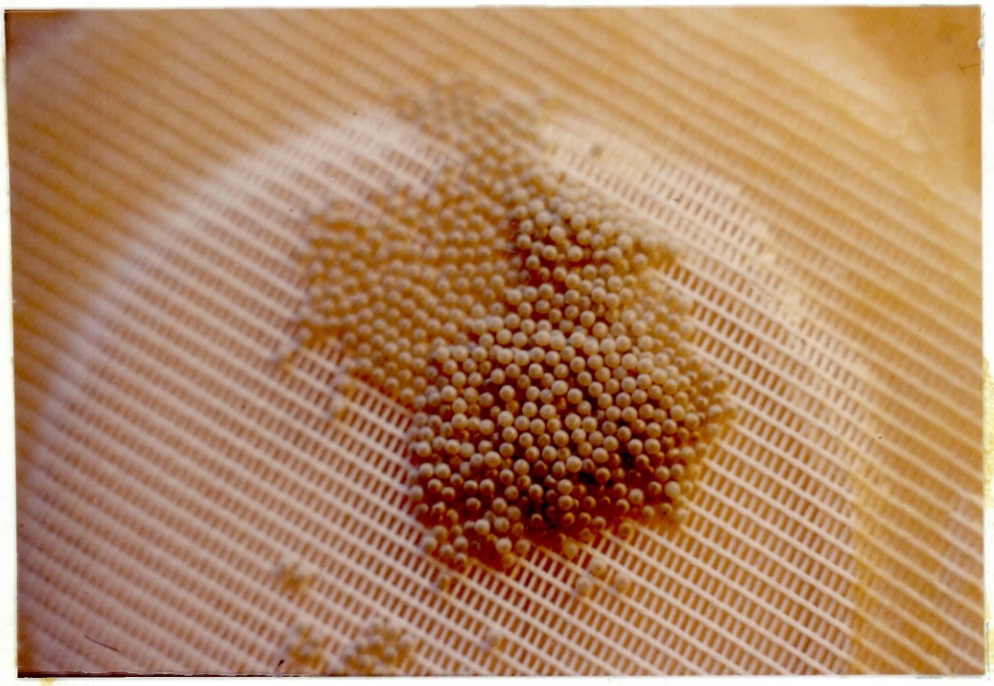


PLATE 1 Mentaxya ignicollis eggs laid on cloth mesh on the top of moth cage in the laboratory.

The female moths produce a sticky substance which glues the eggs together and to the substrate on which they are laid.

2.3.1.2 Larva

The larval stage is typical of the Lepidoptera with three pairs of jointed true legs on the thorax and five pairs of prolegs on the abdomen. Four pairs of the prolegs are located on the abdominal segments 3 - 6 while one pair is located at the extreme posterior abdominal segment 10. Each of the prolegs is armed with fine curved, apical ´teeth´, or crochets, arranged in the form of a semi-circle. The well-developed head and true legs are green in colour. Fully grown larvae are about 3.5 cm long with a body width of 6 mm. There are six larval instars, details of which are given in Table 1.

First instar

First instar larvae have a black head and dark bristles all over the body. The bristles grow from black warts which are arranged in a regular manner in the first thoracic segment, but distributed irregularly in the rest of the body. There are two large, dark spots on the first thoracic segment just behind the head. The body is yellowish green or creamy-white in colour. The head is larger in size proportionally to the body thickness. The larvae have a looping type of locomotion, and they produce silk threads which help dispersal, for example, when descending from a plant. Larval mortality in the laboratory ranged between 51 and 65 per cent.

Table 1 . Mean head capsule and body length measurements, weight and developmental periods of the different larval stages.

Instars	Mean head capsule in mm.	Mean body length in mm.	Mean weight in mg.	Mean developmental period in days
1 st	0.40±0.18	1.99±0.31	1.1±0.4	6.0±1.1
2 nd	0.90±0.29	12.26±0.88	39.4±2.0	7.4±1.2
3 rd	1.97±0.41	21.20±1.45	152.8±3.9	8.1±1.0
4 th	2.13±0.35	27.36±0.87	403.9±3.9	8.7±1.0
5 th	2.88±0.35	29.96±0.69	627.9±5.0	9.8±1.2
6 th	3.09±0.35	34.97±0.86	999.7±7.1	7.5±1.4

Second instar

Most warts and bristles disappear at this instar, but the remaining bristles are distributed on the body in the same manner as on the first instar. The head and body colour are more or less the same as the first instar. The range of larval mortality at this stage in the laboratory was 3 to 23 per cent.

Third instar

The body colour changes to greenish white while the head is now light brown. Bristles are present at this stage, too, but very low in number.

Fourth instar

The greenish colour is maintained but whitish and/or brownish stripes appear on the body. Two whitish stripes on the sides and two broken, brown stripes on the mid-dorsal position run along the length of the body. The head, true legs and prolegs are greenish in colour and the rest of the body is speckled with whitish and reddish-brown colours. The body segments are separated with somewhat reddish lines.

The few bristles maintained so far disappear at the fourth instar. The size of the head capsule, the body length and the weight have increased but not as much as the previous stages. Larval mortality from the third to the sixth instars is below three per cent out of which the higher percentage being in the third larval stage.

Fifth instar

Generally larvae have either light brown or greenish colour. The brown larvae have dark brown or somewhat reddish-brown stripes while the green larvae have white stripes. In both types more visible, discontinuous, faint brown stripes run along the dorsal length of the body.

Sixth instar

Except the body size, the colour pattern is similar to that of the fifth instar. The upper (dorsal) side is red, reddish-brown or light green in colour. The lower (ventral) side and the head are somewhat green. A faint white line runs right down the mid-dorsal position. On

PLATE 2 Mature Mentaxya ignicollis larva

the dorso-lateral position are broken, brown lines running along each side of the body; below these lines there is, on each side of the body, a distinct white line also running the full length of the body. The spiracles are oval in shape and the ocelli are three and four.

The overall larval developmental period to reach pupation stage ranges from 25.0 to 47.0 days with a mean of 32.9 $\pm$ 2.5 days. At the end of this stage the fully developed larva (Plate 2) stops feeding for a day or two before it starts to pupate.

2.3.1.3 Pupa

The fully grown larva burrows into the soil and constructs an oval-shaped earthen cell by moistening soil particles. The pupal cell measures about 17.2mm in length and 10.3mm in width. It is very strong and hard to break, especially when made from black soil particles. The pupation site ranged between 2 and 5 cm (3.5 $\pm$ 1.0 cm) deep below soil surface in the laboratory and 4 to 9 cm (6.4 $\pm$ 1.2 cm) in the field if burrowed by the pupating larvae, but reaches up to 30cm in the cracks of the soil.

Pupation in the cell is completed within two to three days. The pupa is shiny, light or dark brown in colour (Plate 3). It has a mean length of 13.5 $\pm$ 0.7 mm and width of 4.5 $\pm$ 0.7 mm and weighs 576.5 $\pm$ 5.6mg. The Pupation period in the laboratory ranged from 18 to 78 days with an average of 30.9 $\pm$ 3.4 days for 201 pupae under room temperatures

PLATE 3 Red tef worm pupa and an open pupal, earthen - cell in the field (Becho)

ranging between 15° C and 22° C . Most of the pupae appear to enter diapause (resting stage) in the field at the end of the crop season in order to pass the dry period and survive from one crop season to the next.

2.3.1.4 <u>Adult</u>

The adult stage is a greyish or brownish night-flying moth with a wing span of about 3.4 cm for both sexes. The fore wings are grey (female) or light brown (male) with three distinct, dark brown and black markings on the leading edge (Fig.2 and Plate 4). The hind wings are white. Some features of the moths show sexual dimorphism as explained below. Mating occurs at night.

<u>Female moths</u>

The thorax of the female moth has a triangular, black area in the anterior part with greenish spots on either side. Compared to the male, the female moth has also another triangular, conspicuous whitish spot at the posterior end of the thorax. The dorsal part of the thorax is reddish-brown while the ventral part is hairy and white.

There is a distinct, greenish area at the basal part of fore wings. These wings are greyish in colour with three easily recognisable black and dark-brown patches on the leading edge of each wing. Some females have greenish patches also in the middle of the fore wings (and near the antennae), speckled with more green scales along with the grey ones.

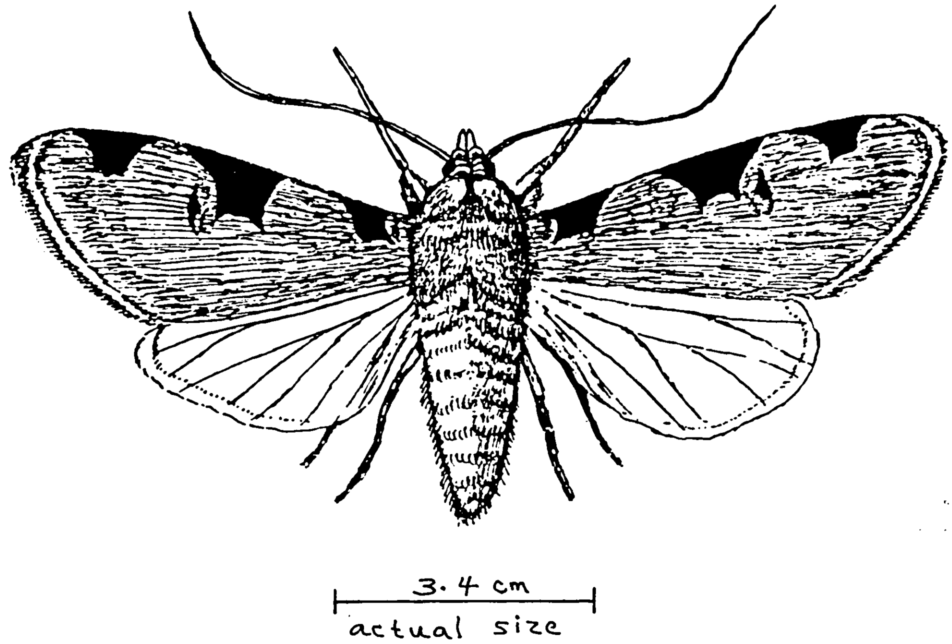


Fig. 2 Mentaxya ignicollis female moth.

The ventral part of the abdomen is whitish in colour with three regularly arranged dark spots on each segment in the middle part. The tip of the abdomen has a noticeable, circular opening and is hairy. The female moths are more robust than the males.

Male moths

The thorax in male moths also has a triangular black area in the front part with inconspicuous or no greenish spots on either side. The dorsal part of the thorax is often brownish and the ventral part is heavily covered with light brown hairs.

There are no conspicuous greenish markings at the base of the fore wings. These wings are light brown in colour with three distinct black and dark brown patterns on the leading margin of each fore wing.

The abdomen is light brown in colour with two regularly arranged large, dark spots on either side of each segment and other irregularly scattered, smaller spots throughout the abdomen. The tip of the abdomen is heavily covered with tufts of light brown hair but no obvious circular opening.

PLATE 4 Male (left) and female (right) moths of red tef worm

2.3.2 Moth longevity

The period moths survived under laboratory conditions was similar for both female and male sexes observed (Table 2). Female moths lived slightly longer than male moths in the number studied.

Table 2 . Range and mean moth longevity in days

Sex	No. of Moths	Longevity Range	Mean
Female moths	76	8 - 30	17.4±2.1
Male moths	54	6 - 33	17.0±2.7

The noctuid moths of tobacco budworm (Heliothis virescens F.) also live approximately two weeks under laboratory conditions (Guerra, 1972; Graham and Wolfenbarger, 1977; Hennberry and Clayton, 1985).

2.3.3 Oviposition

In the laboratory the number of eggs laid ranged from 0 to 3690 per female; the mean was 1031.6 ± 24.8 eggs over the oviposition period which ranged between 3 and 14 days with a mean of 7.0 ± 1.7 days.

Egg hatch was very high with an average of 97.0±1.7 per cent and a range of 85-100 per cent. The egg incubation period ranged from 4 to 7 days with a mean of 5.9 ± 0.8 days. Similar noctuids such as cutworms lay up to 2000 eggs (Kranz *et al*., 1978), and in a study on *Heliothis armigera* (Hb.), Reed (1965) reported that the number of eggs laid per female ranged from 0 - 3065.

Oviposition activities in *M. ignicollis* are mostly nocturnal.

2.3.4 Position of eggs on tef plants

In an observation made in the laboratory on the number of eggs laid on leaves, stems, the top half of the plants or the lower half of the plants, the record of oviposition shows that about 65.1 per cent of the eggs were laid on leaves while 34.9 per cent were laid on stems. Another record shows that most of the eggs (68.7 per cent) are laid in the top half whereas the rest (31.3 per cent) are laid in the botton half of the plant. The majority of African bollworm moth (*Heliothis armigera* Hb.) eggs, another noctuid, are also found on the upper half of the cotton plants (Kranz *et al*., 1978).

Surveys were carried out in the field to determine the proportion and relative position of red tef worm eggs on plant parts, but it was realized that eggs are hardly detectable in the field. However, from the few occasions eggs were found in the field, their proportion and relative position they were laid on in the tef plants confirm the above situation that over 60 per cent of the eggs are oviposited on leaves and on the top half of the plant.

2.3.5 Number of generations

In a laboratory study at a temperature of 14 - 24°C and a relative humidity of 40 - 82 per cent, only four generations of M. ignicollis were obtained in approximately twelve months between December 20, 1983 and December 10, 1984 (Table 3).

The pre-oviposition period throughout this study ranged from 4 to 11 days while the duration of oviposition was between 6 and 16 days. Larval developmental period varied considerably from 27 to 54 days. Pre-pupation period was very short, just 2 - 3 days; but pupation period also varied between 18 and 44 days. Thus, the whole generation period (moth to moth) ranged from 61 to 109 days; mean 86.3$\pm$4.0 days.

There is no clear distinction between consecutive generations of M. ignicollis in the field due to their overlapping. However, based on field collections of larvae, pupae, pupal skins and alternative hosts and moths from light traps, three to four generations per year have been estimated from the general activities of the pest in the field.

A) One generation appears in September, October, November and up to the middle of or late December and feeds on the tef crop.

B) A second generation occupies the period from late December to early April inclusive. A low population of moths emerge late in December or early in January. These moths either continue to breed, forming the second generation, at a very low, non-detectable level in swampy areas, waterways and green patches where some grasses such as Digitaria spp. stay green, or probably die off because of lack of a suitable host. This situation was realized during the dry season survey at which pupal skins and very few moths were encountered. From the dry season survival study of the pest, it was discovered that most of the pupae from larvae which fed on tef in October stay in the soil, probably in diapausing stage, until the short rains arrive between March and April.

C) Third generation - In April and May moths of M. ignicollis emerge from diapausing pupae shortly after the arrival of the small rains and oviposition occurs on alternative hosts such as the wild grass, Digitaria scalarum. This grass was observed surviving in a drying marshland in the Serbo area and supporting a low population of red tef worm; from 50 random quadrat samples only 12 second instar and 15 third instar larvae (about 2.2 larvae/m^2) were obtained. Other grasses appear shortly after the small rains and they may also act as intermediate hosts of red tef worm.

D) Fourth generation - Between late June and early September emerging moths have to lay eggs on wild alternative hosts, as tef is only sown in July/August so plants are not large enough to support an

Table 3. Generation number, mean pre-oviposition, oviposition, larval development, pre-pupation and pupation periods and generation time in days in a laboratory study between 20/12/83 and 10/12/84.

Generation	I	II	III	IV
Dates	20/12/83 - 18/ 3/84	4/ 3/84 - 18/ 5/84	16/ 5/84 - 22/ 8/84	18/ 8/84 - 10/12/84
Temperatures °C	14 - 22	17 - 23	15 - 24	15 - 22
Mean Pre-oviposition period, days	7.0±1.7	6.0±1.4	5.3±0.8	6.2±0.9
Mean duration of oviposition, days	12.0±1.3	10.6±1.9	10.0±1.2	13.0±1.5
Mean larval period, days	28.0±1.0	28.2±1.1	39.8±1.1	52.6±1.1
Mean pre-pupation period, days	2.4±0.7	2.2±0.7	2.5±0.7	2.6±0.7
Mean pupation period, days	26.4±1.9	22.4±1.9	42.3±1.1	42.6±0.7
Mean generation time in days	74.8±1.2	65.0±1.9	92.9±1.2	108.4±0.7

infestation.

However, the next generation (A) feeds on tef, the main host plant in the field, starting some time in the middle of or late September.

2.3.6 Feeding behaviour

Red tef worm moths are nocturnal, and they are not easily seen in the field during the day; so observations were not made on their feeding, but presumably nectars of different plant flowers provide their food.

Larval feeding was observed both in the laboratory and in the field. First instar larvae immediately start feeding on the underside of tef leaves, while leaving the epidermis of the upper leaf surfaces intact. Occasionally they may eat empty egg shells or move away to search for a suitable feeding site. This feeding habit lasts only in this instar and larger larvae consume the whole of a leaf. Until the third instar feeding is limited mostly to leaves and tender stems, but late instars will feed practically on every part of tef plants except old and tough stems.

In the field larvae feed actively on tef leaves and developing heads while the seeds are in their milky stage. Because of their nocturnal habit, their feeding occurs largely at night. Observations early in the morning or in the evening showed large numbers of third and fourth instar larvae feeding, but later in the hot weather towards the middle of the day, larvae hid under shade and in cracks in the soil in a similar manner to other noctuids; for example, mature cutworms such as Agrotis ipsilon (Hfn.) larvae cause main damage to plants by hiding all day in the soil near the food plants and cutting stems below the soil surface at night (Skaife, 1953; Kranz et al., 1978). M. ignicollis larvae feed throughout the night and start to go to their hiding places when it gets warm in the morning sometime between 7:00 and 9:00 am local time. Therefore, infestations with the presence of larvae on the crop are best detected either early in the morning before larvae go back for hiding or better still in the evening when they come out for feeding. Presence of larvae can be detected also from the larval droppings observed on the ground surface at the base of the tef plants.

2.3.7 Feeding rate and weight increase studies

The feeding rate and weight gains by larvae in the laboratory experiment are more or less similar to those of other noctuids such as the African armyworm. From laboratory studies carried out in Kenya on the African armyworm, the feeding rate was relatively low during the first half of the larval period, but increased rapidly during the second half with somewhat proportional weight gains (Brown and Odiyo, 1968). In the red tef worm feeding studies on planted tef and chopped leaves, similar results have been obtained as shown on Tables 4 and 5.

Table 4. Mean weight of larvae, mean number of planted tef consumed and average number of days taken to consume them.

Larval instars	Mean wt. of larvae - mg	Mean No. of plants consumed	Mean no. of days taken to consume
3rd	126.7±2.0	4.9±0.8	7.2±1.0
4th	406.9±4.2	13.6±1.0	8.8±1.1
5th	635.4±5.8	18.0±1.2	9.7±1.2
6th	1024.1±7.1	23.7±1.6	7.9±1.3

The weight gains between instars are not proportional to the number of plants consumed in the respective stages. As the larvae grew, the number of plants consumed increased progressively, especially from the fourth instar onwards. In a similar study by Buntin and Pedigo (1985) on the consumption of alfalfa foliage by variegated cutworms in the laboratory, one — fourth of the total foliage was consumed during the first half of larval development, but 50 per cent of total consumption occurred in the last quarter of larval development; hence, the majority of foliage consumption by variegated cutworms occurred during the last larval stages similar to that of red tef worm.

In another experiment, feeding rate of larvae was observed on chopped tef plants, mostly leaves, and results were similar to the previous experiment in which larvae were fed upon planted tef.

Table 5. Mean weight of larvae, mean weight of leaves consumed and number of days taken to consume the leaves from chopped plant parts.

Larval instars	Mean wt. of larvae - mg	Mean wt of leaves consumed - gm.	Mean no. of days taken to consume
3rd	124.6±1.6	26.4±1.4	7.3±1.0
4th	415.4±4.4	58.1±4.3	8.3±1.0
5th	630.8±5.2	123.0±4.1	9.7±1.2
6th	1012.3±6.6	165.3±4.2	9.7±1.0

2.3.8 Feeding tests of cultivated, possible alternative hosts

In the laboratory when confined in petri dishes, *M. ignicollis* larvae could feed on different cultivated, monocotyledon crops such as maize, sorghum, barley, wheat and tef leaves (and tender stems of the latter three). However, in the field larvae of this pest have not been encountered feeding on other cultivated host crops except tef and wild grasses such as *Digitaria* and *Phalaris* spp.

In the laboratory the larvae fed vigorously on tef and wheat but sluggishly or slowly on maize and sorghum and somewhat intermediate on barley. Those fed on tef and wheat were slightly heavier and better in their appearance compared to those fed on the other alternative hosts. Very few larvae fed on maize and sorghum leaves (Table 6) survived to the adult stage, but those fed on barley were slightly better. Least mortality occurred when larvae were fed on tef, and of the other food plants evaluated, more survived on wheat. Higher numbers of pupae and moths were also obtained from tef and wheat.

Table 6. Percentage larval mortality, number of pupae and moths and fecundity in the feeding tests on cultivated, possible alternative host plants.

Host plants	No. of larvae	Larval % mortality	No. of pupae	No. of moths	Fecundity
Maize	30	93.3	2	2	116.0± 7.0
Sorghum	30	90.0	3	2	141.5± 6.7
Barley	30	80.0	6	4	302.0±13.0
Wheat	30	70.0	9	9	719.6±17.7
Tef	30	23.3	23	20	1519.0±31.7

Fecundity was higher for moths derived from larvae which had fed on tef. Moths from the few larvae which survived on maize and sorghum lived for only 8-12 days compared to those from wheat and tef, which lived for 16-22 days while those from barley were intermediate with a life span of 14-18 days.

The red tef worm has more or less the same tendency as other similar noctuids for selected host preference. When *Spodoptera latifascia* Wlk. larvae were reared in the laboratory on leaves of cotton, soyabean or lettuce, cotton leaves were superior to soyabean and lettuce for the growth and development of the noctuid (Habib *et al.*, 1983). Similar results were reported by Afify *et al.* (1971) when *Spodoptera exigua* Hbn. was fed on three types of food plants (foliage of castor, broad bean and *Trifolium alexandrinum*), with castor being the best. Larvae of the fall armyworm Spodoptera frugiperda (J.E.Smith) were also reared in the laboratory on five food plants and the most suitable were goosegrass (Eleusine indica) and coastal Bermuda grass (Cynodon dactylon), while the least suitable host was yellow nutsedge (Cyperus esculentus); significant differences were noted in larval duration, consumption, pupal weight and duration, adult life span and fecundity between larvae reared on the various food plants (Pencoe and Martin, 1982).

