ACHIEVEMENTS AND HIGHLIGHTS

Crop Borers 1980-1988

The International Centre of Insect Physiology and Ecology

Funded by
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ICIPE SCIENCE PRESS

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FOREWORD

The Project on *Integrated Management of Crop Borers of Basic Food Cereals and Legumes for Rural Africa,* funded by the International Fund for Agricultural Development (IFAD) over the nine-year period 1980–1988, has proved a watershed for the contracting research institute, The International Centre of Insect Physiology and Ecology (ICIPE), for three major reasons. First, it permitted the ICIPE to target its mission-oriented research and technology development (R&D) on the resource-poor farming households in respect of integrated pest management (IPM) of the key insect pests of three major food staples. The foods are maize, sorghum and cowpeas, and the pests are crop borers, which have — for the first time in tropical Africa — received concentrated R&D effort. Second, it enabled the ICIPE to take its considerable knowledge base of crop borers for testing on farmers' fields, initially under ICIPE's own supervision, but later under farmers' control. And, third, it provided an opportunity, under pilot field conditions, to have farmers join with the extension service staff and the ICIPE multi-disciplinary research staff, working on a day-to-day basis as a single applied research, technology development and IPM implementation team. This strategy has proved effective and productive; and the ICIPE will utilize it for all other IPM projects when they reach the pilot stage.

IFAD has proved a most understanding and interactive donor; and we believe that the results of this project will encourage them to fund similar projects in the future.

The IFAD-funded project is now poised for application over a much wider area, involving many more farming households. We greatly appreciate the faith that IFAD has demonstrated in the ICIPE, and the Fund's generosity towards us.

THOMAS R. ODHIAMBO
Director, ICIPE

Nairobi, 25th April 1989

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IFAD REPORT — EXECUTIVE SUMMARY

1. Goal
The current project was initiated in 1980 with the ultimate goal of increasing production of food cereals and legumes by resource-poor, small-scale farmers in rural Africa through improved insect pest management.

2. Strategy
To achieve this goal, the project activities have aimed at developing such strategies for integrated pest management (IPM) as would be environmentally safe and technically as well as socio-economically feasible for the small farmer .

3. Crops and pests studied
The crops studied are sorghum, maize and cowpea. The insect pests taken up for this project are *Chilo partellus* and other borers on sorghum and maize, and *Maruca testulalis* on cowpea.

4. Population studies
(i) Methodology has been developed and standardised for monitoring the populations of the borers through periodical sampling for borer larvae and pupae, and by pheromonal trapping of adult males using specially designed traps.
(ii) Infestation of sorghum/maize by *C. partellus* commences when plants are 2-3 weeks old. *Busseola fusca* attacks the plants about 2 weeks later, and *Eldana saccharina* close to harvest when it can hardly cause any loss.

5. Crop loss assessment
Significant advances have been made in respect of development of standardized methodology for assessing crop losses due to borers, and in generating information on these losses in relation to crop phenology and pest population density. For *C. partellus* it has been established that maximum grain yield loss (80 – 90%) in sorghum occurs if the pest larvae attack about 20-day-old plants. With advance in the age of the plant at infestation, yield loss declines till at 50 – 60 days only 5% grain loss occurs.

6. IPM components
The IPM components that are being developed include:
(i) Intercropping and other cultural practices
(ii) Plant resistance to insect pests
(iii) Biological control
(iv) Behavioural manipulation of pests, particularly for monitoring pest populations as indirect tactics for IPM.

7. Intercropping as an IPM component
It has been established that growing sorghum or maize with cowpea in alternate rows as intercrops reduces the attack of borers by about 40%. But intercropping sorghum and maize together boosts the borer attack. Hence it is recommended that farmers grow either sorghum or maize, with cowpea as an intercrop to protect their crops from borers.

However, since some farmers want to grow sorghum and maize together as a security against drought, it has been established that growing a specific sorghum cultivar with a specific maize cultivar can reduce borer attack.

8. Other cultural practices
Adjustment of planting time and timely disposal of crop residues have been demonstrated to contribute to reduction in borer attacks on cereal crops.