Though tef is the principal host plant of the red tef worm, from this study it appears that if it is not present in the immediate surrounding in the field, it would be possible that wheat and barley could act as potential hosts of red tef worm supporting some degree of infestation by the larvae, if these plants are available.

2.3.9 Survival of M. ignicollis in the dry season

In the early part of the survey, between late December and early March a greater number of live pupae were obtained compared to the number of pupal skins encountered during the same period from the quadrat samples (0.5 x 0.5 m) dug (Table 7). Though the number of live pupa gradually decreases while the number of pupal skins increases over this period of time, the trend is more or less reversed after the arrival of the short rains between late March and April. After the rains a large number of exuviae or pupal skins were found compared to the number of live pupae. It was not possible to take earlier samples in Serbo in the 1983 season.

Table 7. Total number of quadrats dug, live pupae and pupal skins found in the dry season survival study of _M. ignicollis_.

Area	Date	Number of quadrats dug	Total No. of live pupae	Total No. of pupal skins
Becho	31/12/81	40	31	3
	29/ 4/82	40	5	42
	21/ 1/83	50	25	4
	22/ 5/83	50	4	49
	3/ 2/84	75	56	17
	9/ 5/84	75	8	85
Serbo	27/ 4/83	60	60	314
	5/ 1/84	25	16	0
	23/ 3/84	50	2	23
Dejen	12/ 2/83	20	22	2
	14/ 4/83	20	5	34
	5/ 2/84	25	15	3
	17/ 4/84	50	3	21

Pupae which were located deeper in the soil, around 30 cm below the surface, and which did not come into contact with moisture were found alive. In other words, moths did not emerge from live pupae which were not affected by the short rains, in most cases.

M. ignicollis survive during the dry season as pupae, and from the data obtained, it appears that the pupae from which moths emerged after the short rains passed the dry season in a resting stage or diapause because they remain in the soil as pupae for over 90 days.

About 19.5 per cent of the total number of pupae obtained in the Becho area, 8.8 per cent in the Serbo area and 17.9 per cent in the Dejen area were damaged or destroyed by predators such as ants, spiders and carabid beetles.

2.4 Discussion

2.4.1 Larvae

In the study of the life history of red tef worm, two of the weak links were the first and second larval instars, because of the high proportion of larval mortality at these stages. The percentage of egg hatch in the laboratory was very high, but less than 50 per cent of the first larval instars survived to the second larval stage, being very delicate. Though better than the first instar, the second instar larvae are also vulnerable to damage compared to the subsequent stages.

With its high reproductive potential, large larval populations could be expected in the field; but with greater larval densities and vulnerability in the first two larval stages, a large proportion of the population of these instars could be reduced by natural controls. Biological factors such as predators, parasites and diseases and physical factors such as temperature, wind, precipitation and soil type are involved (Watson et al., 1975). The impact of rain drops, for example, can destroy a large number of larvae, especially the first instars, by directly beating or washing them down to the ground from which they will not be able to return. Uvarov (1931) reported that newly hatched larvae of European corn-borer suffered great mortality from rains in which only 3.2 per cent of larvae reached maturity under heavy rain while 20.3 per cent did so with no rain; he also stated that the mechanical action of wind can directly destroy insects by carrying them to unsuitable places for life and reproduction and by interfering with their normal activities.

The susceptibility of 2nd, 3rd and 6th instar larvae of Spodoptera litura (F.) to six insecticides studied in the laboratory in India showed that the second instar larvae were more susceptible than the 3rd, which in turn were more susceptible than the sixth instar larvae. The insecticides used were fenvalerate, chlorpyrifos, permethrin, methamidophos, cypermethrin and deltamethrin (Balsubramanian, 1984). The first and second instars of red tef worm could also be more vulnerable to lower dosages of insecticide spray application, which can be more economical and less contaminating to the environment. However, it is very difficult to detect the first instars in the field, but with a careful search of plants, the second larval instar can be detected. Therefore, efforts can be made to aim control measures at the second larval stages early in the spraying season.

Colour variations exist among the different larval stages of red tef worm. These variations do not appear to differentiate between the sexes. Larval diet does not seem to influence them either, as observed on its limited host range in the field and the various, cultivated possible alternative host crops in the laboratory. In their investigation on the effect of larval diet on the fatty acids of the imago of Heliothis zea (Boddie), Bridges and Phillips (1971) reported that the fatty acid composition of the bollworm moths differs when the larvae are reared on different hosts, but there was no indication of larval diet influence on the colour of the larvae. Population density or crowding does not affect colour variation in the red tef worm as it does in other noctuids such as the African armyworm (Spodoptera exempta) whose colour changes to dark green or black when the larvae are in the "gregarious" phase and light green when in the "solitary" phase. Hence, it is not yet known why colour variations exist in the M. ignicollis larvae.

2.4.2 Oviposition

The reproductive potential of lepidopterous populations is partially dependent on egg and sperm potential and longevity of adults (Callahan and

Chapin, 1960). The fecundity and adult longevity appear to be in favour of the red tef worm moth, contributing to its high reproductive potential, but the spermatophore aspect was not studied. The fecundity of female moths is such that masses of eggs can be laid on plants and tef crops would be devastated by larvae, but natural checks result in considerable mortality.

In the laboratory study of oviposition, eggs were laid singly on the muslin cloth at the top of the rearing cages, while they were oviposited in batches on most plant parts and plastic cage surfaces; thus smooth and uninterrupted surfaces seem to be favoured for egg laying by the female moths.

2.4.3 Feeding behaviour

Red tef worm can be considered to be an oligophagous insect pest. In the field the tef crop is the principal source of food, but a few wild grasses also act as alternative hosts. This limited host range would give opportunity to employ some cultural control methods such as crop rotation to reduce its population. Cultural control would simply be the use of farming or cultural practices associated with crop production to make the environment less favourable for the survival, growth or reproduction of pest species such as the red tef worm. Therefore, use of crop rotation by planting suitable alternative crops such as pulses (chick pea, rough pea), which could enrich the soil, oil crops such as "noug" (Guizotia abyssinica) which suppresses weeds, or other crops which are considered to be important, can have adverse effects on the population of red tef worm. Although tef fields are small in size (0.5 - 3ha), alternative crops can be sown every other season, tef and other crops alternately, through a co-ordinated effort of the members of farmers´ associations by planting tef on some part of a given area and other crops on the rest and reversing the situation in the next season. Under a limited supply of its principal food, a large proportion of red tef worm population would be under natural environmental pressure because such diversification of the agroecosystem could tend to be less favourable for the pest. But simple monocultures of tef, as practised in many parts of the Becho area, could contribute to population increases in red tef worm since it provides favourable conditions for the pest. Tef as the principal source of food is available in the field only during the growing season (Table 8). Hence in the off-season, the population of red tef worm is drastically reduced.

Table 8. Availability of food supply in the field as generations continue to develop.

Date	Sept - Nov.	Late Dec. - Early April	Early April - Early June	Late June - Early Sept.
Generations	1st	2nd	3rd	4th
Tef availability	abundant	none	none	none
Other grasses	available	very little	some	available

2.4.4 Generations

Four generations of red tef worm were obtained in the laboratory. The third and fourth generations had longer larval (feeding) and pupal periods compared to the first and second. Temperature does not seem to have affected them and the food was the same tef plants, so it is not clear what the cause of these differences are.

In the field about the same number of generations were determined per year. The first/second generation occupies a longer period of time because it appears to include a diapausing pupal stage to survive during the dry season.

2.4.5 Survival during the dry season

Cayrol *et al*. (1974) pointed out that among the noctuids which are important pests of crops, there is a group of species having several generations a year, among which it is common for the adults to migrate, and they consider that this migration serves to ensure the survival of the species, most of which do not enter a diapause. In the same way, diapause ensures the survival of non-migratory noctuids such as *M. ignicollis* to pass the harsh dry season in the soil as pupae.

Diapause is a widespread form of dormancy among insects and is characterised by a number of features (Beck, 1968; Lees, 1968). Diapause in *Heliothis* spp. occurs in the pupal stage and manifests itself by a prolonged period between pupation and moth emergence (Cullen and Browning, 1978; Roome, 1979).

While the occurrence of diapause is determined by conditions experienced by the larvae, its duration is largely determined by the conditions experienced by the pupae (Roome, 1979). It was reported by Hackett and Gatehouse (1982) that a high incidence of diapause in H. fletcheri pupae was observed under field conditions in the Sudan and emergence from these diapause pupae occurred in the following rainy season.

Most M. ignicollis larvae have a prolonged pupation period in the dry season starting around the end of November and terminating sometime in March after the short rains, and such pupae are considered to be in diapause. Before the onset of pupation, the soil gets dry, food becomes dry and scarce and night temperatures decrease. From field observations, therefore, it appears that moisture, food and temperature might play an important role in the initiation and termination of diapause in the insect.

Early ploughing of harvested tef fields is one method of cultural control which can be employed to reduce the population of diapausing pupae by exposing them to unfavourable environmental conditions such as desiccation by heat and predation by birds.

CHAPTER 3

POPULATION DYNAMICS OF *M. ignicollis* LARVAE

3.1 Materials and Methods

Observations were made by field surveys during each season between 1981 and 1984 to understand the population dynamics of the red tef worm, especially during its active feeding stage or infestation period in the field. Regions surveyed included the Becho, Serbo and Dejen areas which were visited two to three times every season. The Serbo area was surveyed first as earlier information indicated that infestations began there in September, earlier than in other places. During each visit 40 half-metre, quadrat samples were taken at random in each infested field surveyed (approximately 1.5 ha in size) and larvae counted. According to infestation periods, the Becho area was visited in October and Dejen in November. Following the same procedure, random, quadrat samples were taken and larvae counted and recorded. In each area two to three infested fields of about 1.5 ha each were surveyed for larval counts, and the same fields in each area were used in one particular season.

In all areas there were generally four sampling periods, two early and two late ones for a given area taken from different sites but from the same farms within a given year.

3.2 Results

No samples were taken before infestation began. In the Becho area, near Teji and Asgori villages (5km apart), less than 30 larvae per metre square were found during the first two sampling periods at different dates and sampling sites throughout the four seasons. However, in the third and fourth sampling periods, larval populations rose to between 50 and 130/m^2 (Fig. 3). A trend of population increase was noted in all the sampling periods, but though not recorded, a decreasing trend of larval numbers was also observed about two weeks after the last sampling periods because the larvae pupated by that period, if not killed by an insecticide spray.

In Serbo and dejen areas, larval populations were lower but had similar trend to that of Becho (Fig. 3). Samples were taken from the Kitimbile surrounding of Serbo and Wejel surrounding near Dejen.

3.3 Discussion

Out of the three areas sampled for the population dynamics of red tef worm, Becho was the only area which showed a steady increase of larval numbers over the four seasons with the highest mean number recorded in the 1984 season. However, in Serbo and Dejen, though the highest numbers were recorded in 1982 and 1983 respectively, there was no clear trend of larval increase or decrease in numbers compared to that exhibited in the Becho

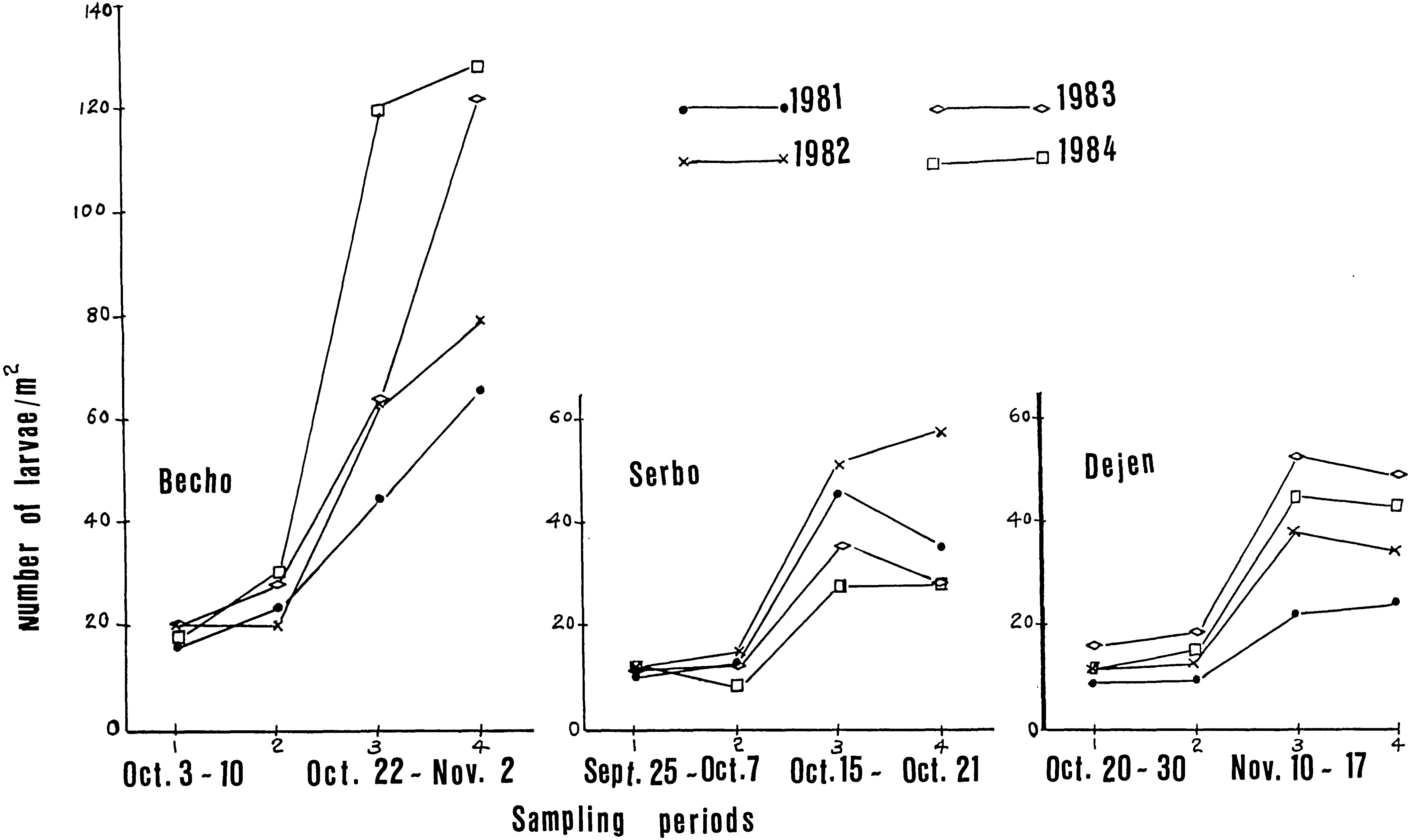


Fig. 3 Mean number of larvae/m^2 in the four sampling periods in Becho, Serbo and Dejen in the 1981 - 1984 tef growing seasons.

area. Although the time scale involved was short, the study in Becho indicated that the importance of red tef worm as an economic pest is increasing from time to time in this area whereas it is not clearly established in the other areas. This situation might have been influenced by cultural practices and environmental factors such as prevailing weather conditions in those seasons for those particular areas.

Tef cultivation takes up 60 - 80 per cent of the arable land in Becho, 25 - 35 per cent in Dejen but only 15 - 20 per cent in Serbo. There is also a greater spread of growing dates in the Becho area due to water-logged conditions. The tendency of tef monoculture in Becho could favour population growth of red tef worm.

To determine, among other factors, whether temperatures and rainfall influenced the population dynamics of larvae, five-year records from Jima town (near Serbo) and Asgori village (in Becho) were examined. Mean maximum temperatures for both areas were approximately 26 °C, but the mean minimum temperature in Asgori was lower (7 °C) than that in Jima (12°C) (see Appendix A1). Total amount of rainfall recorded/season was also lower in Asgori (about 1000 mm) compared to that recorded in Jima (about 1600mm) (see Appendix A2). When the two areas are compared, the lower minimum temperatures and lower total rainfall might have contributed to the population increase in the Becho area. In the Dejen area no reliable temperature data or rainfall records were available, but they would be somewhat similar to those of Serbo area.

The critical time of larval population increase and thus of infestation could be between the second and third sampling periods (Fig. 3) which would be October 10-22 for Becho, October 6-18 for Serbo and October 27 to November 13 for Dejen area. A sharp increase is noted between these two periods on the graphs in Fig. 3 . Over this span of time, not only could threshold levels (25 - 30 larvae/m^2) be reached, but the economic injury level could be surpassed. From this study in the Becho area, the economic threshold level for that area was considered to be 25 larvae/m^2, so from the data in Fig. 3 , farmers should check their tef fields during the above dates when the number of larvae are likely to increase beyond the economic threshold levels. Thus, the pest can be checked before it causes economic damage.

CHAPTER 4

MOTH POPULATION STUDIES

4.1 Introduction

Several meteorological and environmental features affect the distribution of an insect species and its density both on a large and small scale (Johnson, 1969).

Much of the information for forming annual forecasts of the distribution and abundance of noctuids is obtained from regular observations on adult flight. Light and pheromone traps and food attractants can be used to sample moth populations. Ultraviolet light is the most effective attractant as regards number of species (Andreev, 1981), but fermenting baits are also effective against many species. A great number of species are active after sunset and are attracted to light traps. According to Andreev (1981), the hours between 2300 and 0200 are especially useful because flight to light ceases usually after 0300 hours. In his observation one species (*Agrotis exclamationis* L.) increased from 3.7 per cent of the moths taken in 1976 to 36.2 per cent in 1979. This increase must have been due to exceptionally favourable weather conditions; numbers of *Agrotis segetum* (Denis and Schiff) decreased during the same period, probably because conditions were unfavourable for this species.

In a light trap study of moths by Persson (1976), night temperature, night wind and nocturnal illumination, in that order, were the most important factors influencing the catch; wind had a significantly stronger influence on males than on females all year round, temperature a significantly stronger one on females than on males in the summer, probably due to differences in their vertical distribution, females flying lower than the males; nocturnal illumination had a significantly stronger influence on females than on males. He reported that females were most abundant in the first part of the night, males in the second. Temperature, wind and moonlight maintain this nocturnal distribution of the moths which is probably endogenously controlled (Persson, 1976). Female flight is probably linked to oviposition and male flight to response to pheromone release from calling females. Heavy out-of-season rainfall had a negative effect on noctuid populations in the study area and strongly increased both larval and adult mortality (Persson, 1976).

The trapping effect of light traps depends on the angle of light in relation to the insect, the negative reaction of the insect to high light intensity and the speed of the insect; the brighter the light the greater the catch, but too large a catch may be inconvenient (Verheijen, 1960). The catch will thus vary with the height of the trap above ground level, the weather and the brightness of the moon. Light traps may be used for finding the number of different species present, changes in a given population and for estimating the actual population if the relationship to the actual population and influencing factors are known (Walker, 1981a).

It is realized that weather is one of the important factors regulating moth numbers and permitting forecasting to a certain extent. In a cloud of wingless insects or other organisms simply drifting with the wind, volume density is controlled largely by source strength and behaviour of the atmosphere; by contrast, the volume density of winged insects (for example moths) in flapping flight can be strongly affected also by insect behaviour (Pedgley, 1982). For instance, massive and simultaneous take-off or landing can clearly lead to large changes in density.

Light traps are widely used at night to indicate qualitative changes in volume density, but records are more difficult to interpret compared to suction traps because they are affected by other light sources such as the varying time and intensity of moonlight (Bowden and Church, 1973; Bowden and Morris, 1975) and by changes in windspeed (Douthwaite, 1978). Comparing catches at different heights in the same place reduces these difficulties (Pedgley, 1982). Observations by Taylor et al. (1979) at Muguga, near Nairobi, Kenya, using traps at ground level and 24.5m to sample a mixed population of night-flying moths showed that large species tend to fly higher, irrespective of family. This is consistent with the observed downwind flight there because small and therefore generally slow flying moths do not need to fly as high as large species to have the wind dominate their flight direction (Pedgley, 1982).

Photoperiodism controlled by the amount, duration and distribution of moonlight may be widespread in insects at least in the latitudinal belt between the tropics and could be the basis for predicting such behaviour patterns as peak periods of oviposition or of emergence (Bowden, 1973a). In general fewer insects are caught in a light trap at or near full moon than at or near new moon; the reduced catch near full moon is generally thought to be caused by moonlight competing with the light of the trap (Bowden, 1973b). Provost (1959) also reported that British and American workers independently concluded that "light trap captures of night flying insects varied inversely with the intensity and duration of moonlight probably because the moonlight diminished the contrast between background and light emitted by the trap, and lunar periodicity in light trap captures of any night flying insect is not the result of increased flight activity at new moon as such but rather the result of purely physical cycle in the attractant efficiency of the light trap".

Results obtained by Bowden (1982), Bowden and Church (1973) and Bowden and Morris (1975) show that light trap catches of insects are primarily a consequence of the interaction of the two physical components of light trap system, natural and artificial illumination, modified but not changed fundamentally by behavioural and physiological characteristics of the insects which are trapped. Once an insect is airborne, its capture by a light trap depends on whether or not it crosses the boundary of the region of influence which is a random event; the distance from a light source at which that event occurs is determined by the power of the light source and amount of natural illumination, modulated by the spectral response and visual acuity of the species concerned (Bowden, 1982).

The most important factor determining the size of a population sample taken by a given light trap is natural illumination, and that can vary much with time, for example diurnally or seasonally, and with locality, for example latitudinally or because of differences in vegatative cover of trap sites (Bowden, 1984). Sample size for a given trap at a given place is therefore determined by the amount of natural illumination during the flight period of the insect population being sampled.

Light traps are very useful to monitor changes in the distribution of crop pest populations. They also have contributed a great deal to the forecasting of infestations based on the population of moth catches, for example, the African armyworm (Spodoptera exempta), and thus the timely control of pest outbreaks (Odiyo, 1977).

4.2 Materials and Methods

4.2.1 Light trap catches

Moth populations of Mentaxya ignicollis (Walker) were studied at four sites: Ambo (SPL) about 60 km north-west of the Becho area, Holetta Research Station (IAR), some 50 km north-east of the Becho area, Jima Research Station (IAR) about 40km west of the Serbo area and Debre-markos about 70 km west of the Dejen area (Figure 4). Robinson type light traps with light at the top of a metal drum using a mains supply for their operation, were switched on and off at 1800 and 0600 hours respectively each day. The light trap operator removed the collection of moths to the laboratory for sorting. The traps were operated almost throughout the year for the armyworm forecasting service, and unless moths were needed alive they were killed by an insecticide such as dichlorvos placed on cotton wool inside the metal drum. The red tef worm moths were removed from the catch and sexed prior to recording their numbers. Traps were not placed directly in fields where tef was grown due to difficulties in the supply of mains electricity.