9. Plant resistance to insect pests
Evaluations of diverse crop cultivars, suggested by studies on the mechanisms and genetics of resistance to the borers, have resulted in the development of cultivars that are resistant to the pests and, at the same time, give good yields. Most promising of these are: sorghum IS 1044, LRB 5, LRB 6, LRB 8, LRB 9; maize ICZ2-CM, V 37, KRN 1; cowpea 1CV 2, 1CV 12.

10. Biological control
Some insect parasitoids and pathogens of the borers have been identified as promising for biocontrol. Among these, the most important include *Trichogramma mwanzei* (which parasitises *Chilo* eggs) and a protozoan pathogen, *Nosema.* Field experiments have demonstrated the efficacy of these natural enemies for the control of borers.

11. Pilot on-farm trials under farmers' management
Of the above IPM components, intercropping, cultural practices and plant resistance to the borers have already been integrated together for on-farm trials in collaboration with the Ministry of Agriculture in Kenya. Through its extension staff these trials have been conducted in the fields of 50 farmers, 25 each in Kendu Bay and Oyugis Divisions in Western Kenya. The ICIPE's Social Science Interface Research Unit is also collaborating in the trials.

The results show that adoption of the ICIPE's IPM components has given an increase in yield of approximately 40% for sorghum and maize.

RETURN ON INVESTMENT

This research was field-oriented and investigated components of integrated pest management for resource-poor, small-scale farmers in rural Africa. Over the last two years, the research results have been extended to a pilot trial with 50 farmers in Western Kenya. The present status of the research is not amenable to the quanti fication of benefits and costs to facilitate the calculation of return on investment.

However, there are adequate indicators to confirm that the benefits of the research far outweigh the costs and there is a multiplier effect which will increase the benefits severalfold.

ICIPE's emphasis is on technologies which provide sustainability of production using low inputs, for the beneficiary small-scale farmers, rather than on achieving high yields which depend on high inputs. Through a partnership of research scientists, social scientists, extension personnel, and the farmers, research has been based on a knowledge of the needs of the farmers which has led to rapid development of the technology package and its adoption. In the pilot trial, the increase in production resulting from the technological changes has raised the income of the farmers by US$ 100, which is equivalent to a 33% increase in the per capita income in Kenya.

As an indication of the magnitude of the potential benefit, one can examine the case of Kenya where the pilot trials are being undertaken. In 1988, maize production was 3 million metric tonnes. Most of the production was from small-scale farmers who are the beneficiaries of the present project. The pilot trial has recorded average increases of 40% arising from the pest management package. If this were extended throughout the country to the small-scale farmers who produce 80% of the crop, there would be an annual increase in their production of 0.96 million tonnes, valued at US$ 146.7 million. Furthermore, the results from the project are already being used in cooperative network projects in Zambia and Somalia and will be extended to other countries in Africa.

The significant role played by women in food production in Africa has been given due cognizance by the project. For example, of the 50 farmers participating in the first pilot trial, half are women (since they comprise 50% of all farmers).

In order to sustain the technology, the project has undertaken human resource development for institutional management. This will ensure that technological innovations are suitable for the various specific sub-regions of Africa. During the project life, 18 doctoral and 13 masters students from 9 African countries have been trained. These people will help to provide the scientific leadership required to sustain national pest management programmes.

1. INTRODUCTION

Sorghum, maize and grain legumes like cowpea are important staple food crops for millions of people in developing tropical countries, including many in Africa. The majority of farmers growing these crops have poor resources and small farms. One of the most serious constraints to production is attack by various insect pests resulting in heavy losses in grain yield. In Africa, major pests include the stem borers of maize and sorghum *(Chilo partellus, Busseola fusca, Sesamia calamistis, Eldana saccharina),* the sorghum shootfly *(Atherigona soccata)* and the cowpea pod borer *(Maruca testulalis).* Published figures for reduction in sorghum yield caused by borers range from only 5–10% in some areas but up to 83% in others. Similarly, losses of maize due to *C. partellus* also vary widely in different areas, from about 18% in Kenya compared to 26–80% in India. The cowpea also suffers yield losses of 20–100% due to several pests. It is therefore obviously important to control crop borers and thereby increase food production. Various synthetic insecticides can be used, as in developed countries, to control these pests, but such chemicals are widely known to have a number of limitations. They are, for example, hazardous to the environment, to humans and to various beneficial organisms; and their use may lead to the development of resistance in the pest insects. Moreover, resource-poor small-scale farmers cannot afford to buy them and do not know how to handle them properly.