4.2.2 Virgin female baited traps

A pheromone trap baited with virgin female moths was used at Holetta Research Station and at Ambo Scientific Phytopathological Laboratory. A plastic container as used in the laboratory studies was modified with side windows, each 2 x 4 cm, and a circular hole in the lid, each covered with muslin cloth, to cage the females in the trap and allow permeation of the pheromone to the surroundings. The virgin female moths were provided with a 10% sucrose solution in a 6-dram vial plugged with cotton wool. This cage was hung from the top of a square tin drum with four windows measuring 15 x 20 cm. At the bottom, the tin drum was filled with a detergent solution to a depth of about 4 cm. The whole drum was hung on a post so that it was 1.5 m above the ground in an open space, and inspected daily.

Fig. 4 Light trap sites in the Shewa, Kefa and Gojam Administrative Regions.

4.3 Results

4.3.1 Light trap catches

Recording started in 1981 at Ambo and Holetta, although at the latter no moths were trapped until the trap was moved to a more open and higher site in 1984 when large moth catches were recorded (Figures 5 and 6).

In Ambo, catches were relatively low, but over the four seasons the number of moths increased each season. Catches began in July and reached a maximum level in September, before drastically reducing to very low levels in October and zero in November. At Holetta, the trend was similar with catches beginning in June and a peak in July followed by a second peak in September. At both sites no moths were recorded during the dry season though the traps were operated most of the time. Overall more males were trapped than females (ratio 1.3:1) and more at Ambo than at Holetta, although the latter was based on one season only. The sex ratio was similar to that obtained in laboratory cultures.

Light trap records of *M. ignicollis* in Jima and Debre-marcos were started in 1983, but no moths were recorded that year at either site. At Jima only 16 moths were recorded in 1984 after relocation of the trap, but the trap could not be moved at Debre-marcos and continued to fail to attract red tef worm moths.

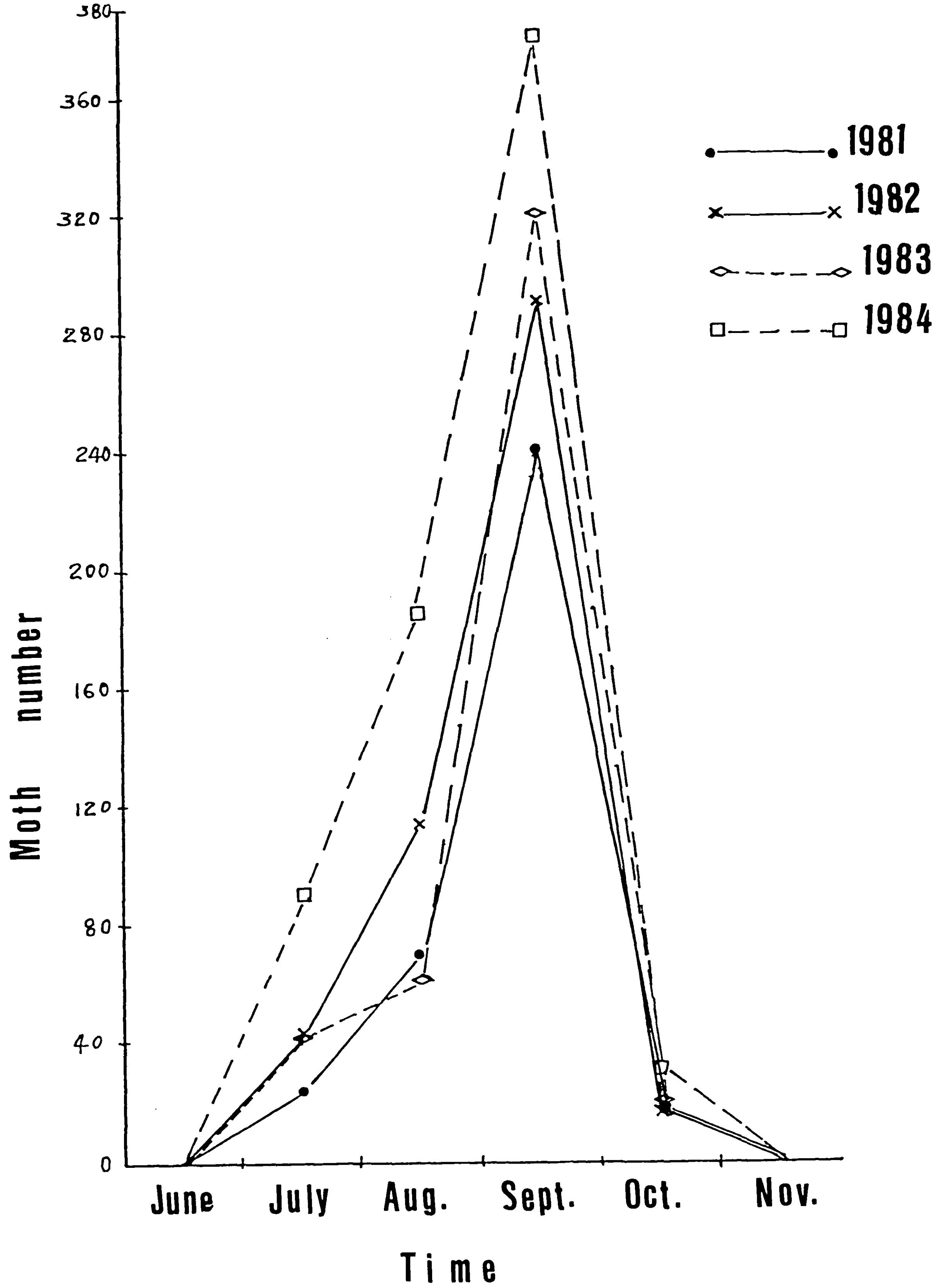


Fig. 5 Monthly total light trap catches of M. ignicollis moths at SPL, Ambo between 1981 and 1984.

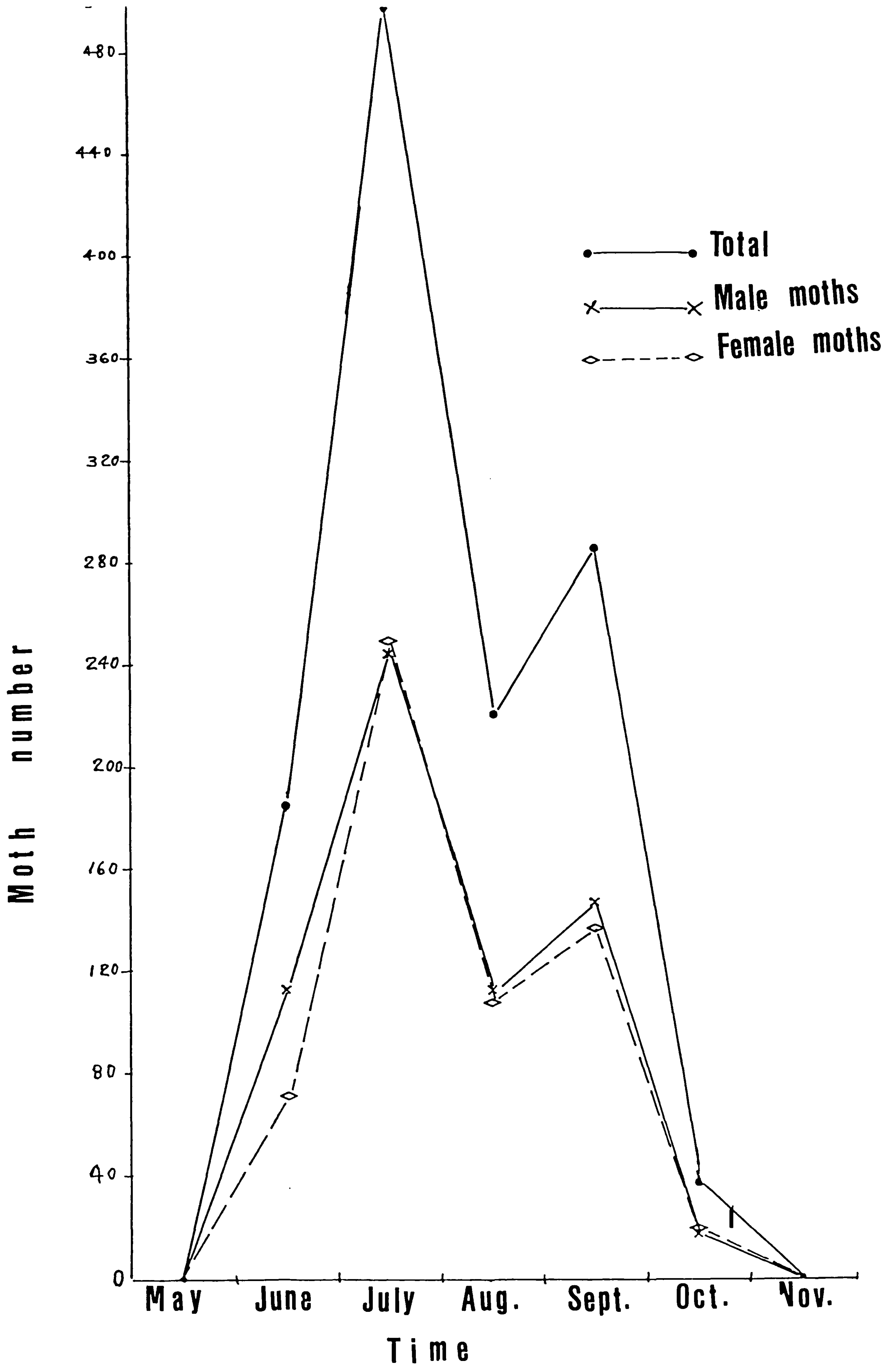


Fig. 6 Monthly male, female and total light trap catches of *M. ignicollis* moths at Holetta in 1984.

4.3.2 Virgin female baited traps

At Holetta and Ambo,no male moths were attracted to any of the three traps set out on four occasions between August and October 1984, but this may be due to the design, orientation or height of the traps.

4.4 Discussion

Though the light trap at Holetta caught most moths in July, the second peak in September corresponded with that at Ambo, and indicated high larval populations could be expected in October to cause serious crop damage, especially in the Becho area.

Failure to catch moths or low catches might be due to different factors such as the distance from breeding sites or the location of the traps, as observed with changes in position improving the catch. Light traps could be a very useful tool to monitor pest populations, as has been the case with the African armyworm, but the traps would need to be installed right in the tef growing areas. With the difficulty of electricity supplies, pheromone traps might be more appropriate to use instead of light traps; so it was unfortunate that the initial experiment failed to trap moths.

CHAPTER 5

DISTRIBUTION

The old synonyms for Mentaxya ignicollis (Walker) are Agrotis decipiens Feld. = Lycophotia muscosa Feld., 1837, = Agrotis ignicollis Walker, 1857, = Georyx ignicollis (Walker) (Laporte, personal communication).

According to Harris (1938), Lycophotia muscosa was observed on tobacco in Tanganyika (Tanzania), but not as a serious pest. Berio (1955) reported the distribution of Georyx ignicollis in South Africa, Kenya, Abyssinia (Ethiopia), Uganda, Congo (Zaire), Tanganyika, Nyasaland (Malawi), Comoro Islands, Lourenco Marques - Mozambique, Madagascar, Belgian Congo (Congo Brazzaville) and Cameroun; these areas were determined from the collections of male and female moths of M. ignicollis received. In his paper, Laporte (1973) has described several species of the genus Mentaxya collected from Cameroun, Central African Republic, Nigeria and Madagascar; however, none of them was the species M. ignicollis. Later on M. ignicollis was described by Pinhey (1975) confirming that this species is found in southern Africa.

There is no mention in the literature of work done on this insect in the countries where it is found, probably because it might not have reached an economic status. Indeed in several African countries species of Eragrostis are grown as pasture crops and it is only in Ethiopia that tef is grown as a grain crop.

In Ethiopia M. ignicollis (Walker) was reported by Berio (1955) from the Elaberet area, Eritrea Administrative Region, but it was not possible to confirm this in the present study. In 1971 it was collected from the Becho and Welkite areas of Shewa Region, and in 1976, this pest of tef was reported from the Serbo area of Kefa Region and Inda-Selassie area of Tigray Region. In 1978, it was collected from the Dejen area of Gojam Region, and later this insect was reported from the Anger-Gutin and Asossa areas of the Welega Administrative Region. However, the major infestation areas to date are Becho, Serbo and Dejen (Figure 7).

Fig. 7 The distribution of M. ignicollis in Ethiopia: 1) Elaberet in Eritrea; 2 and 3) Becho and Welkite in Shewa; 4) Serbo in Kefa; 5) Inda-Selassie in Tigray; 6) Dejen in Gojam; 7 and 8) Anger-Gutin and Asossa in Welega.

CHAPTER 6

NATURAL ENEMIES OF RED TEF WORM

6.1 Introduction

Under natural conditions most phytophagous insect populations are far below the carrying capacity of their food plants and consume such a small amount of the vegetation that damage is negligible; such insects are considered to be under natural control (Klomp, 1966). This situation is of great interest for the economic entomologist who is always concerned with reducing the numbers of pests to economically tolerable levels. Thus, a better understanding of the natural control mechanisms would eventually contribute to a more successful application of artificial control measures against pests such as the red tef worm.

Naturally occurring biological control is very significant in pest suppression and this is what must be generally recognised amongst workers in pest control (van den Bosch, 1966). Manipulation of natural enemies has enhanced pest control in a number of situations, but this applied aspect is only a minor part of the total phenomenon. However, lack of information on the important role of parasitoids and predators in agroecosystems could result in disastrous effects due to indiscriminate use of artificial pest control measures (van den Bosch, 1966).

In considering the use of natural enemies in crop protection, benefits could result from the natural presence of such enemies in the agroecosystem and the benefits can be measured only in terms of losses resulting from their absence; while the importance of natural enemies as a central component of the integrated pest management concept is generally conceded, all too frequently one encounters the statement, " chemical insecticides remain the farmers´ first line of defence against insect pests," but this is true only in the sense that once a standing crop is infested by a threatening pest population, the farmer has little option except to use an insecticide (Sailer, 1981).

Only recently have entomologists realized that outbreaks of pest species often develop from the survival of less than 2 per cent of immatures (Whitcomb, 1981). Satisfactory natural control of many noctuids depends on high predation rates (Morris and Miller, 1954); on the other hand, since arthropod predators function well as low-density population regulators, such biological control agents are a major factor in preventing outbreaks in populations of many pest species (Whitcomb, 1981). According to Sailer (1971), general predators are extremely effective at low prey densities, not being completely dependent on populations of target pests; in contrast, many parasitoids function most effectively at much higher pest densities.

Pathogens also often decimate host populations and may exert a balancing role through mortality or chronic debilitating effects (Huffaker et al, 1976). The entomopathogenic species appear to be density-dependent in nature but only rather loosely because of the complex events that are required to trigger epizootics (Huffaker *et al*, 1971). As Tanada (1964) noted, an epizootic may cause prolonged control through its near annihilative effects. Pathogens also present promising advantages as selective insecticides, thus investigation of the roles of entomopathogenic microbes in population suppression and as regulating factors in the field and also their interactions with other control factors need to be intensified (Huffaker *et al*, 1976).

Skaife (1921) reported that *Lycophotia muscosa* Geyer. (see page 80) was attacked by a fungus (*Entomophthera apiculata* Thaxter) in S. Africa.

6.2 Materials and Methods

Search for natural enemies of *M. ignicollis* was carried out together with the other studies in the most important tef growing areas where red tef worms could be found. Larvae from the field were collected and taken to the laboratory for rearing. The plastic bowl with plastic cylinder described earlier was used as the cage for rearing. Twenty five to fifty larvae were placed in one cage depending on size and age. Tef plants were given to them for food and observations on death, rate of growth and pupation continued. Dead larvae were removed and examined using a binocular microscope for parasitoids, and predators such as mites. Eggs of parasitoids if found were recorded and predators such as mites were collected and recorded. After pupation of larvae, constant observation was made for emergence of parasitoids. If found they were removed from the cages, killed with ethyl acetate vapour, mounted and properly labelled. From such collections of parasitoids, if not identified earlier, a sample was sent to the British Museum in London for identification. Upon receipt of part of the identified specimens and the letter of identification from the British Museum, well-labelled specimens carrying the scientific name were placed in a permanent collection at Holetta. The percentage of parasitism was also recorded.

A constant search was made for any kind of predators of red tef worms in the field while the larvae were feeding on tef. Also attempts were made to find predators while looking for the survival of red tef worm in the dry season by digging soil patches or quadrats on harvested tef fields. Vertebrate and invertebrate predators were observed and recorded.

Inactive, diseased or dead larvae found in the field were also collected separately in dry, 8 - dram vials and labelled with the date and place of collection and name of collector. Then they were taken to the Scientific Phytopathological Laboratory (SPL) in Ambo, Ethiopia, for identification. Larval collections were made from the Becho area of Shewa Region and Serbo area of Kefa Region.

6.3 Results

6.3.1 Parasitoids

Only one parasitoid wasp was obtained throughout the study period from the field collected larvae of *M. ignicollis*. Reared in the laboratory from larvae collected in the Becho area it was identified as *Enicospilus rudiensis* Bischoff (Hymenoptera: Ichneumonidae) by the British Museum in London.

The highest rate of parasitism by this wasp observed in the laborarory from field collected larvae was only 2.5 per cent based on 375 larvae. The adults of this parasitoid wasp were also seen in the field near Teji village at Becho, but none was found or observed in the other areas surveyed. Some parasitoid eggs were observed on field collected larvae from the Teji area in Becho, but no adults emerged from them.

6.3.2 Predators

During the cropping seasons between 1981 and 1984, crows and other small birds were repeatedly observed preying on red tef worms on farmers´ fields particularly in the Becho area.

Some mites, presumably predators, were seen on the body of few larvae.

Pupae of *M. ignicollis* were destroyed by ants, spiders and carabid beetles in the cracks of black soil at Becho, Serbo and Dejen during the dry period. In the dry season survival study of red tef worm, the rates of pupal predation were about 19.5, 8.8, and 17.9 per cent respectively, of the total number of pupae (see page 56) recorded in each of the three areas mentioned above.

6.3.3 Pathogens

Diseased larvae were collected from tef fields in Becho and Serbo areas and one type of bacterium was identified as *Bacillus thuringiensis* Berl. by the SPL in Ambo, Ethiopia. Again, the rate of larval attack by diseases was low, just between 1.5 and 3 per cent as observed on about 400 field collected larval specimens.

6.4 Discussion

Very few natural enemies of red tef worm were discovered during this study, but more could be discovered in further studies over a longer period.

The contribution of these natural enemies, particularly predators, in the suppression of red tef worm populations cannot be ignored because in their absence pest populations and crop losses could be intolerable. Hence these natural enemies should be protected by restricting the use of pesticides to only once a year where and when necessary, by avoiding the repeated use of the same insecticide year after year, particularly if it is an organo-chlorine compound such as DDT which has been used for several years by farmers in the Becho area (see page 116), and by making the agroecosystem more suitable to the natural enemies, if possible.

The application of broad-spectrum insecticide will usually destroy the beneficial insects thus permitting the insect on which they feed to increase to pest status, or if it is a pest already, to a serious resurgence level. Thus, the ongoing control of red tef worm by predators, parasitoids or pathogens occurring naturally in the area could be maintained by conservation which is the modification of the environment to make it more suitable to the natural enemies (Watson et al, 1975). This could involve anything from routine agronomic practices such as crop rotation to the use of sound economic levels on which to base insecticide application decisions. Even where insecticide applications are needed, it may be possible to protect part of the beneficial insect complex by spot treatments and using the minimum dosages needed to kill the pest, or when possible, the use of more selective insecticides which are more toxic to the pest than to the natural enemies. However, further studies are needed which may involve some of the newer insect growth regulators that were not available for study in Ethiopia.

CHAPTER 7

ALTERNATIVE HOSTS

7.1 Introduction

Alternative hosts of crop pests can provide food for the maintenance, growth and survival of pest populations, particularly during adverse conditions at a period when the main host plants are not available in the field. Thus, the removal of such alternative hosts would reduce the population of pests, especially during the off-season.

One important aspect of sanitation which can adversely affect a pest is the elimination of alternative hosts and weedy areas which may serve as overwintering site or some other sort of pest reservoir, and it is usually accomplished by direct mechanical or chemical destruction (Coopel and Mertins, 1977).

In India and Pakistan, various species of sugarcane borers utilize semi-cultivated or wild grasses and sedges near cane fields as alternative host plants (Nagarkatti and Ramachandran Nair, 1973). This frequently leads to rapid pest increases in sugarcane at the beginning of the rainy season (Carl, 1962). Mechanical removal of plants, such as wild sorghum, can reduce infestations in sugarcane by as much as 50 per cent (Gupta and Kulshreshtha, 1957), although increased cultivation of sugarcane with two crops a year has made the borers less dependent on alternative wild host plants (Nagarkatti and Ramachandran Hair, 1973).

One insect pest which is somewhat similar to red tef worm as a grass family feeder is the African armyworm. The African armyworm (Spodoptera exempta Walk.) is a migrant noctuid pest of cereals and grasses in Africa south of the Sahara, southwest Arabia, southeast Asia, Australasia and Hawaii, whose moths often travel long distances and lay eggs on cereals and pasture on which the armyworms (larvae) will feed (Brown and Swaine, 1966; Brown et al., 1969; Brown and Dewhurst, 1975).

However, while red tef worm feeds only on tef and very few wild grasses, the African armyworm feeds on all types of cultivated cereal crops and grass pastures, usually appearing in devastating, outbreak numbers.

7.2 Materials and methods

Extensive surveys for wild alternative hosts of red tef worm were carried out in the tef growing areas of Becho and Welkite in the Shewa Administrative Region, Serbo in the Kefa Administrative Region and Dejen in the Gojam Administrative Region where red tef worm was causing damage. During the tef growing seasons, possible alternative hosts were examined. Each plant was searched for feeding larvae or for eggs. When found, sample plants were collected and placed in a plant press for preservation noting the date and place of collection. Fresh plants were also taken to the laboratory for further observations of larval feeding.

If seeds were available, they were also collected for identification and germination tests, if not, then tags were placed on selected samples for later collection of seed as plants with flowers or seeds are more suitable for identification.

In the dry season an intensive search for wild alternative hosts of red tef worm was carried out on river banks, water ways, drying river beds, drying ponds or small lakes and any green patch encountered anywhere in the tef growing regions. Wild grasses encountered were closely examined for eggs or feeding larvae and if any were found, both the wild host and insect were collected and procedures mentioned above followed.