Within this context the present project, funded by the IFAD, was initiated at the ICIPE in 1980 to achieve the goal and objectives spelt out below. Details of the work carried out since then have been submitted to IFAD every year in the Annual Reports of the project. However, the significant contributions and achievements during the entire period of the project (1980–1988) are highlighted in this report, with special reference to integrated pest management (IPM).

2. PRIMARY GOAL

The Project's ultimate goal has been to increase the production of food cereals and legumes in rural Africa, and elsewhere in the developing tropics, through effective IPM.

3. OBJECTIVES

In order to achieve this goal, the Project has pursued the following objectives:

(i) Developing strategies for the management of key insect pests, particularly borers of sorghum, maize and cowpea, by methods that would be environmentally safe and both technically and socio-economically feasible for the small-scale, resource-poor farmer.

(ii) Interacting and collaborating with national and international agricultural research centres with similar interests.

(iii) Raising the level of national scientific capability through training in this field.

4. TARGET CROPS AND INSECT PESTS

The crops selected for this project were sorghum, maize and cowpea.

The insect pests under study thus include the sorghum and maize stem borers *(C. partellus, B. fusca, E. saccharina, S. calamistis)*, the sorghum shootfly *(A. soccata)* and the cowpea pod borer *(M. testulalis)*. Of the borers attacking sorghum and maize, *C. partellus* has been taken as the model for detailed studies in view of its importance not only in Africa but world-wide. However, certain aspects were studied in other borers when they interacted with *C. partellus* in the field. In view of this, the present report deals mainly with *C. partellus* for sorghum/maize and *M. testulalis* for cowpea.

5. STUDY SITES

The project activities were carried out at the following sites:

(i) The ICIPE Field Station located at Mbita Point (MPFS) on the shores of Lake Victoria in western Kenya.

(ii) National Agricultural Research Stations at Alupe (Busia), Katumani (Machakos), Mtwapa (Kilifi, on the coast).

(iii) Farmers' fields in western Kenya

6. APPROACH

In order to achieve these objectives, a balanced emphasis has been placed on basic research with applied potential, followed by development of different modes of practical application. These activities have been taken up in three stages:

Stage 1. Investigative studies on various aspects directly or indirectly related to the IPM components being developed.

Stage 2. Testing (under ICIPE management) the elements found promising in stage 1, in farmers' fields in different agro-ecological zones.

Stage 3: Pilot trials with IPM elements found promising in stages 1 and 2, on farmers' fields under their own management but Project supervision, in collaboration with social scientists and national programmes.

7. COMPONENTS OF INTEGRATED PEST MANAGEMENT

The components of IPM that have been under development in this project are shown diagramatically in Figure 1. They belong to four broad categories:

(i) Intercropping and other cultural practices.

(ii) Varietal resistance in plants to insect pests.

(iii) Utilization of natural enemies of the pests for their biological control.

(iv) Behavioural manipulation of pests, particularly for population monitoring, as indirect tactics in the pest management programme.