Collected and pressed plants with flowers or seeds were submitted to the plant taxonomists or weed specialists of IAR for identification, after confirmation that a given wild grass was an alternative host of red tef worm in the field. In addition to obsevations that red tef worm was feeding on a particular wild plant in the field, sufficient plants were collected and fed to laboratory cultures of red tef worm to check that it was accepted.

7.3 Results

During this study, only two alternative hosts of *M. ignicollis* larvae were found in the field, one in the Becho area and the other in the Serbo area.

Phalaris paradoxa L., a wild grass weed, was observed supporting small numbers of red tef worms in the Becho area along field borders and in small areas within tef fields where tef growth was sparse. It was easily recognized during the period of tef infestation because this grass heads at the same time, but before this period it was difficult to detect it. Fresh samples collected were fed to larvae in the laboratory and were easily accepted.

In the Serbo area, another wild grass, *Digitaria scalarum*, was encountered being eaten by red tef worms during the cropping season. It was also detected in the off-season on drying marshland supporting a low population of red tef worms.

7.4 Discussion

The survey of alternative hosts of red tef worms was not exhaustive, but the host range of this pest appears to be limited. This situation could offer an opportunity to destroy or remove such alternative hosts from field borders and waste land without much difficulty.

More attention needs to be given to those wild alternative hosts during the dry season when supporting larval populations which survive the dry period and eventually contribute to tef infestations through subsequent generations. Such wild grasses can be cut and fed to livestock or grazed so that surviving populations of red tef worms can be drastically reduced in the dry season.

CHAPTER 8

THRESHOLD DETERMINATION

8.1 Introduction

The establishment of an economic threshold of pest species is fundamental to control programmes. Without adequate knowledge of pest populations, there is often a complete reliance on prophylactic treatment schedules because of the uncertainty involved.

Stern et al. (1959) were the first to define the economic threshold of an insect infestation as the population density at which control measures should be initiated to prevent an increasing pest population from reaching the economic injury level. This is the lowest density that will cause economic damage to the crop. From a practical point of view, it becomes economically profitable to apply supplementary pest control measures at this level. If these measures are not initiated and the pest population passes the economic injury level (Fig. 8), damage will occur and result in a loss to the farmer. The general equilibrium position indicated in Fig. 8 is the average density of a population in a given area, over a period of time in the absence of permanent environmental change (Stern, 1966).

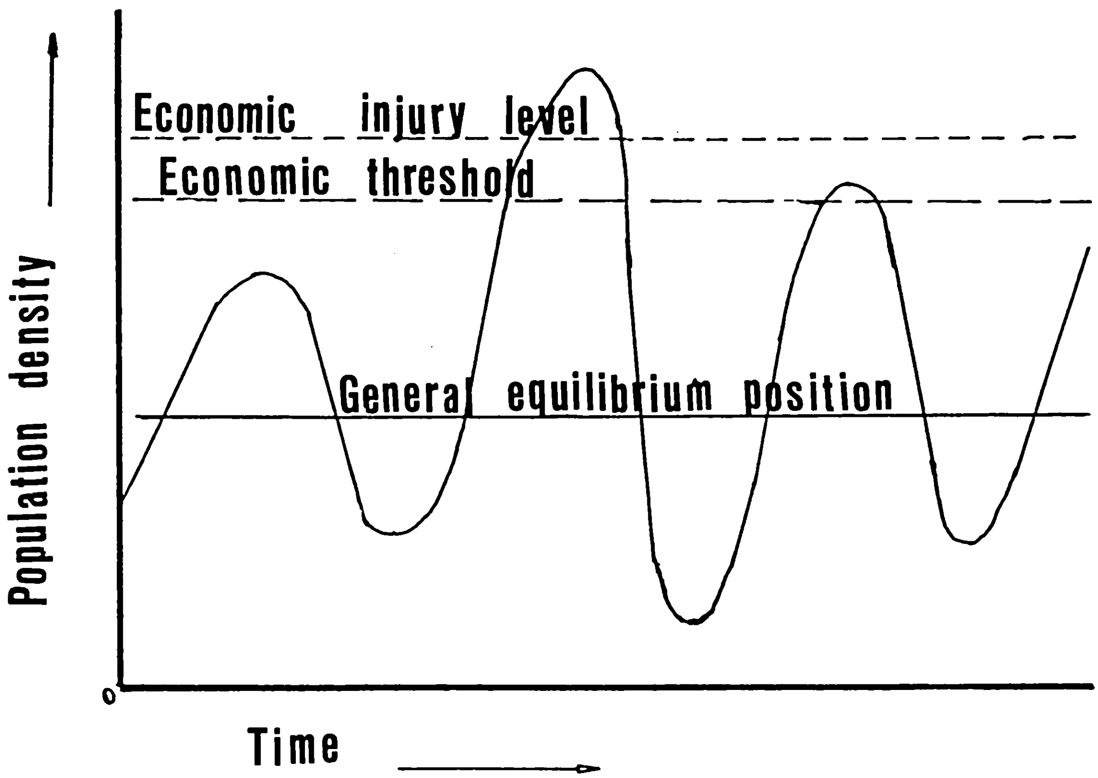


Fig. 8 Schematic graph of a theoretical arthropod population over a period of time and its general equilibrium position, economic threshold and economic injury level (after Stern, 1966)

According to Graham et al. (1972), the economic threshold permits the farmer or supervising entomologist to make full use of naturally occurring predators and parasitoids to control the pest, thereby increasing profits and reducing adverse effects encountered, when insecticides are used judiciously. The use of an economic threshold is a better alternative to prophylactic control in many respects. It enables pest control measures to be more precisely tuned to the pest population and the damage that is being caused. Control is potentially more efficient and hence can serve more closely the goal of profit maximization if this is the objective (Conway and Norton, 1976). Where pesticides are used there is the added benefit that the amounts applied are likely to be less than under a prophylactic or schedule spraying programme.

With field crops, determination of thresholds of insect damage is usually necessary to developing sound insect control recommendations because those hosts are often able to tolerate considerable infestations and apparent damage before economic damage occurs (Lincoln, 1968). Thresholds of insect damage are dependent upon the level of insect infestation, upon the ability of the host to tolerate and to compensate for insect attack and upon the end use of the host. Where an effective control measure is available, its cost must be balanced against the returns expected.

Economic threshold recommendations are now given for a wide range of crops (FAO, 1971). The problem of their practical application to the crop systems is that they are determined by a wide range of variables which may differ between seasons and geographical areas. However, as Stern (1973) stated, "initial tentative values, although conservative, will give both useful short term benefits and aid the long term development of the concept."

8.2 Materials and methods

In earlier work on red tef worm, threshold levels of infestation were studied in 1981 and 1982 in the Becho area of the Shewa Administrative Region. When infested fields were found during a survey near Teji and Asgori villages, 2 x 3 metre plots were superimposed on farmers' fields of tef. A DDT e.c. formulation and untreated check were compared four times at four sites, two near each of the villages. After the pre-spray count and record of larvae/m^2 , DDT 25 per cent e.c. was applied with a Gloria knapsack sprayer at the rate of 625 g a.i. /ha. The number of living larvae was recorded 72 hours after the insecticide had been applied. Stakes at the four corners of each plot were left so that the plots could be subsequently harvested. When matured, the tef was cut and threshed later at the Holetta Research Station. Clean grain was weighed and percentage yield loss estimated. This study was repeated in 1982 in the Becho area but at different places near Teji and Asgori villages, using the same procedures and materials.

8.3 Results

In the 1981 season pre-spray samples, mean larval counts were between 50 and 60 per metre square, but in the treated plots this population was reduced to below three larvae/m^2 (Table 9). When these plots were harvested, grain yields were greater in the treated plots. From the difference in yields the percentage yield losses were calculated for both areas at about 8 per cent with a range of 3.2 to 11.2 per cent.

In the following year (1982) similar results were obtained (Table 9)

Table 9. Pre-spray and post-spray mean larval counts/m^2, yields and percentage loss in the Becho area during the seasons of 1981 and 1982.

Year	Becho Area	Treat-ment	Mean number larvae / m^2 Pre-spray	Post-spray	Yield kg/ha	Calculated % loss
1981	(1)	DDT	56.3±4.2	2.5±1.1	1555±12	
	(1)	Check	54.5±4.3	54.3±4.2	1431±14	8.0±1.6
	(2)	DDT	63.0±3.8	1.8±1.3	1481±14	
	(2)	Check	58.0±5.1	55.8±4.8	1350±12	8.8±1.9
1982	(1)	DDT	68.3±4.4	3.3±1.1	1771±10	
	(1)	Check	58.8±4.8	58.0±4.9	1617±14	8.7±1.9
	(2)	DDT	51.0±3.5	2.0±1.3	1817± 9	
	(2)	Check	49.0±3.9	47.8±3.8	1685±11	7.3±1.5

8.4 Discussion

In the threshold determination studies at Becho, the red tef worm infestation samples from the four different areas were not very high, but nevertheless caused sufficient injury to the tef crops to decrease yields.

From the two years' limited study, the scale of infestation, the range of thresholds, the economic threshold level and the subsequent range of yield losses were determined as shown in Table 10.

Table 10. The scale of infestation and losses to red tef worm with regard to threshold levels derived from Appendices B1 and B2.

Scale of infestation	Threshold levels (No. of larvae/m^2)	Percentage yield losses	Regions
Light	up to 20	3 (* 3.2)	
Medium	25 - 60	3.7 - 9(3.7 - 8.9)	
(economic threshold)	25	3.7	Becho
	30	4.5	others
Heavy	70 and over	10 and above (10.3)	

* percentage yield loss in brackets are those obtained in the study.

Larval infestations have been categorized in a scale of light, medium and heavy. The first category is light which implies low infestation, thus application of control measures may not be needed. However the economic threshold of red tef worm infestation was determined to be 25 larvae/m^2 within the medium scale of infestation (Table 10). According to Stern et al. (1959), this is the sample population density at which control measures should be initiated. Larval numbers above 25/m^2 would approach the economic injury level of about 30 larvae/m^2. Such an injury level would cause a yield loss of approximately 4.5 per cent.

If the lowest tef yield was 1481 kg/ha (Table 9), then 4.5 per cent of this will be about 70 kg/ha. According to Newsom (1980), the local price of this yield difference would more than offset the cost of controls imposed to suppress the population of red tef worm. More than one spray application at the appropriate time would not be needed to sufficiently reduce, below economic levels, a threatening population of M. ignicollis larvae in the field. However, regular inspections by walking through the crop is essential not only to examine the status of insect pests, diseases and weeds, but also to assess plant development (Matthews, 1984).

Though specific studies related to economic thresholds have not been carried out in other places, their tentative economic threshold level could be estimated to be around 30 larvae/m^2, from other observations made on them. When yields in other areas, where red tef worm threshold level has not been studied, are much lower than that of Becho, this level of infestation if prevented would at least offset the cost of control imposed to suppress red tef worm populations.

Because of the great variability in the effect of factors causing economic losses, long term experiments with specific pests in specific ecological areas are necessary to resolve the problem of economic thresholds in relation to intensity of pest attack (Judenko, 1972). In the light of the above statement, the threshold study conducted at Becho for two seasons was not adequate to reach a valid conclusion.

This limited study over two seasons provided data to derive a tentative economc threshold, but further study is needed to assess yields over a greater range of insect populations in different seasons. Nevertheless, the study did confirm that significant losses occurred even with relatively low pest populations.

CHAPTER 9

CROP LOSS ASSESSMENT

9.1 Introduction

Failure to prevent economic losses deprives a hungry and crowded society of food and fibre. On the other hand, unnecessary treatments increase the cost of production and may have undesirable side effects in upsetting natural control and adding to environmental contamination.

To clarify the fundamental relationships between insects and crop loss, it is necessary to distinguish between the presence of insect numbers, the effect of these insects on the plants and the subsequent loss in quantity or quality of the harvested product. The relationship between the level of pest population and the injury it causes is linear, at least until densities where intra-specific competitive interactions take place (Southwood and Norton, 1973). However, the generalized insect number-yield relationship is not a simple straight line direct function. Basically, as pointed out by Tammes (1961), the relationship is of the sigmoid form.

For most crop plants, the relationship between injury and yield varies with the growth stage of the plant at the time of attack (Bardner and Fletcher, 1974). Hence, early planting, as a general rule has long been used as a method of cultural control to avoid pest damage. The period following sowing and germination is a critical one because individual plants usually cannot survive injuries that an older plant would normally tolerate. Before the flowering period, plants become more tolerant to injuries and usually a moderate infestation is much less likely to affect yield than late attacks (Edwards and Heath, 1964; Wood, 1965; Dina, 1976). A new critical period is reached when the inflorescence is produced. Plants with a short flowering period like cereals are usually unable to tolerate injury to their reproductive organs (Bardner and Fletcher, 1974).

Compensation may occur at the level of crop population, neighbours expanding to fill the gaps caused by dead or damaged plants (Conway and Norton, 1976), or when other branches, leaves or tillers are produced by the injured plant. Often compensation can only be effective if sufficient time elapses between the infliction of injury and the end of the yield forming process. It should, therefore, be realized that the amount of economic loss depends not only on the amount of attack but also on the plant reaction to that attack (Johnson, 1965; Judenko, 1969; Bardner, 1968).

Often a pest outbreak occurs in such a way that parts of a crop are affected but others remain pest free or a gradation of pest intensity is noted. One of the methods of crop loss assessment is based on a comparison of the yields from two sets of plants that are precisely the same and, as far as known, are growing under identical conditions in all respects except that one is unattacked and the other is attacked by the specific pest being considered (Judenko, 1972). Small areas can be sampled for the presence or absence of a pest; then, at harvest standard areas of affected and unaffected parts of the crop are sampled as close to each other as possible and appropriate components of yield per sample are recorded (Richardson, 1981). These methods and procedures were used in the crop loss assessment studies undertaken.

9.2 Materials and methods

Fields infested with red tef worm were surveyed in October 1983 and 1984 in the Becho area of the Shewa Adminstrative Region and in November 1983 and 1984 in the Dejen area of the Gojam Administrative Region. The number of damaged and undamaged tef plants were counted inside 0.5 x 0.5 m quadrats. Ten to fifteen random samples per field were taken out of which four samples per field with higher larval counts were considered. In each place ten fields of tef were sampled. The sampled plots (quadrats) with lowest number of larval counts (5 or less) were also marked with stakes for yield comparison. During the harvesting period, plots were harvested with sickles and the bundles of tef from both areas were threshed separately. Threshing was done manually by hired labour. Weights were taken and yields per metre square and per hectare determined. Then percentage loss in yield was estimated by comparing yields of damaged and undamaged plots or quadrats of tef.

Crop loss was also assessed in 1984 in the Becho and Dejen areas by taking stratified samples at random across fields. Both areas were checked for infestations in October and November of the same year respectively, in which fields were sampled for damage due to tef worm. In infested fields, areas each 120 x 50 m were divided into four strata (30 x 50m) from each of which ten samples were taken by throwing the half-metre metal quadrats at random diagonally across the field. Larvae in each quadrat were counted and the number of larvae per metre square determined. Near these fields, two areas in Becho and one in Dejen (30 x 50 m each), with less than 5 larvae per quadrat, were sampled to compare yields from damaged and undamaged plants. Areas with high and low larval counts were demarcated with pegs for subsequent harvesting to determine yields. Each sample area was cut with a sickle and the tef bundle(s) put in a cloth bag with its respective label. The bags were taken to the Station and the grain from the plants threshed manually on a canvas sheet. Weights were taken separately and differences in yield were used to estimate crop losses and were related to larval infestations.

9.3 Results

In these samples from farmers' fields in 1983, the average number of larvae/m^2 for the ten sample locations in Becho area reached 125.7 ± 4.6 while that for Dejen was 54.8 ± 1.9; the harvested yields of tef also confirmed that losses proportional to the level of infestations occurred in the field when mean yields/ha from damaged and undamaged plots were compared (Table 11) (see also Appendices C1 and C2).

The 1984 random samples stratified across fields in the Becho area had mean larval counts of 87.3 ± 3.5/m² for site one and 80.1 ± 2.7/m² for site two, while it was only 25.5 ± 2.0 for the Dejen area (Table 11 and Appendix C3). Thus, the levels of infestation were less than encountered in the previous year in both areas. Consequently grain losses were lower in both areas but proportional to the amount of damage. The higher yields recorded in 1984 may have been due to different locations being sampled in the same respective areas.

Infestation and yield percentages were plotted (Fig. 9) showing relative losses in yield due to red tef worm larvae.

Table 11. Percentages of yield loss from comparison of damaged and undamaged plots in Becho and Dejen areas in the 1983 and 1984 seasons.

Year	Area	From damaged plots			From undamaged plots	
		Mean No. larvae/m²	Yield kg/ha	% yield loss	Mean No. larvae/m²	Yield kg/ha
1983	Becho	125.7±4.6	1201± 9	18.7±1.8		1478±10
	Dejen	54.8±1.9	1186±14	8.1±0.9		1290±14
1984	Becho 1	87.3±3.5	1883± 7	13.7±1.4	4.8±1.1	2182±14
	Becho 2	80.1±2.7	1956± 5	12.7±1.1	5.6±1.1	2241±14
	Dejen	25.5±2.0	1623± 6	4.2±0.9	5.6±0.8	1675±11

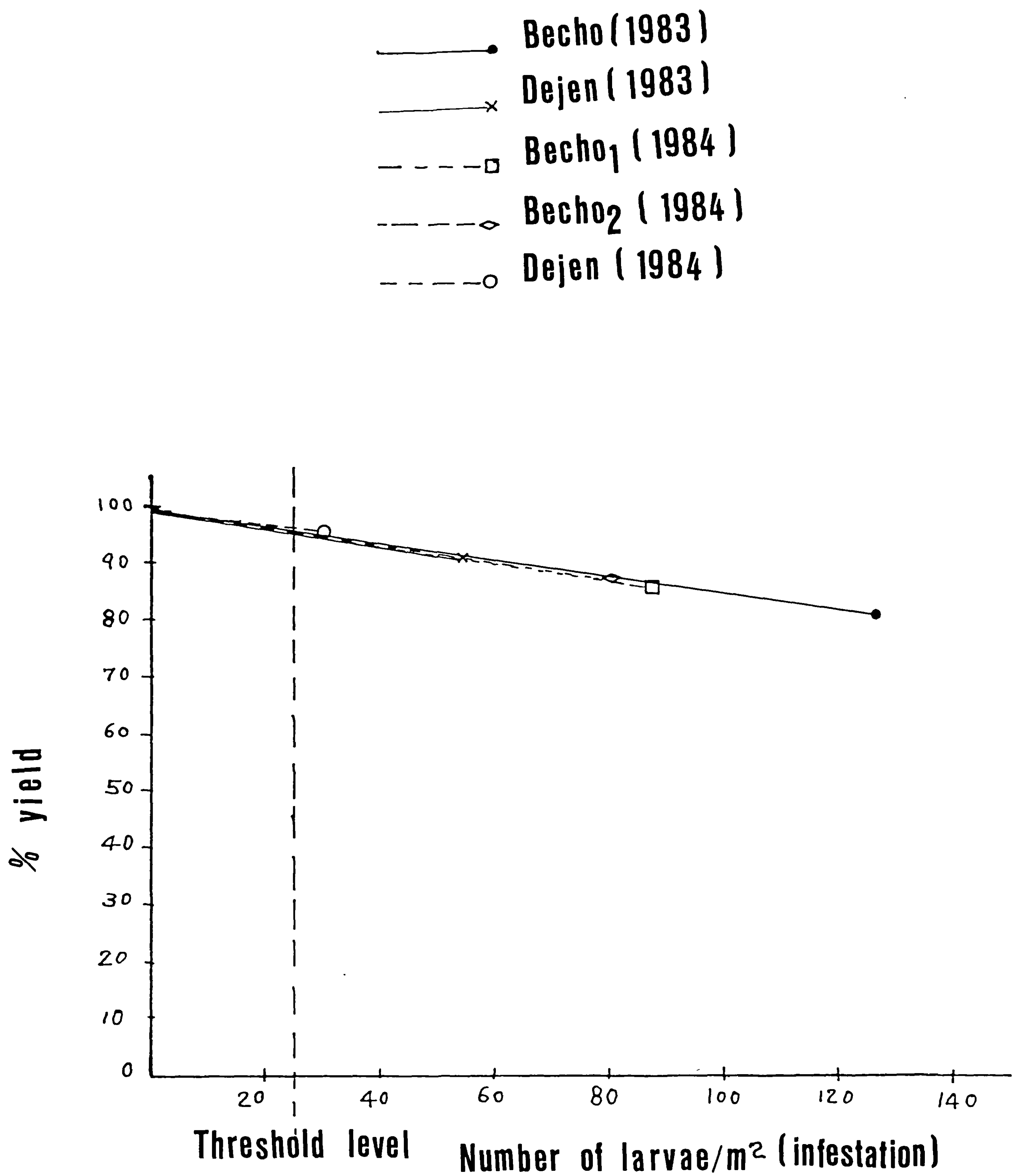


Fig. 9 Yield losses due to red tef worm in the Becho and Dejen areas in 1983 and 1984

9.4 Discussion

Harvests from the unaffected sites were considered to be the 100 percent expected yields for that site. Consequently, the economic loss was estimated by comparing the actual yield in the affected area with the expected yield for each site.

The relationship beteeen the level of red tef worm (larvae) population or injury is more or less linear with the loss in yield (Fig. 9). Walker (1977) pointed out that yields may be reduced proportionally as infestation increases.

Plant compensation by tef is possible when red tef worm attacks it prior to seed formation, as it occurs sometimes in the Becho area and quite often in other areas. Given optimum conditions, the tef plant tolerates injury and even produces more leaves and tillers to compensate for the lost parts. However, most of the critical infestations occur, especially in Becho, at the drier period in October when the tef plant produces its grain. Therefore, at this stage there is no time gap nor optimum condition for recuperative effect of the plants. Thus, direct economic loss occurs with losses proportional to the amount of injury unless attacks are prevented at the appropriate time. Hence, it is before the flowering period or before the grain development period that the plants become more tolerant to injury and usually a moderate infestation is much less likely to affect yield than late attacks.

No tef diseases were encountered in this study (or other parts of the general field studies of the whole project). Other pests such as African bollworm, semi-loopers and other lepidopterous larvae were encountered, but they were very few in number so accounted for less than one per cent of the total number of pests. Thus, yield losses of 4 per cent and above were caused principally by the red tef worm attack and are considered to be of economic significance and should be reduced by one spray application before such losses are incurred.

CHAPTER 10

CONTROL OF RED TEF WORM

10.1 Introduction

A new era of pest control started with the development of synthetic organic pesticides , the first insecticides, DDT and HCH (BHC) being followed by a wide range of pesticides: insecticides, fungicides, herbicides, nematicides and rodenticides. Because there seemed to be a direct relationship between yield and the amount of pesticides used, and persistent organochlorine products such as DDT were available, farmers often timed treatments on a calendar schedule. As a consequence, pest control came to rely on the use of chemicals.

Ripper (1944) realized very early that chemical controls were affecting natural controls, but it took several years for others to see that pesticide use was also creating problems: first existing pests were becoming resistant to chemicals; for example, the cotton bollworm (*Heliothis virescens* F.) has developed resistance at least in part of its geographical range and is practically resistant to all available insecticides (Adkisson, 1969); second, species previously only secondary pests because beneficial insects kept populations generally below damaging levels, have become primary pests (Luckmann and Metcalf, 1975).

Many workers (such as Isley and Baerg, 1924; Isley, 1926; Isler and

Fenton, 1931; Isley, 1934) practised integrated pest management before the introduction of DDT. However, the concept of integrated pest control was later articulated by entomologists (Smith and Allen, 1954; Stern et al, 1959) as an approach to applied ecological principles in utilizing biological and chemical control methods against insect pests. It was subsequently broadened to include all control methods (Smith and Reynolds, 1965). Scientific pest control has always required a knowledge of ecological principles, the biological intricacies of each pest and the natural factors that tend to regulate their numbers (Smith et al, 1976).

Many scientists, institutions and governments were thus encouraged to return to alternative measures of controlling pests such as biological control, cultural measures and plant resistance. The combined effect of biological and chemical methods, integrated control, has been defined as an applied pest control system that combines and integrates biological and chemical measures into a single unified pest control programme. Chemical control is used only where and when necessary, and in a manner that is least disruptive to beneficial regulating factors in the environment. It may make use of naturally occurring insect parasitoids, predators and pathogens as well as biotic agents which are artificially increased or introduced (NAS, 1969). Van den Bosch and Messenger (1973) defined integrated control as a pest population management system that utilizes all suitable techniques (and information), either to reduce pest populations and maintain them at levels below those causing economic injury or to so manipulate the populations that they are prevented from causing such injury. Its goal is the reduction of pest populations only to a level compatible with the economic production of the crop and the concurrent maintenance of environmental integrity.

Each control technique has a potential role to play in pest control, and as much as possible, use of plant resistance should dominate. However, no individual technique, most emphatically this includes pesticides, should be rejected from consideration in integrated systems. There are many pest problems, such as the African armyworm, for which the use of insecticides provides the only acceptable solution when an outbreak occurs, before a given crop is devastated. Pesticides are still widely used throughout the world and in practice have remained as the main tool in controlling pests. Newsom (1970) stated that the intelligent use of chemical insecticides is an ecologically sound and necessary component of modern pest management systems.

The use of chemical insecticides against crop pests results in generally increased crop yields, but also it could pollute the environment depending on how much is used and how much gets in the wrong place; at any rate, chemical control is a necessary tool and its use should be rationalized at all times (Bullen, 1970). The value of the crop yield per hectare has an important effect upon the economic viability of control measures.

Graham-Bryce (1977) pointed out that when an insect pest in a crop canopy had to be controlled, as little as 0.2 per cent of the applied insecticide was effective to suppress the infestation.

The dosage applied to pests in the field is very much greater than that required in laboratory bioassays, since only a small fraction of the pesticide reaches its intended target; but when foliage is the target, perhaps up to 30 per cent of a chemical is retained and absorbed into the leaves (Matthews, 1984). Sprays have to reach their intended target, and this can be achieved by using conventional hydraulic nozzles or by more novel means such as using spinning discs. The application of pesticides is made under a wide range of climatic conditions, and so spray performance must also involve a balance between adequate spray reaching and remaining on the target and reducing the risk of damage to other crops, particularly when using herbicides (Clipsham, 1980).

For spray application, some air movement is essential, but no spraying should be done under strong or very turbulent wind conditions liable to magnify the problem of drift considerably; in general, crop spraying should be avoided in the tropics in the heat of the day when wind conditions are more turbulent and air convection tends to carry small droplets upwards and restrict their penetration of foliage (Matthews, 1973). Thus, instead of spraying through the day, insecticide applications may be more effective if applied in the evening when conditions are more stable and many pests are more active (Johnstone et al, 1974). Besides, particularly controlled droplet application with minimal volumes permits more rapid spraying so timing can be improved and restricted to periods of favourable meteorological conditions (Matthews, 1977a), though farmers seldom do so but spray when they can.

Application techniques are seldom examined despite wide recognition that they are mostly extremely inefficient and that even small improvements could greatly improve biological effectiveness (Matthews, 1977b). Advice to farmers with a pest infestation may be merely to apply a particular amount of pesticide per hectare; yet when the pesticide is applied, only a small proportion of the pest population may be at a vulnerable stage or within that particular area being treated (Matthews, 1977b). As pointed out by Walker (1981), pests should be sampled when their effects on yield are at a maximum, that is, at a critical stage of crop growth.

The full potential of insect pathogens as control agents has yet to be realized. Although insect pathogens have long been observed to devastate insect populations under certain circumstances and attempts have been made for over a century to exploit micro-organisms as insecticides, they constitute a small portion of the total crop protection materials applied, and in part this is because of the striking successes achieved with chemicals in ridding crops of insect pests (Splittstoesser, 1981). However, the increasing occurrence of insect resistance to chemicals and public awareness of and concern for environmental quality, with the resultant removal of more toxic pesticides from the market and/ or restrictions placed on their use, have focused more attention on research and development of biological agents either as alternatives or in integrated programmes. So a biological agent, <u>Bacillus thuringiensis</u> Berl. bacterial preparation, was included in this study along with several chemical insecticides. _Bacillus thuringiensis_ (Bt) is widely used but biological agents in general need just as much safety testing, for example some can cause allergies (Matthews, personal communication).

Bt is probably the most versatile insect pathogen at present, as it is active against numerous lepidopterous larvae of economic importance and can be produced in large quantities. The continuing development of new and more active strains, better formulations and more stable products has added to the continously expanding uses of Bt. Preparations of Bt must be ingested to be effective and are typically applied as sprays or dusts to plant foliage (Splittstoesser, 1981). The effect on the majority of susceptible insects is due to the presence of toxic proteinaceous crystals (Cooksey, 1971; Faust, 1974; Faust; 1975) formed by the bacteria during sporulation.

In many instances, the Bt preparations are as effective as, or sometimes more effective than, the chemical pesticides recommended for a particular insect host system. According to Rezk _et al_. (1981), results of field tests carried out in Egypt to see the effectiveness of sprays of Bactospeine (a spore preparation of Bt) or chlorpyrifos (Dursban) at various rates for the control of _Spodoptera littoralis_ (Boisd.) larvae showed that Bactospeine was generally more effective than chlorpyrifos and gave good control. In field plot tests in North Carolina sprays of several commercial preparations of Bt applied at recommended rates were evaluated for the control of _Heliothis virescens_ (F.) on tobacco, and they were usually as effective at lower rates as higher rates

(Mistic and Smith, 1973). Sprays of Bacillus thuringiensis were as effective as endrin in preventing damage by Protoparce sexta (Joh.), although less effective initially in reducing larval populations (Guthrie et al., 1959).

Information was gathered both from farmers and extension agents on what farmers use to control red tef worm in the infestation areas. In Becho, which is the most important area where tef growers are conscious of the need to control red tef worm in order to save their crops from heavy losses, they said that the pest was around for a long time, but they started to control it using insecticides about seven to ten years ago with the help of the extension agents of the Ministry of Agriculture in Ethiopia. Among the products they applied as sprays were emulsifiable concentrate (e.c.) formulations of DDT and malathion . They also used DDT dust in the early period when they first started using chemicals, but they did not like it because it was not effective against the worms. Comparing the two insecticides which they had used, the farmers at Becho preferred to use DDT e.c. to malathion e.c. for the same reason. This preference was also confirmed by local extension agents. Farmers buy their stocks of insecticides either from the Ministry of Agriculture Extension Office at Teji at subsidized prices or from private traders at higher prices. They prefer to pay a higher price if they can get hold of DDT e.c. formulation. Thus, farmers in Becho have been using DDT repeatedly whenever they can get it. However,it has been confirmed that if relatively fresh stock of malathion e.c. formulation is applied at recommended dosage, good results could be obtained.

Since DDT is a broad-spectrum insecticide, its repeated use could cause disruption of the agroecosystem by killing natural enemies even though a relatively small quantity is applied every year. It should either be used alternatively with other insecticides or its use discontinued. As in many countries, DDT is now being excluded from the pesticides market in Ethiopia.

Heavy infestations have been rare in the Serbo area, so farmers have not used insecticides against red tef worm except for DDT dusts which were applied once or twice about four-five years ago when they had heavier infestations on their tef fields.

In the Dejen area red tef worm infestations are rarely severe, and farmers are not familiar with the use of insecticides except to control African armyworm against which sprays are applied either by the Ministry of Agriculture technicians or the Desert Locust Control Organization of Eastern Africa (DLCO-EA).

10.2 Dosage determination of emulsifiable concentrate (e.c.) and wettable powder (w.p.) formulations in pot tests

10.2.1 Materials and Methods

The effect of different dosages of insecticides was determined by treating larvae on tef plants grown in pots in a glasshouse, three organo-phosphorus (OP), one chlorinated hydrocarbon and one pyrethroid insecticide and one biocontrol agent were chosen to be used in this and subsequent field studies based on their relatively low mammalian toxicity, potential effectiveness against insects and availability. Most of them meet at least two of the criteria for choice.

Diazinon is a non-systemic OP insecticide with some acaricidal action, mainly recommended for a wide range of sucking and leaf-eating insects. The acute oral LD_{50} for rats is 300 - 850 mg/Kg. Fenitrothion is a contact OP insecticide recommended for control of a large number of lepidopterous pests. The acute oral LD_{50} for rats is 250 - 500 mg tech./Kg. Trichlorphon is a contact and stomach OP insecticide with penetrant action recommended for lepidopterous larvae and fruit flies. The acute oral LD_{50} for rats is 560 - 630 mg/Kg. Endosulfan is a broad spectrum chlorinated hydrocarbon, non-systemic, contact and stomach insecticide effective against numerous insects and certain mites attacking crops. The acute oral LD_{50} for rats is 80 - 240 mg tech./Kg; highly toxic to fish, but in practical use, it should be relatively less harmful to wildlife and bees. Cypermethrin is a stomach and contact pyrethroid insecticide effective against a wide range of insect pests, particularly leaf and fruit eating Lepidoptera. It has good residual activity on treated plants and no case of phytotoxicity has been reported; the acute oral LD_{50} for rats is 303 - 4123 mg/Kg (Worthing, 1979).

<u>Bacillus</u> <u>thuringiensis</u> Berliner is a bacterial biocontrol agent

and while harmless to humans, livestock and plants, has a good potential in the control of many lepidopterous pests (Steinhaus, 1951; Tanada, 1956).

Each insecticide was tested at three replicates with three dosage levels (Table 12) each with three pots. There were a total of 18 pots for each dosage level for all treatments. In each dosage level two pots were treated with a given insecticide and one pot was untreated. For each treatment 27 pots of tef were used including the untreated check pots.

Table 12. Treatments and dosage levels in ppm in the pot tests.

Treatments	Dosage level in ppm		
	1	2	3
diazinon 60% e.c.	360	480	600
fenitrothion 50% e.c.	400	500	600
trichlorphon 50% e.c.	400	600	800
endosulfan 35% e.c.	280	560	840
cypermethrin 25% e.c.	40	80	120
Bacillus thuringiensis w.p. (16,000 ITU/mg)	400	600	800
untreated check	-	-	-

Red tef worm larvae were reared to third instars and five larvae were placed in each pot and were left there for 24 hours prior to spraying with the respective dosage of insecticide. Each dosage was carefully measured with graduated cylinders or weighed on a sensitive balance and mixed with 125 ml of water. The sprays were applied with a small (0.5 litre capacity) hand sprayer until the leaves were wetted to "run-off", i.e. both pots at each dosage level were sprayed for five seconds. Dead and living larvae were counted 24 and 48 hours after application. Depending on the efficiency of larval kill, dosages were subsequently selected for field experiments.

10.2.2 Results

Larval mortality was low with most of the chemicals after 24 hours, except cypermethrin with over 95 per cent achieved at the highest dosage (Table 13). After 48 hours only a few larvae were present where trichlorphon had been applied, but more larvae survived the Bt treatment (Table 13). With endosulfan the best larval mortality occurred after 72 hours (Table 13) while that for trichlorphon was after four days and Bacillus thuringiensis w.p. preparation (Bt) after five days. Cypermethrin, fenitrothion and diazinon gave the best level of larval mortality with the second and third dosage levels at 48 hours after spraying.

Table 13. Percentage mortality after different periods following treatment

Treatment	Dosage level 1	2	3	Check
<u>After 24 hours</u>				
diazinon	33	70	76.7	2.2
fenitrothion	53.3	67.7	73.3	0
trichlorphon	30	36.7	50	0
endosulfan	46.7	63.3	70	0
cypermethrin	63.3	86.7	96.7	2.2
Bt	0	6.7	13.3	0
<u>After 48 hours</u>				
diazinon	73.3	100	100	4.4
fenitrothion	86.7	100	100	0
trichlorphon	56.7	63.3	83.3	0
endosulfan	76.7	86.7	96.7	0
cypermethrin	93.3	100	100	2.2
Bt	0	26.7	33.3	0
<u>After 72 hours</u>				
diazinon	83.3	100	100	4.4
fenitrothion	93.3	100	100	0
trichlorphon	67.7	76.7	86.7	0
endosulfan	86.7	93.3	100	0
cypermethrin	100	100	100	2.2
Bt	16.7	36.7	46.7	0

10.2.3 Discussion

The pot tests gave a satisfactory indication to determine or estimate what dosage would be effective in the field. The dosage applied to pests is usually very much greater than that required in laboratory bioassays, since only a small fraction of the pesticide reaches its intended target (Matthews, 1984). For this reason, minimum effective dosages obtained in the pot tests had to be increased to a higher level, in some cases, when applied in the field.

Most wastage of pesticide is undoubtedly due to the largest droplets which have a high terminal velocity and fall rapidly (Matthews, 1984). Even if large droplets impact on foliage, they are liable to bounce off, unless the amount of surfactant in the formulation increases retention (Merritt, 1980). Wastage of pesticides landing on non-target areas due to drift by wind or evaporation would be more pronounced in the small droplet sprays such as the ultra-low volume (ULV) formulations than in a coarser spray as used with the emulsifiable concentrate and wettable powder formulations mixed with water.

10.3 Additional small scale tests

10.3.1 Materials and methods

In another study, tests were carried out to determine the dosage at which 50 per cent mortality occurred. Ten third instar larvae were used at each dosage level using the same insecticides as previously and an untreated check. Three to seven dosage levels were used depending on how quickly the LD_{50} was determined. For each of the treatments and dosage levels (Table 14) ten larvae were established on each pot of tef plants 24 hours prior to spraying the insecticides made up in 50 ml of water and applied with a small hand sprayer until the plants were wet to "run-off". Larval mortality was checked and recorded at 24 hours after application.

Table 14 . Treatments and dosage levels in LD_{50} tests.

Treatments	Dosage levels in ppm
diazinon 60% e.c.	600,840,900,960 1020,1080
fenitrothion 50% e.c.	500,750,1000
trichlorphon 50% e.c.	700,1000,1300,1600,1700,1900
endosulfan 35% e.c.	490,700,910, 980,1015,1050,1120
cypermethrin 25% e.c.	50,100,125,150,
Bacillus thuringiensis (16,000 ITU/mg)	1000,1050,1600,1800,2000,2500

10.3.2. Results and discussion

The dosage needed to achieve 50 per cent larval mortality (Table 15) was greater compared with the dosages determined in the previous tests which were continued for 72 hours, except for cypermethrin, where mortality was much more rapid than with the other insecticides.

Table 15. Dosage level to achieve 50 per cent mortality

Treatment	Dosage in ppm
cypermethrin	125
diazinon	960
fenitrothion	1000
endosulfan	1015
trichlorphon	1900
Bacillus thuringiensis	2500

10.4 Small scale evaluation of ULV spraying

10.4.1 Materials and methods

Insecticides formulated for ULV application were studied in pot tests to determine the distribution of spray across swaths and the dosage level required to achieve effective control. In these tests plastic bowls containing tef plants, about 35 cm tall, were spaced in rows in an open space outside the laboratory. Five third instar larvae were transferred to each pot 24 hours prior to treatment with 5 per cent ULV cypermethrin, 50 per cent ULV fenitrothion or 25 per cent ULV endosulfan. These insecticides were sprayed with a hand-carried, battery-operated, spinning disc sprayer (Micron 'ULVA') with a 1.4 mm diameter restrictor (red). Tests were made with swaths of 3,6,9 and 12 metres, using ten pots for each swath width and 40 pots for each insecticide. While spraying the operator walked at approximately one metre per second along the edge of the swath holding the sprayer about 60 - 70 cm above ground level. Dead and living larvae were recorded at 24 and 48 hours after application.

Using the same technique the distribution of droplets per square centimetre was determined using a fluorescent tracer, Saturn yellow, mixed with each ULV insecticide, at 0.5 per cent concentration. After application, two leaves were removed at random from the centre of each pot and the number of droplets counted under ultra-violet (UV) illumination.

The most effective swath from these two observations, mortality and droplet density, were used in the field trials described below.

10.4.2 Results and discussion

Mortality decreased with increasing swath width (Table 16), but in all tests, mortality was very high even at the 12 m swath after 48 hours.

Table 16 . Treatments, dosage and mortality of red tef worm larvae

Treatment	Dosage g a.i./ha	Number of larvae	Percentage mortality at swaths 3 m	6 m	9 m	12 m
After 24 hours						
cypermethrin	106	50	96	90	86	78
fenitrothion	1167	50	90	92	82	72
endosulfan	519	50	84	74	68	60
After 48 hours						
cypermethrin	106	50	100	100	96	90
fenitrothion	1167	50	100	96	92	80
endosulfan	519	50	94	88	84	76

Table 17. Mean droplet counts per square centimetre of leaf surface

Treatment	Swaths			
	3 m	6 m	9 m	12 m
cypermethrin	53.2 ± 2.8	34.7 ± 3.5	27.5 ± 2.3	19.0 ± 1.2
fenitrothion	43.8 ± 2.4	34.8 ± 2.0	25.2 ± 1.9	17.9 ± 1.1
endosulfan	39.8 ± 1.9	27.1 ± 2.2	21.1 ± 2.2	16.3 ± 1.2

The change in mortality with swath width was affected by the number of droplets (Table 17), which decreased significantly at the wider swaths. Staniland (1960) introduced the use of fluorecent tracers as a quick method of qualitatively assessing the distribution of spray deposits, and on the basis of these results, the 3 to 9 metre swaths were selected for the field trials, the 12 metre swath being considered too wide especially as in the field wind conditions are likely to vary much more while spraying larger areas.

10.5 Observations on timing of sprays for the control of red tef worm

10.5.1 Materials and methods

In 1984, tef fields at two sites in Becho, about 2 km apart, within the Bantu Alito Farmers´ Association holdings were examined in the first week of October to detect whether eggs or young larvae of *M. ignicollis* were present. Second instar larvae were found and large plots (30 x 40 m) were laid out to compare early and late sprays applied to separate plots. The corners of each plot were pegged and before spraying, larvae were counted in five quadrats taken at randon across each diagonal of each plot. Early sprays were applied with the hand-held, battery-operated, spinning-disc sprayers (Micron ULVA) using 5 per cent ULV cypermethrin at 2.3 litres per hectare, while walking at 1 m/s. Larvae were counted three days after the spray application.

Two weeks after the first early spray, other plots were sampled prior to a late spray using the same insecticide and method of application. Again post-spray larval counts were made after three days. Farmers were spraying in these fields so it was not possible to continue these plots until harvesting.

10.5.2 Results and discussion

Larval mortality was satisfactory, whether early or late sprays of cypermethrin were applied (Table 18), although the timing was not based on a threshold, merely on the observation that eggs and young larvae were present. According to Walker (1981), pests should be sampled when an effect on yield would be expected to be at a maximum, that is at the most critical stage of crop growth. This coincided with the time of the late spray application, when farmers also decided to spray. Although early sprays appear to be promising, further studies are needed before any recommendations can be made.

Table 18 . Mean pre-spray and post-spray living larvae in plots sprayed either early or late.

Site	Time of spray	Larval counts (Number/m^2) Pre-spray	Post-spray
1	early	18.5 $\pm$ 1.1	0
	late	31.3 $\pm$ 2.0	0.3 $\pm$ 0.3
2	early	15.8 $\pm$ 1.7	2.0 $\pm$ 1.4
	late	37.8 $\pm$ 2.3	1.3 $\pm$ 1.1

10.6 Field assessments of red tef worm control

The control of red tef worm in the field was studied largely in the Becho area west of Addis Abeba and in the Serbo area near Jima town in the Kefa Administrative Region (Figure 1). The Becho area is mostly flat with black, deeply cracking soils which are water-logged and less weedy during the wet season. Tef occupies 60 - 80 per cent of the arable land in this area as it tolerates water-logged conditions. In the Serbo area, land is undulating with black soil in the valleys and red soil higher in the hills.

10.6.1 Materials and Methods

A field trial was sown on a smooth and compact seed-bed for good growth, fertilized and hand-weeded, but unfortunately the infestation was so light that no insecticide was applied. Surveys indicated heavier infestations on farmers´ fields in that area so an insecticide trial was superimposed on fields 10 km away from the original site, on the Bantu Alito Farmers' Association holdings. A randomized complete block design with seven treatments and four replicates was laid out with 3 x 4 m plots demarcated by 70 - 80 cm tall stakes easily seen above the tef crop.

A pre-spray larval count was made by throwing metal quadrats at random four times in each plot. The treatments and rates of application are shown in Table 19. The amount of insecticide for each treatment was mixed with water and applied using a lever-operated knapsack sprayer. A post-spray larval count was made at 48 and 72 hours after application. The stakes were left and with the field plan it was possible to harvest these plots, which were visited regularly so that crop maturity could be checked. The ripe tef was harvested with sickles and the sheaves taken in separate, labelled hessian sacks for each plot. At Holetta Research Station, the tef was dried, threshed, cleaned by hand, and weighed before the grain was returned to the farmers.