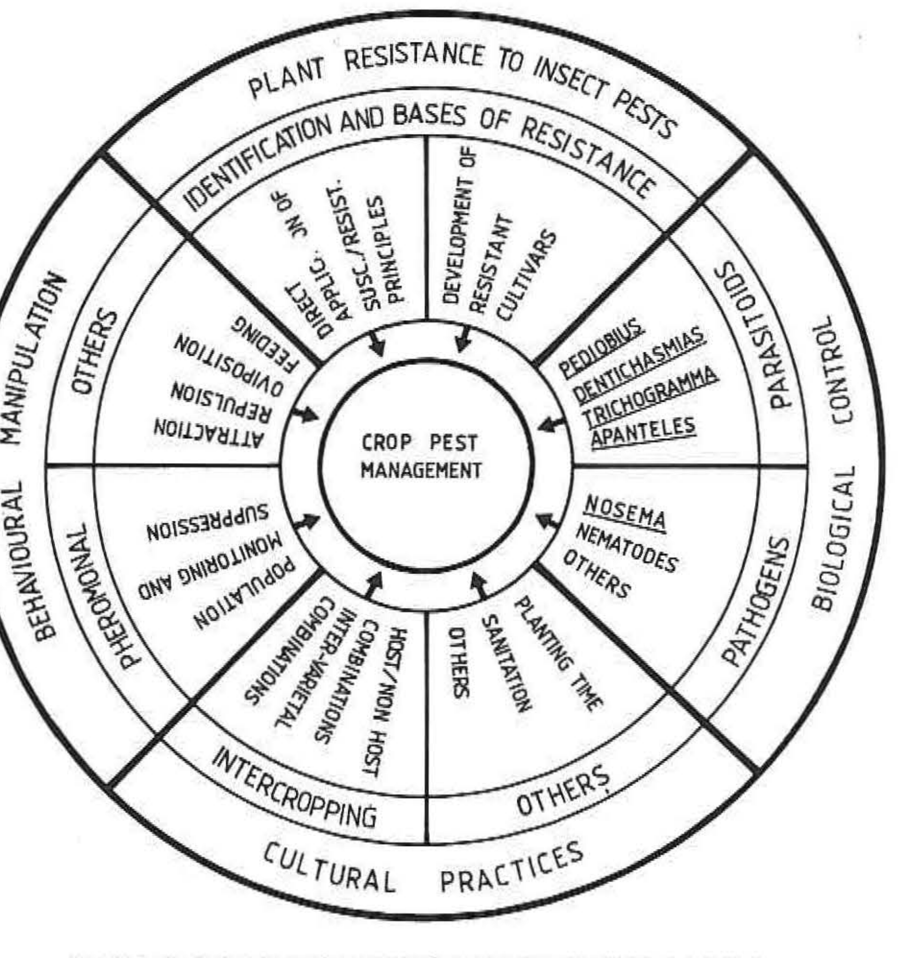

Figure 1. Insect pest management components being developed at the ICIPE.

8. POPULATION PATTERNS OF STEM BORERS ON SORGHUM AND MAIZE

Detailed population studies of the two most important borer species were carried out at Mbita in South Nyanza District, Western Kenya, in order to understand their distribution in the target zone.

A survey of representative districts of Kenya showed that the predominant stem borer species of sorghum and maize was *C. partellus* in Coast, Eastern and Western Provinces. *Busseola fusca* predominated in Rift Valley Province, particularly at altitudes of 900 m (about 3000 ft) or more above sea level and was also important in Western Province. Another species, *Chilo orichalcociliellus* was also abundant in Coast Province. *Sesamia calamistis* and *E. saccharina* were also observed to attack these two crops occasionally, and to varying degrees, in most parts of Kenya, *S. calamistis* being quite important in Coast Province.

The populations of these five borer species were monitored at MPFS and in farmers' fields during 1981–1986, and some of these results have already been published. During this period, *C. partellus* was observed to start infesting sorghum or maize when the plants were 2–3 weeks old. The percentage of infested plants ranged from 3–28% for sorghum and 3–10% for maize. The population density of the larvae at this plant developmental stage was in the range of 4–42 and 2–30 larvae/100 plants of sorghum and maize, respectively. Following these initial infestation levels the borer population fluctuated during the cropping season, with 2 or 3 peaks in both crop species.

With *B. fusca* the infestation commenced on both crops when plants were 3–5 weeks old and the percentage of plants damaged at this stage was 3–6%. The density of the population was up to 20 larvae/100 plants of sorghum and maize. There were 2–3 population peaks during a season.