Table 19. Treatments and rates of application

Insecticide	Formulation	Dosage (g a.i./ha)
diazinon	60% e.c.	600
fenitrothion	50% e.c.	625
trichlorphon	50% e.c.	1000
endosulfan	35% e.c.	700
cypermethrin	25% e.c.	187.5
Bacillus thuringiensis	16000 ITU/mg	700

A similar field experiment was sited in one of the infestation prone black soil valleys of Serbo area but the infestation there was also too light to continue the experiment that year.

In 1984, the trial was repeated in the Becho area near Teji Village at another site, the Alengo Farmers´ Association area, where the infestation was high in the previous year. Once again the infestation was too low where the trial had been sited, so a trial was superimposed in another area where the infestation was heavy, at about 12 km north-west of Teji Village in the Kuncho Kelina Farmers´ Association area. The experiment was similar to the previous year.

Dead larvae were not considered in the data analysis because a large number of larvae affected by insecticide spray go down the cracks in the soil and never return to the plants, so a representative sample is impossible to obtain.

Undamaged and damaged areas of tef are illustrated in Plates 5 and 6 respectively while Plate 7 shows knapsack spraying on plots superimposed on farmers´ fields.

PLATE 5   Undamaged tef field in the Becho area

PLATE 6 Red tef worm damaged field with tef plants in the centre of which leaves and developing seeds (heads) have been stripped by feeding larvae

PLATE 7 Conventional spraying on experimental plots

10.6.2 <u>Results</u>

Mean pre-spray larval counts are shown in Table 20. Highly significant differences in the number of larvae on plots after spraying occurred in both seasons (Table 21) (see also Appendices D1 and D2).

Table 20. Mean pre-spray larval counts on field trials in 1983 and 1984

Insecticide	Number of larvae / m^2	
	1983	1984
diazinon	38.3	68.5
fenitrothion	71.3	66.5
trichlorphon	56.3	70.8
endosulfan	52.5	65.5
cypermethrin	52.3	64.5
Bacillus thuringiensis	69.5	71.5
untreated check	46.5	68.3
standard error	1.3	0.61

Table 21. Post spray larval counts /m^2 after 48 and 72 hours

Year	1983		1984	
Time after spray (h)	48	72	48	72
Insecticide				
diazinon	3.25 a *	2.50 a	5.50 a	2.50 a
fenitrothion	6.00 a	2.50 a	5.50 a	2.25 a
trichlorphon	7.00 ab	3.25 a	8.00 a	3.75 a
endosulfan	2.00 a	2.75 a	4.75 a	2.75 a
cypermethrin	1.50 a	0.25 a	1.50 a	0.50 a
Bt	19.25 b	10.75 b	25.25 b	11.00 b
untreated check	41.50 c	47.50 c	58.50 c	50.75 c
Means	11.5	9.9	15.6	10.5
C.V.	66.5	26.0	32.1	26.2
Standard error	3.82	1.29	2.50	1.38

* No significant difference between means followed by the same letter.

Table 22 . Yields from the two field trials (Dosages given in Table 19)

Treatment	Yield in kg/plot		Yield in kg/ha	
	1983	1984	1983	1984
	*			
diazinon	1.78 bc	2.79 c	1483	2325
fenitrothion	1.92 ab	3.08 ab	1600	2567
trichlorphon	1.60 cd	2.49 de	1333	2075
endosulfan	1.84 ab	2.93 bc	1535	2442
cypermethrin	1.95 a	3.23 a	1625	2692
Bt	1.51 d	2.45 e	1258	2042
untreated check	1.30 e	1.79 f	1083	1492
Means	1.70	2.68		
C.V.	5.6	6.5		
Standard error	0.05	0.09		

* No significant difference between means followed by the same letter

Duncan´s new multiple range test (Steel and Torrie, 1960) was used at the 5 per cent level of probability, and showed significant differences between the post-treatment larval counts and final yields. The coefficient of variation was high in 1983 for post-treatment larval counts, and significant differences occurred between some of the synthetic organic insecticides. Cypermethrin had the lowest larval population and yielded better than diazinon and trichlorphon in each trial. Cypermethrin was not significantly better than fenitrothion in either trial, or than endosulfan in the first one. All treatments, including Bacillus thuringiensis, yielded significantly better than the untreated check plots (Table 22 and Appendix D3). Although Bacillus thuringiensis treatment gave the lowest increase in yield, due to its greater selectivity it may be a suitable alternative in the long term. The overall range of yield increases from one spray application was 16 - 50 per cent in 1983 and 37 - 80 per cent in 1984.

10.6.3 Discussion

Larval populations were significantly reduced and yields increased with only one application of insecticide in both trials. As spraying of tef is likely to continue, cypermethrin is a first choice, although fenitrothion and endosulfan would be suitable alternatives. No insecticide should be used repeatedly season after season in order to avoid even the slightest possibility of selecting a resistant population. A general spraying programme of alternating pyrethroids such as cypermethrin and an organophosphate, such as fenitrothion between areas and seasons is suggested. Caution should be made with the use of diazinon because the formulation used caused some phytotoxicity to tef plants at dosages higher than the ones used.

Bacillus thuringiensis has a good potential in the control of red tef worm, but needs to be used only on young larvae, e.g. second instar, due to its slow action, even though such small larvae do not pose such a threat to the yield, particularly if they come before the critical stage of crop growth when heading or seed production takes place.

10.7 Field assessment of ULV formulations and swaths for the control of red tef worm

The effectiveness of three ULV formulations and three swaths was studied in the Bantu Alito and Kuncho Kelina Farmers´ Associations areas of Becho near Teji Village in the Shewa Administrative Region, in both 1983 and 1984 seasons.

10.7.1 Materials and Methods

The Becho area was surveyed and when heavily infested fields were detected, a split-plot design with two replications was superimposed on farmers´ fields. The main plots were 30 x 24 metres for different insecticide treatments, with sub-plots for swaths of 3, 6 and 9 metres and an untreated check. The insecticides and dosages are given in Table 23.

Table 23 ULV formulations used and the dosages applied for the control of red tef worm

Insecticide		Dosage (g a.i./ha)
fenitrothion	50% ULV	1150
endosulfan	25% ULV	500
cypermethrin	5% ULV	110

The insecticides were sprayed with a hand-carried, battery-operated, spinning disc sprayer (Micron 'ULVA 8') fitted with a red restrictor (1.4 mm in diameter). The ULV sprays were applied in the evening or late afternoon when the larvae had left the shade or the cracks in the soil and climbed the plants to feed on the tef. Pre-spray larval counts were taken in half-metre quadrats taken at random eight times along each swath including the untreated swath. One sprayman did all the treatments to minimize variations in walking speed at approximately 1 - 1.3 m/s. Wind velocity varied between about 5 and 7 km/h with the wind direction approximately at right angles to the walking line. The spray disc was held at about 0.5 m above the crop, but when the wind velocity increased slightly, it was lowered to 0.4 or 0.3 m to minimize drift. Post-spray counts of larvae were made 48 and 72 hours after spray application. Dead larvae were not included in the data for reasons explained above.

10.7.2 Results

Forty-eight hours after spray application, the mean number of living larvae was reduced to between 0.3 and 5.5 per square metre for the treated plots, while the untreated check populations remained between 51 and 67 per square metre in both trials (Table 24) (see also Appendices El and E2). Lower counts were obtained after 72 hours, but there was no significant difference between the counts (Appendices E3 and E4). Numbers of larvae were low irrespective of the swath width used, although there was a trend to a higher number on the widest swath. There was no significant difference between replications or insecticides in both seasons, but the number of larvae was significantly greater on the untreated check ($P<0.001$). A significant interaction between the swath and insecticides occurred in the second season ($P<0.05$), which showed that the two groups of factors were not independent of each other.

Table 24. Mean pre- and post-treatment larval counts in the ULV sprayed areas (Numbers/m^2)

Treatment	Swath width in metres							
	1983 trial				1984 trial			
	3	6	9	C	3	6	9	C
Pre-spray larval counts								
fenitrothion	89.0	71.8	109.0	67.3	83.8	92.0	77.8	78.0
endosulfan	69.3	74.0	63.8	77.0	90.0	82.5	84.0	86.3
cypermethrin	71.3	75.8	63.0	76.0	90.0	83.5	91.3	85.8
S.E.	2.1	1.1	3.6	2.3	2.0	2.3	2.3	1.8
Post-spray larval counts (48 hours)								
fenitrothion	0.5	5.5	3.5	62.5	1.3	3.5	5.5	51.8
endosulfan	1.3	2.5	4.3	61.3	0.8	1.5	3.3	67.0
cypermethrin	0.3	1.0	1.0	65.5	0.2	1.0	1.3	65.8
S.E.	0.6	1.2	0.8	2.1	0.5	1.0	1.1	1.9
Post-spray larval counts (72 hours)								
fenitrothion	0	0	0.8	52.5	0.3	1.0	1.5	54.0
endosulfan	0.3	0.5	0.8	55.6	0	0.8	1.8	49.0
cypermethrin	0	0	0.7	61.0	0	0.5	0.8	61.0
S.E.	0.3	0.3	0.3	3.3	0.3	0.5	0.4	1.6

C is untreated check.

Yields could not be measured on such large plots.

10.7.3 Discussion

All ultra-low volume insecticides gave satisfactory control of red tef worm, but on the basis of their toxicity to non-target organisms, particularly fish (Worthing, 1979), in case of drift, cypermethrin and fenitrothrion would be safer to use than endosulfan. Since endosulfan is an organo-chlorine insecticide, and may have an adverse effect on certain natural enemies, it should be used cautiously as an alternative ULV formulation for the control of red tef worm infestations.

Ultra-low volume (ULV) spraying of pesticides at less than five litres per hectare has the advantage of increasing substantially the work capacity of the operator. Under many circumstances, improved spray collection has been obtained in the target area, plant or insect (Joyce, 1968), so it reduces the cost of application. The efficiency of ULV spraying is such that at a time of threatening populations of red tef worm, it can be used to treat large areas of tef crops in a relatively short period of time, thus avoiding losses which may not be prevented with a conventional spraying operation which requires more man-days per hectare.

Hand-held spinning disc sprayers such as the Micron ULVA ´8´ used in this field experiment are therefore an ideal alternative to conventional hydraulic knapsack sprayers, being particularly attractive to small-holding farmers or even farmers´ associations especially in areas where water is scarce.

The main advantages of hand-held spinning disc sprayers and ULV spraying as observed on red tef worm control operation studies are;

a) Ease of operation, battery powered

b) Waterless spraying, ready-to-use formulation

c) Improved timing and higher rate of work

d) Small droplets resulting in improved coverage

e) Improved adherence to and/or penetration into plant canopy

f) No ´run-off´ of insecticides (no wastage of products) and better rainfastness compared to conventional spraying.

One of the disadvantages could be that since the droplets are very small, they are easily affected by stronger wind velocity thus increasing the risk of drift to non-target areas.

The success of good coverage depended on sufficient droplets penetrating the canopy and collecting on the surfaces of tef plants along which the larvae move as reported by Bals (1979). If the nozzle is flooded with liquid spray, very large droplets are formed; but if used correctly, droplet size can be controlled by the speed of rotation. The range of droplet sizes with the spinning disc sprayer is generally narrower than with other types of nozzles, but the rotational speed decreases as the batteries are exhausted (Johnstone et al, 1973) and flow rate affected by viscosity also influences droplet size (Matthews, 1971). As wind velocity frequently changed, narrow overlapping swaths were used so that some droplets were thrown directly from the disc between the plants. Narrow swaths in effect provide more release points just as do more nozzles with the conventional spraying technique, but the main factor affecting spray penetration is droplet size (Matthews, 1977b). Himel (1969) referred to the optimum droplet size as that which gave maximum control using a minimum amount of insecticide and a minimum ecosystem contamination. Droplet sizes most suitable for deposition throughout most foliage are in the range 41 - 100 micrometres (Himel, 1969; Joyce, 1975). The Micron ULVA ´8´ used in the red tef worm control studies produce droplet sizes of such range (Matthews, 1979) that the spray coverage was satisfactory. The sites for deposition of pesticides can now be more accurately defined and, for impaction on a particular target (such as that on tef crop), pesticides can be confined more efficiently to the target area (Matthews, 1977b).

There was no statistical difference among treated swaths; all of them gave satisfactory results with regard to larval mortality. However, the 3 m swath is too narrow to use because, requiring more time, it consumes more power from the batteries and could use more insecticide. The 9 m swath is too wide especially if the wind velocity drops below 6 km/hour. Thus, the 6 m swath is a satisfactory compromise.

Movement of droplets after release from a nozzle depends on their size, wind velocity and direction and height of release above the crop (Matthews, 1979).

A swath width of 6 metres is generally recommended for the control of red tef worm because considering the factors which affect movement of droplets from the 50 cm height of release, it is ideal for satisfactory coverage throughout the plant foliage or canopy. Since the larvae of M. ignicollis move up and down the tef plant to shades and cracks of the soil for hiding during the heat of the day, good spray coverage is essential.

While conventional spraying will remain the choice of individual farmers for the control of red tef worm as they have the experience and equipment, ULV spraying with the hand-held spinning disc sprayers has a good potential for farmers' cooperatives and farmers' associations who work in groups. Some members of these groups can be trained as operators of ULV spraying by extension agents to handle pest control or crop protection activities including scouting tef fields for red tef worm and also other crops and pests. However, the availability and cost of batteries could pose a problem.

Efforts should be made to employ some of the cultural and other alternative methods of reducing the population of red tef worm. Nevertheless, until such time that satisfactory, non-chemical methods of control are found through further research work, insecticides will remain the first line of defence in red tef worm control when larval populations reach threatening economic injury levels, because the prime benefits of insecticidal treatments are economy, speed, persistence and good yield (Watson et al., 1975).

CHAPTER 11

SUMMARY

11.1 The light pinkish eggs, spherical in shape and with longitudinal ridges are laid singly or in batches ranging from two to over 300 per batch, sometimes in two or three layers. On average 1031.6 ± 24.8 eggs per female were oviposited in the laboratory. Eggs hatch in about 4 to 7 days and the mean larval-developmental period with six instars was 32.9 ± 2.5 days. The average pupation period was 30.9 ± 3.4 days.

11.2 Moths have an average wing span of 3.4 cm and forewings with three easily recognizable black and dark-brown patches on the leading edge of each wing in both sexes. They lived, on average, 17 days with females living slightly longer than males.

11.3 Four generations were estimated in the field with the main generation causing damage to tef crops appearing in the period between September and November.

11.4 Larvae feed at night actively on tef leaves and developing heads while the seeds are in their milky stage. During the day most larvae hide under shade and in cracks in the soil and come out in the evening to feed through the night.

11.5 Feeding tests showed that two cultivated crops, wheat and barley were possible alternative hosts and two wild grasses, Digitaria scalarum and Phalaris paradoxa were actual alternative hosts of red tef worm.

11.6 *M. ignicollis* may continue to breed at low population levels in green patches, water ways or river beds, but most survive the dry season as pupae in the soil, probably in a diapause.

11.7 Of the three areas sampled for red tef worm populations, Becho was the only area in which a steady increase of larval numbers occurred over the four seasons studied (1981-1984). In Serbo and Dejen areas no clear increase or decrease in larval numbers was detected. The critical period of larval population increase and thus infestation of tef crops in the Becho area would be between the second week and end of October when farmers should check their fields frequently before economic damage occurs.

11.8 Light traps showed that catches began in July at Ambo and June at Holetta. Peak catches in September for Ambo and July and September for Holetta gave a prior warning of larval infestations at Becho in October.

11.9 *M. ignicollis* was found in Southern Africa (Pinhey, 1975) and in many other African countries under different genus (Georyx) (Berio, 1955), but it is not important as an economic pest. In

Ethiopia, though it has been recorded in other regions; the major, tef growing, infestation areas to date are Becho (Shewa), Serbo (Kefa) and Dejen (Gojam).

11.10 Only one parasitoid wasp, Enicospilus rudiensis Bischoff (Hymenoptera: Ichneumonidae) was obtained from rearing larvae. Crows and other small birds, ants, carabid beetles and spiders are important predators. One type of bacterial pathogen (Bacillus thuringiensis)was identified at SPL from diseased red tef worms.

11.11 An economic threshold level of 25 larvae per square metre was determined for Becho and 30 larvae per square metre estimated for other areas.

11.12 Mean percentage yield losses determined ranged between 4.2 ± 0.9 and 18.7 ± 1.8 in the 1983 and 1984 seasons, and such range is within an economic loss level.

11.13 In the pot tests, the emulsifiable concentrate formulations gave high percentages of larval mortality 48 hours after treatment while Bt (w.p.) gave good control after 5 days. Similar trends were observed in the 50 per cent mortality tests with all of the e.c. and w.p. formulation.

11.14 ULV sprays, particularly cypermethrin, gave high larval mortality 24 and 48 hours after treatment in the laboratory and were effective in the field.

11.15 Early field sprays were very effective but should be studied further.

11.16 The best larval mortality and yield over the untreated check were obtained with cypermethrin, fenithrothion, endosulfan and diazinon in the field assessments of red tef worm control using e.c. formulations. Trichlorphon e.c. and Bt w.p. were very slow in their effect on larval mortality.

11.17 Sprays applied with a 6-metre swath gave the best compromise as narrow, 3 m swaths, involved more power consumption and the wider, 9-metre swaths, gave lesser coverage due to changes in wind strength and density.

11.18 Only one, correctly timed, insecticide spray per season is needed to reduce crop losses due to red tef worm infestations to below economic levels, but adequate field checks are needed to optimise its timing.

CONCLUSION

Walker (1981b) pointed out that the assessment of pests or their effects is important, if not essential, for six main purposes: to study the biology of pests; to survey pests, in place and time; to assess the effects of pesticide trials; to relate to crop losses and to develop economic thresholds and in all aspects of pest management. These objectives have been used to gain information needed to provide overall management of red tef worm.

Inevitably in the time available the amount of information obtained has been limited and appropriate facilities were not available for certain investigations, such as possible use of pheromones. Further studies should continue to improve the assessment of economic threshold levels, the importance of natural enemies and alternative hosts and whether control methods other than by insecticides can be developed. The chemical control programme, however, provides a minimal input which can increase yields by at least 30 per cent on well managed tef crops.

ACKNOWLEDGEMENTS

I am greatly indebted to my supervisor, Dr. G. A. Matthews, for his supervision, useful advice and encouragement throughout the research programme and his visit to Ethiopia while I was carrying out laboratory and field studies of the project; his invaluable help and consistent guidance during the preparation of the thesis are also gratefully acknowledged.

I wish to express my sincere gratitude to Alemu Kebede, Kemal Ali and Adugna Haile of the Entomology Section, Holetta Research Station (IAR) and Bayssa Mormene and other staff members of the Coffee Entomology section at Jima Research Station (IAR) for their unreserved assistance in the laboratory and field studies of red tef worm.

I extend my thanks to Mulugeta Negeri, Dr. S. Chekmenev, Dr. Titov and Abdulhafiz Ahmed of the Entomology Section, SPL, Ambo, for their assistance in some parts of the study of the biology of red tef worm.

I am also grateful to Rezene Fisehaye and other staff members of the Weed Science Section, Holetta Research Station, for the identification of alternative, wild host plants.

I express my thanks to Dr. Getinet Gebeyehu and Dr. Mesfin Amha, officers-in-charge of Holetta and Jima Research Stations (IAR) respectively, for the provision of transport to field survey and experiment areas.

I wish to thank Dr. J. D. Holloway of the CIE and the British Museum for confirmation of identification and provision of some information.

My thanks are due to Ms D. Ragg, Mr A. Arnold and Mr. E. W. Thornhill of the International Pesticide Application Research Centre (IPARC) for their cheering up and help in various ways. I am also thankful to the administrative, secretarial, office and other services personnel of the Imperial College at Silwood Park for their full cooperation in many ways.

I am grateful to all my colleagues at Silwood Park, particularly to Kwame Afreh Nuamah and his wife, Joyce, for their companionship, encouragement and cheering up.

The financial and material support by FAO and the Institute of Agricultural Research of the Socialist Government of Ethiopia which made this study possible is gratefully acknowledged.

I wish to thank Mrs. M. Matthews for her encouragement and for typing the manuscript neatly and efficiently.

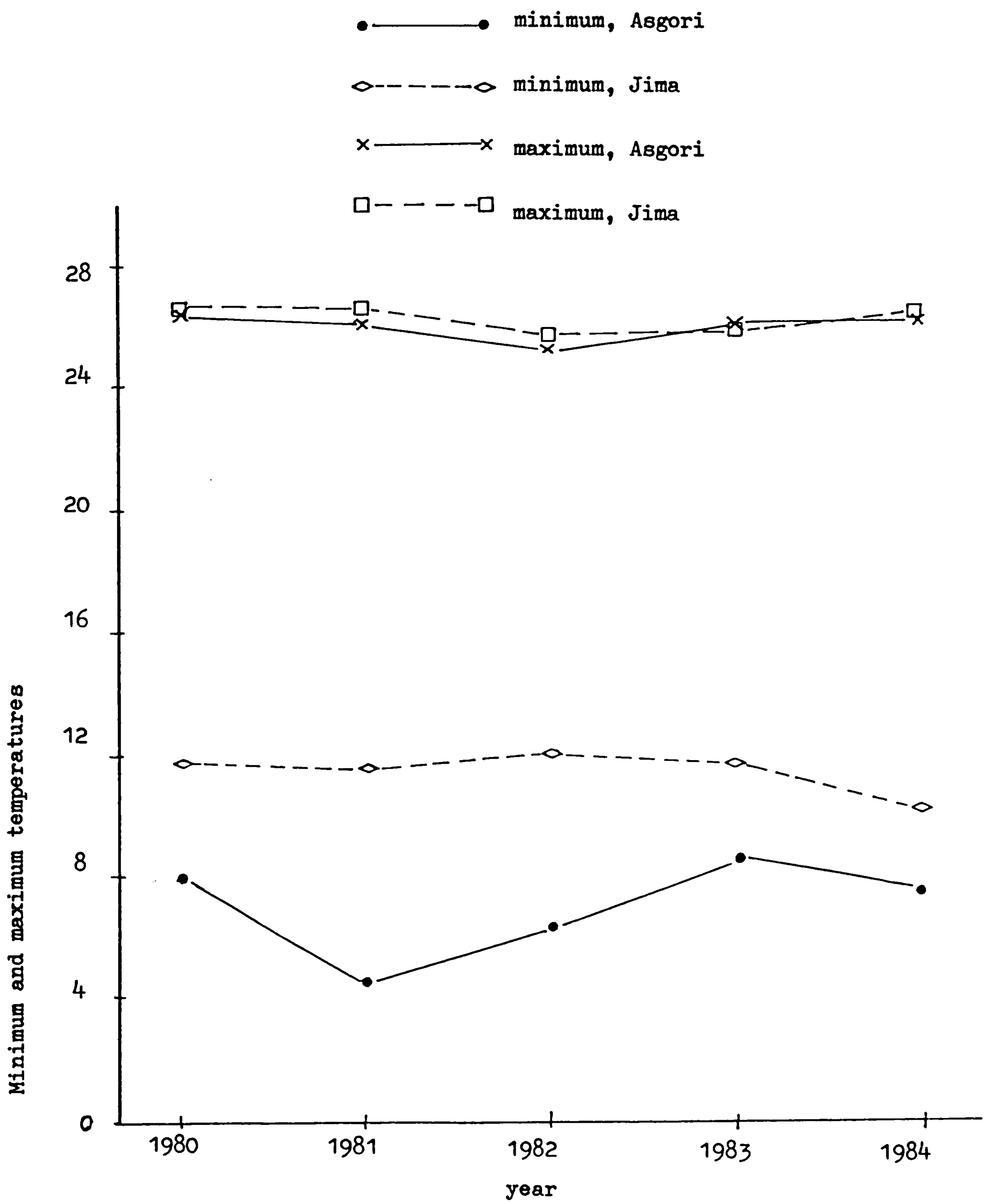
I would like to express my deepest gratitude to my friend, Dr. Desta

Beyene, and his wife, Hewan; my brother, Tsehaye and other friends and relatives for their earnest and constant support and encouragement to me and my family throughout the study period.

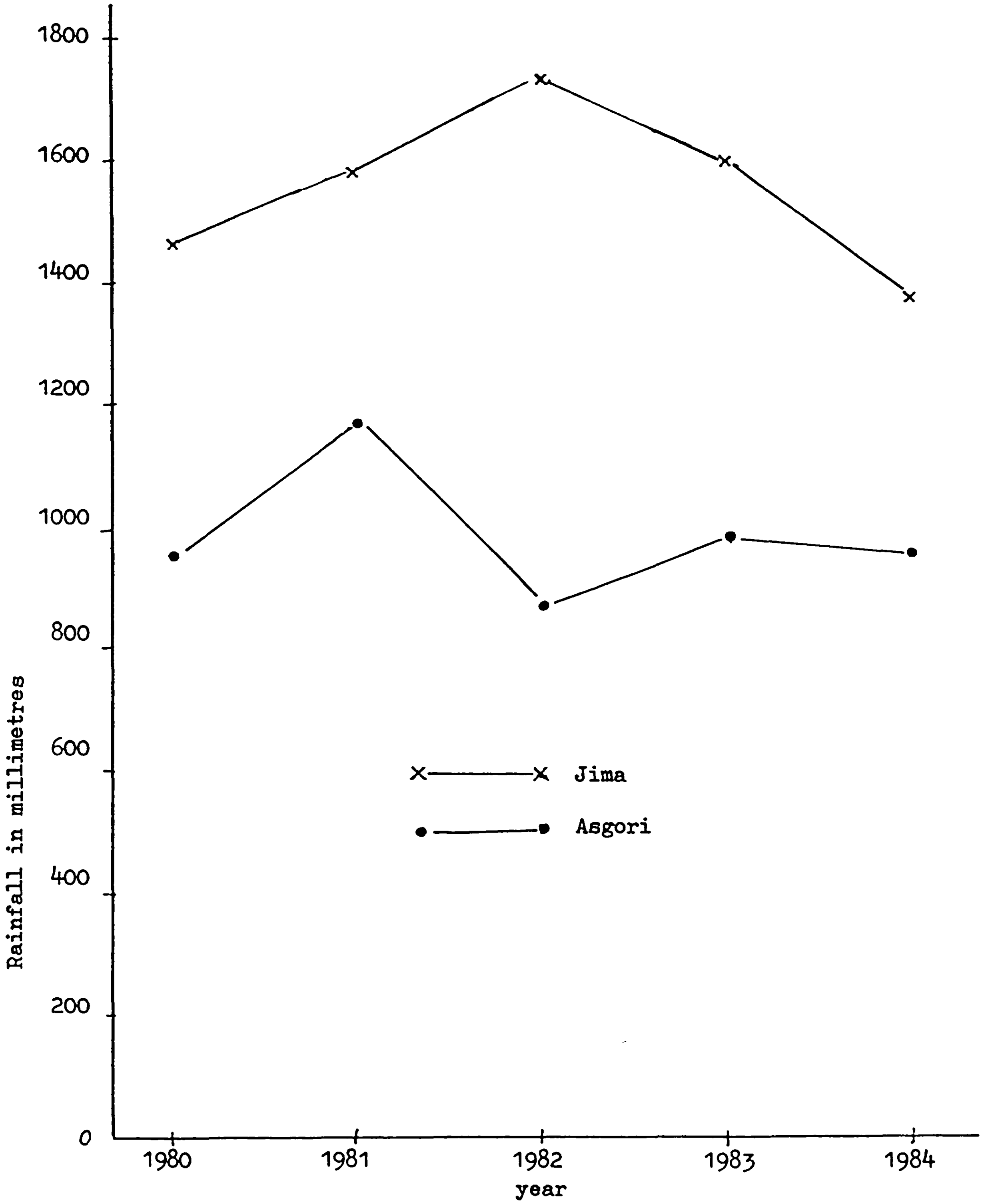
Finally, I wish to extend my special thanks to my wife, Zewdi, for her unfailing support and encouragement to me and her constant dedication and sole responsibility for our children throughout the project period.

APPENDICES

APPENDIX A 1. Annual mean minimum and maximum temperatures for Asgori and Jima in the 1980 - 1984 seasons.



APPENDIX A2. Annual total rainfall for Asgori and Jima for the period 1980 - 1984.



APPENDIX B1

Mean pre-spray and post-spray larval counts per square metre in the threshold studies of the 1981 and 1982 seasons in four areas at Becho.

Season	Area	Treatment	Blocks				Mean larval No./m²	
			I	II	III	IV	Pre-spray	Post-spray
1981	1	DDT	48	39	57	81	56.3 ± 4.2	
	1	Check	35	45	76	62	54.5 ± 4.3	
	2	DDT	83	51	65	53	63.0 ± 3.8	
	2	Check	67	20	75	70	58.0 ± 5.1	
	1	DDT	3	1	2	4		2.5 ± 1.1
	1	Check	36	43	74	64		54.3 ± 4.2
	2	DDT	4	0	2	1		1.8 ± 1.3
	2	Check	63	21	72	67		55.4 ± 4.8
1982	1	DDT	68	43	73	89	68.3 ± 4.4	
	1	Check	40	36	82	77	58.8 ± 4.9	
	2	DDT	38	44	66	56	51.0 ± 3.5	
	2	Check	28	59	60	49	49.0 ± 3.9	
	1	DDT	3	3	2	5		3.3 ± 1.1
	1	Check	41	34	78	79		58.0 ± 4.9
	2	DDT	0	2	2	4		2.0 ± 1.3
	2	Check	29	55	62	45		47.8 ± 3.8

APPENDIX B2

Yields in g/plot and kg/ha and percentage yield losses in the threshold studies of the 1981 and 1982 seasons in four areas at Becho.

Season	Area	Treatment	Yields in g/plot				Mean Yield in
			I	II	III	IV	kg/ha
1981	1	DDT	995.0	955.8	871.2	909.6	1555 ± 12
	1	Check	943.3	891.8	773.6	825.9	1431 ± 14
	2	DDT	903.0	831.6	838.8	981.0	1481 ± 14
	2	Check	810.1	804.9	745.3	880.2	1350 ± 12
1982	1	DDT	1077.5	1099.2	1053.6	1018.8	1771 ± 10
	1	Check	1013.5	1040.4	925.2	902.2	1617 ± 14
	2	DDT	1128.6	1057.2	1101.0	1073.4	1817 ± 9
	2	Check	1081.7	964.5	1002.9	995.3	1685 ± 11
			Percentage yield loss / replicate				Mean % loss
1981	1		5.2	6.7	11.2	9.2	8.0 ± 1.6
	2		10.3	3.2	11.1	10.3	8.8 ± 1.9
1982	1		5.9	5.3	12.2	11.4	8.7 ± 1.9
	2		4.2	8.8	8.9	7.3	7.3 ± 1.5

APPENDIX C1

Estimates of the extent of damage by red tef worm and assessment of yield losses by comparing damaged and undamaged plot samples from farmers' fields in the Becho area - 1983.

	From red tef worm damaged plots							From adjacent undamaged plots	
Sample	Number per square metre				Yield			Yield	
	larvae	plants damaged	plants undamaged	plants total	g/m^2	kg/ha	% loss	g/m^2	kg/ha
1	108	432	1226	1658	123.1	1231	16.4	147.2	1472
2	101	427	1319	1746	128.8	1288	15.0	151.5	1515
3	120	551	1018	1569	114.2	1142	18.2	139.6	1396
4	117	468	1322	1790	131.0	1310	18.8	161.3	1613
5	112	381	909	1290	107.7	1077	17.0	129.8	1298
6	161	656	1033	1689	113.8	1138	24.0	149.7	1497
7	118	552	1143	1695	130.3	1303	16.9	156.8	1568
8	116	497	985	1482	114.8	1148	15.5	135.9	1359
9	162	672	1079	1751	120.7	1207	24.6	160.1	1601
10	142	586	1092	1678	116.8	1168	20.2	146.4	1464
Total	1257	5222	11126	16348	1201.2	12012	186.6	1478.3	14783
Mean	125.7	522.2	1112.6	1634.8	120.1	1201.2	18.7	147.8	1478.3
S.E ±	4.6	9.9	11.8	12.3	2.8	8.9	1.8	3.2	10.2

APPENDIX C2

Estimates of damage by red tef worm and assessment of yield losses by comparison of damaged and undamaged plot samples from farmers' fields in the Dejen area - 1983.

From red tef worm damaged plots — From adjacent undamaged plots

Sample	Number per square metre				Yield			Yield	
	larvae	plants damaged	plants undamaged	plants total	g/m²	kg/ha	% loss	g/m²	kg/ha
1	55	351	1151	1502	111.8	1118	8.4	122.0	1220
2	56	483	1120	1603	124.4	1244	9.1	136.8	1368
3	50	315	735	1050	94.6	946	7.6	102.4	1024
4	54	417	1013	1430	106.9	1069	7.2	115.2	1152
5	51	375	1334	1709	148.2	1482	6.7	158.8	1588
6	57	426	1119	1545	113.8	1138	8.2	124.0	1240
7	52	390	996	1386	99.0	990	8.0	107.6	1076
8	62	469	1329	1798	149.3	1493	9.4	164.8	1648
9	53	386	1226	1612	129.9	1299	7.5	140.4	1404
10	58	432	1043	1475	107.7	1077	9.0	118.4	1184
Total	548	4044	11066	15110	1185.6	11856	81.1	1290.4	12904
Mean	54.8	404.4	1106.6	1511.0	118.6	1185.6	8.1	129.0	1290.4
S.E ±	1.9	7.2	13.3	14.3	4.4	13.8	0.9	4.6	14.4

APPENDIX C3

Yield losses from comparison of damaged and undamaged samples of tef in the Becho and Dejen areas in the 1984 season.

A. Becho (1)

Stratum	Sample	Mean number larvae/ m^2	Mean yield g/m^2	Yield kg/ha	Percentage yield loss
1	Damaged	98.4	184.4	1844	15.5
2	"	88.5	187.9	1879	13.9
3	"	92.4	186.6	1866	14.5
4	"	70.0	194.2	1942	11.0
Mean		87.5 ± 3.5	188.3 ± 2.1	1883 ± 7	13.7 ± 1.4
1	Undamaged	4.0	231.3	2313	
2	"	5.6	205.1	2051	
Mean		4.8 ± 1.1	218.2 ± 4.3	2182 ± 14	

B. Becho (2)

1	Damaged	74.0	198.1	1981	11.6
2	"	83.2	194.7	1947	13.1
3	"	76.4	197.2	1972	12.0
4	"	90.0	192.3	1923	14.2
Mean		80.9 ± 2.7	195.6 ± 1.6	1956 ± 5	12.7 ± 1.1
1	Undamaged	6.4	210.4	2104	
2	"	4.8	237.8	2378	
Mean		5.6 ± 1.1	224.1 ± 4.4	2241 ± 14	

C. Dejen

Stratum	Sample	Mean number larvae/ m^2	Mean yield g/m^2	Yield kg/ha	Percentage yield loss
1	Damaged	24.4	161.0	1610	3.9
2	"	23.6	161.2	1612	3.8
3	"	22.4	161.5	1615	3.6
4	"	31.6	158.4	1584	5.5
Mean		25.5 ± 2	162.3 ± 1.8	1623 ± 6	4.2 ± 0.9
1	Undamaged	5.2	175.3	1753	
2	"	6.0	159.8	1598	
Mean		5.6 ± 0.8	167.6 ± 3.3	1676 ± 11	

APPENDIX D1

Analysis of variance for post-spray count of living larvae 48 and 72 hours after chemical application (1983).

Source of variation	degrees of freedom	Sums of squares	Mean square	Observed F	Expected F 5%	Expected F 1%
blocks	3	282.43	94.14	1.61NS	3.16	
treatments	6	5075.50	845.92	14.48**		4.01
error	18	1051.50	58.42			
total	27	6409.00				
blocks	3	17.86	5.95	0.89NS	3.16	
treatments	6	6849.86	1141.64	171.16**		4.01
error	18	120.14	6.67			
total	27	6987.86				

** highly significant at the 1% level.

APPENDIX D2

Analysis of variance for post-spray count of living larvae 48 and 72 hours after chemical application (1984).

Source of variation	degrees of freedom	Sums of squares	Mean square	Observed F	Expected F 5%	Expected F 1%
blocks	3	31.15	10.38	0.41NS	3.16	
treatments	6	10047.36	1674.56	66.93**		4.01
error	18	450.35	25.02			
total	27	10528.86				
blocks	3	24.43	8.14	1.07NS	3.16	
treatments	6	7832.00	1305.33	171.98**		4.01
error	18	136.57	7.59			
total	27	7993.00				

** highly significant at the 1% level.

APPENDIX D3

Analysis of variance for yield (1983 and 1984)

Source of variation	degrees of freedom	Sums of squares	Mean square	Observed F	Expected F 5%	1%
1983 Season						
blocks	3	0.01	0.0033	0.37NS	3.16	
treatments	6	1.38	0.2300	25.84**		4.01
error	18	0.16	0.0089			
total	27	1.55				
1984 Season						
blocks	3	0.69	0.23	7.67**		5.09
treatments	6	5.71	0.95	31.67**		4.01
error	18	0.46	0.03			
total	27	6.86				

** highly significant at the 1% level.

APPENDIX E1

Analysis of variance on the effect of ULV formulation and swaths on the control of red tef worm, post-spray larval count 48 hours after insecticide application (1983)

Source of variation	degrees of freedom	Sums of squares	Mean square	Observed F	Expected F 5%	Expected F 1%
(main plots)	5	203.55	40.71			
replications	1	0.26	0.26	0.0026NS	18.51	
insecticides	2	4.77	2.39	0.0241NS	19.00	
error (a)	2	198.52	99.26			
(sub-plots)	23	17352.49	754.46			
swaths	3	16721.37	5573.79	131.99**		6.99
interaction	6	47.48	7.90	0.1871NS	3.37	
error (b)	9	380.09	42.23			

CV (a) = 28.6%: CV (b) = 18.7%

** Highly significant at the 1% level of probability.

APPENDIX E2

Analysis of variance on the effect of ULV formulation and swaths on the control of red tef worm, post-spray larval count 48 hours after insecticide application (1984)

Source of variation	degrees of freedom	Sums of squares	Mean square	Observed F	Expected F 5%	Expected F 1%
(main plots)	5	95.68	19.14			
replications	1	8.76	8.76	0.30NS	18.51	
insecticides	2	27.90	13.95	0.47NS	19.00	
error (a)	2	59.02	29.50			
(sub-plots)	23	16395.99	712.87			
swaths	3	15936.28	5312.09	604.33**		6.99
interaction	6	284.94	47.49	5.40*	3.37	
error (b)	9	79.09	8.79			

CV (a) = 16.1%: CV (b) = 8.8%

** Highly significant at the 1% level of probability.
* Significant at the 5% level

APPENDIX E3

Analysis of variance on the effect of ULV formulation and swaths on the control of red tef worm, post-spray larval count 72 hours after insecticide application (1983)

Source of variation	degrees of freedom	Sums of squares	Mean square	Observed F	Expected F 5%	Expected F 1%
(main plots)	5	85.96	17.19			
replications	1	7.04	7.04	0.23NS	18.51	
insecticides	2	18.14	9.07	0.30NS	19.00	
error (a)	2	60.78	30.39			
(sub-plots)	23	14441.83	629.91			
swaths	3	14113.58	4704.53	228.04**		6.99
interaction	6	56.61	9.44	0.48NS	3.37	
error (b)	9	185.68	20.63			

CV (a) = 19.2%: CV (b) = 15.8%

** Highly significant at the 1% level of probability.

APPENDIX E4

Analysis of variance on the effect of ULV formulation and swaths on the control of red tef worm, post-spray larval count 72 hours after insecticide application (1984)

Source of variation	degrees of freedom	Sums of squares	Mean square	Observed F	Expected F 5%	Expected F 1%
(main plots)	5	49.68	9.94			
replications	1	1.26	1.26	0.14NS	18.51	
insecticides	2	30.27	15.14	1.67NS	19.00	
error (a)	2	18.15	9.08			
(sub-plots)	23	13298.99	578.17			
swaths	3	13085.62	4361.87	830.83**		6.99
interaction	6	116.48	19.41	3.70*	3.37	
error (b)	9	47.21	5.25			

CV (a) = 10.6%: CV (b) = 8.0%

** Highly significant at the 1% level of probability.
* Significant at the 5% level.

REFERENCES

ADKISSON, P.L. (1969) How insects damage crops, in: How crops grow a Century later. Conn. Agr. Ex. Sta. Bull., 708: 155-164.

AFIFY, A.M., EL-KADY, M.H. and ZAKI, F.N. (1971) Difference in effectiveness of three kinds of foliage on larval growth and adult fecundity of the sugarbeet armyworm Spodoptera exigua Hbn. (Lepidoptera : Noctuidae). Acta Entomologica Bohemoslovaca, 68: 77-82.

ANDREEV, V.A. (1981) [Forecasting the development of Noctuids] Zashchita Rastenii No.11, pp 41-42 Laboratoriya VNIILR, USSR.

ANON. (1962) Tef: A source of protein. Nutrition Review, 20: 310-311.

BALASUBRAMANIAN, G. and BALASURAMANIAN, M. (1984) Susceptibility of different larval instars of Spodoptera litura (Fabricius) to insecticides. Indian Journal of Agricultural Sciences, 54: 72-74.

BALS, E.J. (1970) Rotary Atomisation. Agric. Aviat., 12: 85-90.

BALS, E.J. (1975) Droplets in Air: Part 1; the generation and behaviour of air-borne dispersions. Society of Chemical Industry Symposium (unpublished).

BARDNER, R. (1968) Wheat bulb fly, Leptohylemyia coarctata Fall. and its effect on the growth and yield of wheat. Ann. Appl. Biol., 61: 1-11.

BARDNER, R. and FLETCHER, K.E. (1974) Insect infestations and their effects on the growth and yield of field crops: a review. Bull. ent

Res., 64: 141-160

BECK, S.D. (1968) Insect Photoperiodism. Academic Press, New York. 288pp.

BERIO, E. (1955) Georyx Mucosa Gey. e le specie affini (Lepid. Noct.). Rev. Zool. Bot. Afr.,Ll,3-4, 53: 213-222.

BEYENE, D. (1984) A review of the state of research on biological nitrogen fixation in Ethiopia. A paper presented at the first conference of the African Association for Nitrogen Fixation, Nairobi, July 23-27, 1984.

BOGALE, B. (1982) Summaries of rainfall and temperature data, 1976-1981. Ministry of Agriculture, Agricultural Devel. Dept., Addis Abeba, Ethiopia, 266pp.

BOT, J. (1966) Rearing Heliothis armigera (Hubn.) and Prodenia litura F. on an artificial diet. S. Afr. J. Agric. Sci., 9: 535-538.

BOWDEN, J. (1973a) The significance of moonlight in photoperiodic responses of insects. Bull. ent. Res., 62: 605-612.

BOWDEN, J.(1973b) The influence of moonlight on catches of insects in light-traps in Africa, Part I. The moon and moonlight. Bull ent. Res., 63: 113-128.

BOWDEN, J. (1982) An analysis of factors affecting catches of insects in light traps. Bull. ent. Res., 72: 535-556.

BOWDEN, J. (1984) Latitudinal and seasonal changes of nocturnal illumination with a hypothesis about their effect on catches of insects in light traps. Bull. ent. Res., 74: 279-298.

BOWDEN J. and CHURCH, B.M. (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 MORRIS, M.G. (1975) The influence of moolight on catches of insects in light traps in Africa. Part III. The effective radius of a mercury vapour light trap and the analysis of catches using effctive radius. Bull. ent. Res., 65: 303-348.

BRAUN, A. (1841) Bemerkungen uber die flora von Abyssinien, "Flora" XXIVI, p261.

BRAUN, A. (1848) Baitrag zur kenntnis der Abyssinschen. Culturpflanzen, "Flora" XXXI (6) p92.

BRIDGES, J.R. and PHILLIPS, J.R. (1971) The effect of larval diet on the fatty acids of the imago of Heliothis zea (Boddie), in: G.A.Matthews (Ed.) Cotton Insect Control: Proceedings of the Cotton Insect Control Conference, Blantyre, Malawi, March 24-27th.

BROWN, E.S., BETTS, E. and RAINEY, R.C. (1969) Seasonal changes in distribution of the African armyworm Spodoptera exempta (Wlk) (Lepidoptera : Noctuidae) with special reference to eastern Africa. Bull. ent. Res., 58: 661-728.

BROWN, E.S. and DEWHURST, C.F. (1975) The genus Spodoptera (Lepidoptera:

Noctuidae) in Africa and the Near East. Bull. ent. Res., 65: 221-262.

BROWN, E.S. and ODIYO, P. (1968) The rate of feeding of the African armyworm Spodoptera exempta (Walk.) and its significance for control operations. E. Afr. Agric. For. J., 33: 245-256.

BROWN, E.S. and SWAINE, G. (1966) New evidence on the migration of moths of the African armyworm, Spodoptera exempta (Wlk.) (Lepidoptera: Noctuidae). Bull. ent. Res., 56: 671-684.