The incidence of *S. calamistis* and *E. saccharina* was mostly low. But occasionally (e.g. 1982–1983) *E. saccharina* was quite abundant on maize (up to 180 larvae and pupae/100 plants) and sorghum (up to 60 larvae and pupae/100 plants), though at the 13th week when it does not cause much damage. In general, the pest populations were lower during the long rains (March/April–June/July) than in the short rains (September/October–December/January).

These studies clearly show that *C. partellus* and *B. fusca* are the most important stem borers. Furthermore, the relationship observed above, between the larval population density and the phenological stage of the plants at infestation time, is important in preparing pest management strategies.

9. CROP LOSSES DUE TO STEM BORERS

It is important to know the magnitude of crop losses by insect pests before deciding on the control measures to be adopted, or indeed whether they are worth the costs to be incurred. The existing estimates of grain yield losses in sorghum, maize and cowpea due to borers are based on scanty and inadequate experimental data. In this respect, the work on this project has made significant advances, firstly by standardizing the methodology for crop loss assessment and, secondly, by generating information on grain yield losses due to the target borer species.

The method found to give the most reliable and reproducible results for assessing crop loss is the "caged method". Sorghum and maize plants are caged to prevent natural infestation by the pest. The protected plants are then artificially infested at different phenological stages with different numbers of newly hatched *C. partellus* larvae. Uninfested plants in the same cages are used as controls, rather than plants treated with insecticides. The grain yields of the infested and uninfested plants are then compared to measure losses.

Table 1. Grain yield and yield losses of sorghum artificially infested with *Chilo partellus* at different plant ages (days after emergence–DAE)

	No. of larvae/plant			
	5		10	
Plant age DAE	Yield kg/ha	% loss	Yield kg/ha	% loss
10	1031^{c}	75.4	503^{d}	88.0
20	2468^{b}	41.1	780^{d}	81.4
30	2559^{b}	39.0	2347^{c}	44.1
40	3640^{a}	13.2	2781^{c}	33.7
50	3907^{a}	6.8	3122^{bc}	25.5
60	4110^{a}	2.0	3650^{ab}	12.9
Control (uninfested)	4192^{a}		4192^{a}	

Means in each column followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P > 0.05$).

The results are presented in Table 1 and show that the grain yield of sorghum infested with 5 larvae/plant of *C. partellus* 10 days after plant emergence (DAE) suffered a loss of 75.4% compared with the control. At 40, 50 and 60 DAE, the yields were not significantly different from the control or from one another. Thus, at a low larval density, late infestations of sorghum by *C. partellus* have little effect on the yield. At a higher larval density (10 larvae/plant), the grain yield loss also decreased with postponement of infestation to older stages.

Two mathematical models have been developed that quantitatively relate larval population density with grain yield loss at two phenological stages of the sorghum plant.

Similar observations were also made on maize to assess grain yield losses caused by various densities of *C. partellus* larvae at different growth stages of the crop.

These studies show that the age of sorghum or maize at the time of infestation and the density of the larval infestation are crucial in determining the magnitude of the yield losses. Therefore control measures for *C. partellus* need to be applied when the crop is about 20 days old. Furthermore, early planting of sorghum and maize in the whole area can reduce yield losses, as all the plants are past the most vulnerable stage at the time of maximum borer infestation.

10. PHEROMONAL TRAPPING OF ADULTS FOR POPULATION MONITORING

Sex pheromones of many different species of insects have been widely used for trapping the adults and thereby monitoring population fluctuations. Alternatively, pheromones have been used to suppress populations by confusing the opposite sex and interfering with mating activity. However, there are very few reports relating to the sex pheromones of *C. partellus* and *B. fusca* . The study of these aspects was adopted for *C. partellus* and *B. fusca.* This allowed monitoring of the stem borer populations to ensure the most appropriate timing of IPM measures, and then to see the impact of the IPM components themselves.