BULLEN, F.T. (1970) Benefit/cost analysis of various degrees of crop protection. Proc. ecol. Soc. Aust., 5: 63-75.

BUNTIN, G.D. and PEDIGO, L.P. (1985) Variegated cutworm (Lepidoptera: Noctuidae) foliage consumption and larval development on alfalfa. J. Econ. Entomol., 78: 482-484,

CALLAHAN, P.S. and CHAPIN, J.B. (1960) Morphology of the reproductive systems and mating in two representative members of the family Noctuidae, Pseudaletia unipuncta and Peridroma margaritosa with comparison to Heliothis zea. Ann. Entomol. Soc. Am., 53: 763-782.

CARL, K.C. (1962) Graminaceous moth borers in West Pakistan. Commonwealth Inst. Biol. Control Tech. Bull. 2: 29-76.

CAYROL, R., POITOUT, S. and ANGLADE, P. (1974) [Comparitive study of the respective biological characters of some species of migratory and non-migratory multi-voltine Noctuids]. Annales de Zoologie, Ecologie

Animale . 6: (1), ppl-10. Station de Zoologie, Centre de Recherches d'Avignon, INRA,France.

CENTRAL STATISTICS OFFICE (1978) Statistics Abstract, Addis Abeba, Ethiopia. 269pp.

CENTRAL STATISTICS OFFICE (1983) Agricultural sample survey: preliminary results on area, production and yield of major crops for Ethiopia, Addis Abeba, pp3-5.

CHIARAPPA, L. (Ed.) (1971) Crop Loss Assessment Methods Food and Agriculture Organisation, Rome.

CIFERRI, R. and BALDRATI, I.(1939) Il "Tef" (*Eragrostis tef*) cereale da pinificazione dell' Africa Orientale Italian montana. Agron. per l'Africa Italiana, Firenze XI.

CLIPSHAM, I.D. (1980) The influence of target area on the variability of spray deposits, in: J.O.Walker (Ed.) Spraying Systems for the 1980's. BCPC Monograph. 24: 133-138.

COMMONWEALTH INSTITUTE OF ENTOMOLOGY (1971) Identification of insects from Ethiopia, submitted by the Institute of Agricultural Research,Addis Abeba, Ethiopia. List No.7650 (Africa) Coll. No.A 4578.

CONWAY, G.R. and NORTON, G.A. (1976) The economic and social context of pest, disease and weed problems, in: M. Cherrett and J. Sagar (Eds.) The origins of pest, disease and weed problems. Symp. Brit. Ecol. Soc. pp205-226.

COOKSEY, K.E. (1971) The protein crystal toxin of *Bacillus thuringiensis*: biochemistry and mode of action, in: H.D. Burges and N.W. Hussey (Eds.) *Microbial control of Insects and Mites*. Academic Press, New York. Chapter 11.

COOPEL, H.C. and MERTINS, J.W. (1977) *Biological insect pest suppression*. Springer-Verlag, Berlin. 314pp.

CROWE, T.J. and SHITAYE, G.M. (1977) *Crop Pest Handbook*, Third (revised) ed. Inst. Agric. Res., Addis Abeba, Ethiopia, 55pp.

CROWE, T.J., TADESSE, G.M. and TSEDEKE, A (1977) *An annotated list of insect pests of field crops in Ethiopia.* Inst. Agric. Res., Addis Abeba, Ethiopia. 71pp.

CULLEN, J.M. and BROWNING, T.O. (1978) The influence of photoperiod and temperature on the induction of diapause in pupae of *Heliothis punctigera*. *J. Insect Physiol.*, *24*: 595-601.

DINA, S.O. (1976) Effect of insecticidal application at different growth phases on insect damage and yield of cowpea. *J. Econ. Entomol.*, *69*: (2): 186-188.

DOUTHWAITE, R.J. (1978) Some effects of weather and moonlight on light trap catches of the armyworm *Spodoptera exempta* at Muguga, Kenya. *Bull. ent. Res.*, *68*: 533-542.

EBBA, T. (1969) Tef (*Eragrostis tef*): The cultivation, usage and some of the known diseases and insect pests. Part I *Experiment Station Bulletin* No. 60 HSIU, College of Agriculture, Dire Dawa, Ethiopia.

56pp.

EBBA, T. (1975) Tef (Eragrostis tef) cultivars: Morphology and classification. Part II. Experiment Station Bulletin No. 66 Addis Abeba University, College of Agriculture, Dire Dawa, Ethiopia. 73pp.

EDWARDS, C.A. and HEATH, G.W. (1964) The Principles of Agricultural Entomology. Chapman and Hall, London.

ETHIOPIAN NUTRITION SURVEY (1959) A report by the Interdepartmental Committee on Nutrition for National Defense. Washington, D.C. September 1959.

FAUST, R.M. (1974) Bacterial Diseases. in: G.E. Cantwell, (Ed.) Insect Diseases. Vol I. Marcel Dekker, New York. Chapter 3.

FAUST, R.M. (1975) Toxins of Bacillus thuringiensis: Mode of action. in: J.D. Briggs, (Ed.) Biological regulation of vectors, a conference report. U.S. Department of Health, Education and Welfare. Publ. No. (NIH) 77-1180. Washington, D.C. p.31.

GRAHAM, H.M., LINGREN, P.D., LINCOLN, C. and ADKISSON, P.L. (1972) The economic threshold for Heliothis spp. on cotton. USDA Southern coop. series Bull., 169, 7-15

GRAHAM, H.M. and WOLFENBARGER, D.A. (1977) Tobacco budworm: labelling with rubidium in the laboratory. J. Econ. Entomol., 70: 800-803.

GRAHAM-BRYCE, I.J. (1977) Crop protection: a consideration of the effectiveness and disadvantages of current methods and the scope for improvement. Phil. Trans. R. Soc. Lond., B28, 163-179.

GUERRA, A.A. (1972) Induction of sexual sterility in bollworms and tobacco budworms by heat treatment of pupae. J. Econ. Entomol., 65: 368-370.

GUPTA, B.D. and KULSHRESHTHA, D.P.(1957) Control of Johnson grass (Sorghum helepense), an alternative host of sugar cane stalk borer Chilotrea auricilia Dudg. Newsl. Indian Inst. Sugar Res. Lucknow, 3: 1-2.

GUTHRIE, F.E., RABB, R.L. and BOWERY, T.G. (1959) Evaluation of candidate insecticides and insect pathogens for tobacco hornworm control 1956-1958. J. Econ. Entomol., 52: 798-804.

HABIB, M.E.M., PALEARI, L.M. and AMARAL, M.E.C. (1983) Effect of three larval diets on the develcpment of the armyworm Spodoptera latifascia Walker (Lepidoptera: Noctuidae) Revista Brasilerra de Zoologia 1: 177-182, UNICAMP, Sao Paulo, Brazil.

HACKETT, D.S. and GATEHOUSE, A.G. (1982) Diapause in Heliothis armigera (Hubner) and H. fletcheri (Hardwick) (Lepidoptera: Noctuidae) in the Sudan Gezira. Bull. ent. Res., 72: 409-422.

HARRIS, W.V. (1938) Annual Report of the entomologists for the year 1937. Ent. leaflet. Dept., Agric., Tanganyika No.16 Dar-es-Salaam, 8pp.

HENNEBERRY, T.J. and CLAYTON, T.E. (1985) Tobacco budworm moths (Lepidoptera: Noctuidae): effect of time of emergence, male age and frequency of mating on sperm transfer and egg viability. J. Econ.

Entomol. , 78: 379-382.

HIMEL,C.M. (1969) The optimum size for insecticide spray droplets. J. Econ. Entomol., 62: 919-925.

HUFFAKER, C.B., MESSENGER, P.S. and DeBACH, P. (1971) The natural enemy component in natural control and the theory of biological control, in: C.B.Huffaker (Ed.) Biological Control, Plenum, New York. pp 16-67.

HUFFAKER, C.B., SIMMONDS, F.J. and LAING, J.E. (1976) The theoretical and empirical basis of biological control, in: C.B. Huffaker and P.S. Messenger (Eds.) Theory and practice of biological control, Academic Press, New York, pp 41-78.

INSTITUTE of AGRICULTURAL RESEARCH (1980) Tef production guidelines, IAR, Addis Abeba, Ethiopia. 9pp.

INSTITUTE of AGRICULTURAL RESEARCH (1984) Tef Research Report: the 16th national crop improvement conference, April 16-18th, 1984, Addis Abeba, Ethiopia.

ISLER, D.A. AND FENTON, F.A. (1931) Preliminary report on controlling pink bollworm in Texas by winter cultural methods. J. Econ. Entomol., 24: 795-807.

ISLEY, D. (1926) Protecting cotton from injury by the bollworm. Univ. Arkansas Coll. Agric. Extens. Circ., 218, 2pp.

ISLEY, D. (1934) Relationship of early varieties of cotton and boll weevil injury. J. Econ. Entomol., 27: 762-766.

ISLEY, D. and BAERG, W.J. (1924) The boll weevil problem in Arkansas. Arkansas Agric. Expt. Sta. Bull., 190, 29pp.

JANNONE, G. (1941) Osservazioni e rilievi singolare attaco di Epilachna (Chnootriba) similis ssp. Tellinii Wse. (Coleoptera: Coccinellidae) alle colture di orzo e di frumento dell´ Uollo Jeggiu, (Scioa, A.O.I.), Agricoltra Colon., 19: 1-25.

JOHNSON, C.G. (1965) Entomology department report, Rothamsted Expt. Sta., 1964, pp 177-194.

JOHNSON, C.G. (1969) Migration and Dispersal of Insects by Flight Metheun, London. pp 22-763.

JOHNSTONE, D.R., HUNTINGTON, K.A. and KING, W.J. (1973) Battery operated ultra-low volume hand sprayers I. Effect of voltage variation on droplet characteristics. COPR Misc. Rep., No. 7.

JOHNSTONE, D.R. HUNTINGTON, K.A. and KING, W.J. (1974) Micrometeorological and operational factors affecting ultra-low volume spray application of insecticides on to cotton and other crops. Agricultural Meteorology, 13: 39-57.

JOYCE, R.J.V. (1968) Trials with ultra-low volume spraying of Dimecron 100 (phosphamidon) in East Pakistan. Pest Articles and News Summaries Section A., 14: 257-265.

JOYCE, R.J.V. (1975) Sequential aerial spraying of cotton at ULV rates in the Sudan Gezira as a contribution to synchronised chemical application over the area occupied by the pest population. Proc. 5th. Int. Agric. Aviat. Congr., pp 47-54.

JUDENKO, E. (1969) An experiment to assess losses caused by frit fly (Oscinella frit L.) shoot attack and the application of phorate in a crop of sweet corn (Zea mays L.). Pest Articles and News Summaries (PANS)., 15: 47-53.

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

KLOMP, H. (1966) The analysis of density dependence in studies on insect population regulation, in: Proceedings of the FAO Symposium on Integrated Pest Control. 11-15th October 1965, FAO, Rome pp 25-31.

KRANZ, J., SCHMUTTERER, H. and KOCH, W. (Eds.) Diseases, pests and weeds in tropical crops. John Wiley and Sons Ltd., Chichester, U.K. 666pp.

LAPORTE, B. (1973) Nouvelles especes de Noctuelles d´Afrique et de Madagascar. Bulletin de la Societe entomologique de France. Tome 78, pp 53-58.

LEES, A.D. (1968) Photoperiodism in insects, in: A.C.Giese (Ed.) Photophysiology, Academic Press, New York, pp 47-137.

LINCOLN, C. (1968) Threshold of insect damage, Ag. Chem., pp 22-24.

LUCKMAN, W.H. and METCALF, R.L. (1975) The pest management concept, in: R.L. Metcalf and W.H. Luckman (Eds.) Introduction to Insect Pest

Management . John Wiley and Sons, New York.

MATTHEWS, G.A. (1971) Ultra-low volume spraying of cotton - a new application technique Cotton Handbook of Malawi, Amendment 2/71, Agricultural Research Council of Malawi.

MATTHEWS, G.A. (1973) Nozzles for pesticide application in the tropics. PANS., 19: 583-600.

MATTHEWS, G.A. (1977a) C.d.a. - Controlled Droplet Application. PANS., 23: 387-394.

MATTHEWS, G.A. (1977b) The biological target Pestic. Sci., 8: 96-100.

MATTHEWS, G.A. (1979) Pesticide Application Methods, Longman Group Ltd., London, 336 pp.

MATTHEWS, G.A. (1984) Pest Management, Longman, London. 231 pp.

MENGESHA, M.H. (1966) Chemical composition of tef (Eragrostis tef) compared with that of wheat, barley and grain sorghum. Econ. Bot., 20: 268-273.

MENGESHA, M.H. and GUARD, A.T. (1966) Development of the embryo sac and embryo of tef (Eragrostis tef) Can. Journ. Bot., 44: 1071-1075.

MERRITT, C.R. (1980) The influence of application variables on the biological performance of foliage applied herbicides. BCPC Monograph. 24: 35-43.

MISTRIC, W.J.,Jr. and SMITH, F.D. (1973) Tobacco budworm: control on flue-cured tobacco with certain microbial pesticides. J. Econ. Entomol., 66: 979-982.

MORRIS, R.F. and MILLER, C.A. (1954) Development of life tables for the spruce budworm. Can. J. Zool., 32: 283- .

NAGARKATTI, S. and RAMACHANDRAN NAIR, K. (1973) The influence of wild and cultivated Graminae and Cyperaceae on populations of sugarcane borers and parasites in north India. Entomophaga., 18: 419-430.

NATIONAL ACADEMY OF SCIENCES (1969) Insect Pest Management and Control. Nat. Acad. Sci. Publ. 1695.

NEWSOM, L.D. (1970) The end of an era and future prospcts for insect control. Tall Timber Conference on Ecological Animal Control by Habitat Management., No.2, pp 117-136. Tall Timber Res. Sta., Tallahassee, Florida.

NEWSOM, L.D., KOGAN, M., MINER, F.D., RABB. R.L., TURNIPSEED, S.G. and WHITCOMB, W.H. (1980) General accomplishments toward better pest control in soybean, in: C.B. Huffaker (Ed.) New Technology of Pest Control. John Wiley and Sons, New York. pp 51-98.

ODIYO, P.O. (1970) The use of insect light traps for monitoring changes in the distribution of crop pests in E. Africa, in: C.P.F. de Lima (Ed.) Advances in medical, veterinary and agricultural entomology in eastern Africa. (Proc. 1st. E.A. conf. ent. pest control. Nairobi, 6-10th. Dec. 1976) pp 102-106.

PEDGELEY, D.E. (1982) Windborne pests and diseases: Meteorology of airborne organisms. John Wiley and Sons, New York. 250 pp.

PENCOE, N.L. and MARTIN, P.B. (1982) Fall armyworm (Lepidoptera: Noctuidae) larval development and adult fecundity on five grass hosts. Environmental Entomol., 11: 720-723.

PERSSON, B. (1976) Influence of weather and nocturnal illumination on the activity and abundance of population of noctuids [Lepidoptera] in south coastal Queensland. Bull. ent. Res., 66: 33-63.

PINHEY, E.C.G. (1975) Moths of Southern Africa. Tafelberg Publishers Ltd., Cape Town.

PROVOST, M.W. (1959) The influence of moonlight on light trap catches of mosquitoes. Ann. Ent. Soc. Am., 52: 261-271.

REED, W. (1965) Heliothis armigera (Hb.)(Noctuidae) in Tanganyika I. Biology with special reference to the pupal stage. Bull. ent. Res., 56: 117-125.

REZK, G.N., AZMY, N.M. and HAMED, A.A. (1981) The relative toxicity of Dursban (chlorpyrifos) and Bacillus thuringiensis Berliner to the cotton leafworm. Research Bulletin No. 1675 6pp Ain Shams University, Cairo, Egypt.

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/CAB, Slough, U.K. pp 59-63.

RIPPER, W.E. (1944) Biological control as a supplement to chemical control of insect pests. Nature, 153: 448-452.

ROOME, W.E. (1979) Pupal diapause in Heliothis armigera (Hubner) (Lepidoptera: Noctuidae) in Botswana; its regulation by environmental factors. Bull. ent. Res., 69: 149-160.

ROSEN, D and DeBACH, P. (1973) Systematics, morphology and biological control. Entomophaga., 18: 215-22.

ROUK, H.F. and MENGESHA, H. (1963) An introduction to tef (Eragrostis abyssinica Schrad): A nutritious cereal grain of Ethiopia Experimental Station Bulletin. No. 26, Haile Selassie I University, Dire Dawa, Ethiopia. 21pp.

SABROSKY, C.W. (1955) The interrelations of biological control and taxonomy. J. Econ. Entomol., 48: 710-714.

SAILER, R.I. (1971) Invertebrate predators, in: Toward integrated control , USDA For. Ser. Res. Paper NE-194. Northeastern Forest Exp. Stn., US Department of Agriculture, Upper Darby, Pa.

SAILER, R.I. (1981) Extent of biological and cultural control of insect pests of crops, in: D.Pimentel (Ed.) Handbook of Pest Management Vol. II. CRC Press, Inc., 57-67.

SKAIFE, S.H. (1921) Notes on some South African Entomophtheraceae. Trans. R. Soc. S. Africa., Cape Town, ix, Pt. 1, pp 77-86.

SKAIFE, S.H. (1953) African Insect Life. Longmans, Green and Co. Ltd., London. 387 pp.

SMITH, R.F. and ALLEN, W.W. (1954) Insect control and the balance of nature. Sci. Am., 190: 38-42.

SMITH, R.F., APPLE, J.L. and BOTTRELL, D.J. (1976) The origins of integrated pest management concepts for agricultural crops, in: J.L.Apple and R.F.Smith (Eds.) Integrated Pest Management. Plenum Press, London, 200 pp

SMITH, R.F. and REYNOLDS, H.T. (1965) Principles, definitions and scope of integrated pest control, in: Proceedings of the FAO Symposium on Integrated Pest Control, Vol. I pp11-17.

SOUTHWOOD, T.R.E. and NORTON, G.A. (1973) Economic aspects of pest management strategies and decisions. in: P.W. Geier, L.R. Clarke, D.J. Anderson and H.A. Dix (Eds.) Studies in population management., Mem. Ecol. Soc. Australia, 1: 168-184.

SPLITTSTOESSER, C.M. (1981) The use of pathogens in insect control, in: D. Pimentel (Ed.) Handbook of Pest Management, Vol. II. CRC Press, Inc., pp 285-298.

STANILAND, L.N. (1960) Field tests of spraying equipment by means of fluorescent tracer technique. J. Agric. Engng. Res., 5: 42-82.

STEEL, G.D. and TORRIE, J.H. (1960) Principles and procedures of statistics, with special reference to the biological sciences. McGraw-Hill Book Company Inc., London, 481pp.

STEINHAUS, E.A. (1951) Possible use of Bacillus thuringiensis

Berliner as an aid in the biological control of the alfalfa caterpiller. Hilgardia., 20: 359-381.

STERN, V.M. (1966) Significance of economic threshold in integrated pest control, in: Proceedings of the FAO Symposium on Integrated Pest Control Vol. II, 11-15th October 1965, Rome, pp41-56.

STERN, V.M. (1973) Economic threshold. Ann. Rev. Entomol., 18: 259-280.

STERN, V.M., SMITH, R.F., van den BOSCH, R. and HAGAN, K.S. (1959) The integration of chemical and biological control of the spotted alfalfa aphid. Part I. The integrated control concept. Hilgardia., 29: 81-101.

TAMMES, P.M.L. (1961) Studies of yield losses II: injury as a limiting factor of yield. Tidschr. Pl. Ziekt., 67: 257-263.

TANADA, Y. (1956) Microbial control of some lepidopterous pests of crucifers. J. Econ. Entomol., 49: 320-329.

TANADA, Y. (1964) Epizootiology of insect diseases, in: P. DeBach (Ed.) Biological control of insect pests and weeds. Reinhold, New York. pp 548-578.

TAYLOR, L.R., BROWN, E.S. and LITTLEWOOD, S.C. (1979) The effect of size on the height of flight of migrant moths. Bull. ent. Res., 69: 605-609.

TROTTER, A. (1918) Eragrostis tef (Zucc.) Trotter: the Poa tef

Zuccagni. and *Eragrostis abyssinica* (Jacq.) Link. *Bull. of the Ital. Soc. Bot.*, No. 4.

UNGER, F. (1866) *Botanische Streifzuge auf dem Gebiete der culturgeschichte,* Sitzber. Wein. Akad. Wissensch. Mat.-Nat. KI, LIV I (1866) S42. LV 1 (1867) S202.

UVAROV, B.P. (1931) Insects and Climate. *Trans. Ent. Soc. London.*, *79*: 1-247.

van den BOSCH, R. (1966) the role of parasites and predators in integrated control, in: *Proceedins of the FAO Symposium on Integrated Pest Control* Vol II, 11-15th October 1965, Rome, pp 143-147.

van den BOSCH, R. and MESSENGER, P.S. (1973) *Biological Control*. Intext, Educ. Publications, New York, 180 pp.

VAVILOV, N.I. (1935) *The origin, variation, immunity and breeding of cultivated plants*. (translated by U.S. Chester), New York, The Ronald Press Company. pp 37-38.

VERHEIJEN, F.J. (1960) Mechanisms of the trapping effect of artificial light sources upon animals. *Archives Neerlandaises de Zoologie.*, *13*: 1-107.

WALKER, P. (1977) Crop losses: some relationships between yield and infestations. *Med. Fac. Landbouww. Rijksui. Gent.*, *42*: 919-926.

WALKER, P. (1981a) The measurement of insect populations, their distribution and damage, in: L. Chiarappa (Ed.) *Crop Loss Assessment*

Methods - Supplement 3., FAO/CAB pp 43-49.

WALKER, P. (1981b) Methods of studying the pest/yield relationship and for appraising losses due to insects and mites, in: L. Chiarappa (Ed.) Crop Loss Assessment Methods - Supplement 3., FAO/CAB pp 73-78.

WATSON, T.F., MOORE, L. and WARE, G.W. (1975) Practical insect pest management: a self-instruction manual. W.H.Freeman and Company, San Francisco, 196pp.

WHITCOMB, W.H. (1981) THe use of predators in insect control, in: D.Pimentel (Ed.) Handbook of Pest Management in Agriculture Vol II. CRC Press Inc., pp 105-123.

WOOD, E.A. (1965) Effect of foliage infestation of the English grain aphid on yield of Triumph wheat. J.Econ. Entomol. 58: 778-779.

WORTHING, C.R. (Ed.) (1979) The Pesticide Manual: A World Compendium. 6th Edition. British Crop Protection Council, U.K. 655pp.