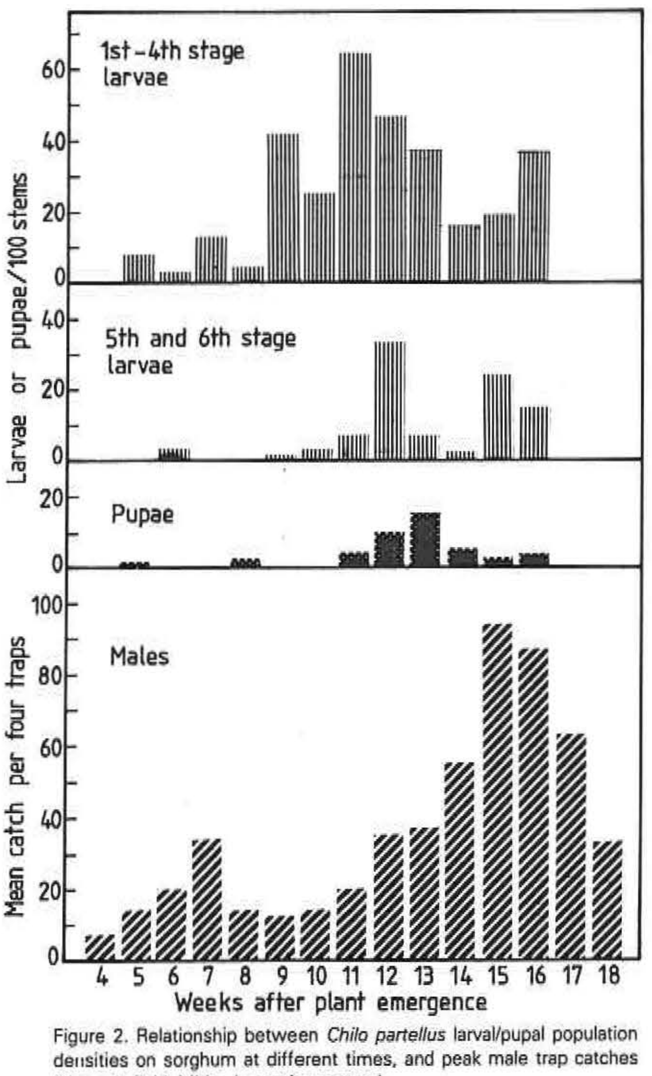

Figure 2. Relationship between *Chilo partellus* larval/pupal population densities on sorghum at different times, and peak male trap catches (farmer's field, Mbita, long rainy season).

These studies showed that virgin females used as bait were more effective in trapping males than the synthetic female sex pheromone preparations of *C. partellus* available from the Overseas Development National Resources Institute (ODNRI) in U.K. Several factors were elucidated which determine the effectiveness of the female sex pheromone in trapping males. Virgin female age, number of females per trap, trap design, inter-trap distances, and trap height all contribute to maximum reproducible trap catches of males. Two traps designs were found to be most efficient; a water pan trap and a sticky delta trap having slits in its side walls. The latter was developed under this programme and is most convenient for use in the field. An example of the results of using this trap for monitoring adult male populations of *C. partellus* and larval and pupal populations (determined by dissecting sorghum plants) is given in Figure 2.

11. CULTURAL PRACTICES: THEIR MANIPULATION FOR IPM FOR CROP BORERS

The cultural practices found promising as components of IPM for crop borers, particularly *C. partellus,* include intercropping, planting time and field sanitation and disposal of crop residues.

11.1 Intercropping

Farmers in Africa, particularly those who have small farms, traditionally plant two or more crops often mixed together haphazadly in the same plot. But the effects on yield of different crop combinations in such mixed cropping are either unknown, or based on inadequate evaluations. The necessary evaluations for the effects of stem borers on sorghum and maize have been carried out under this project and some of the results have already been published. These studies tested crop combinations of two types, host-nonhost intercropping, and host-host inter-varietal intercropping. The results achieved are summarised below with particular reference to sorghum.

Host-nonhost intercropping consisted of growing a host species (e.g. sorghum) and a nonhost species (e.g. cowpea) in alternate rows. Tests at the field station and in farmers' fields have shown that stem borer attack on sorghum IS 18520 (Serena) intercropped with cowpea ICV 6 (ex-Luanda) is reduced by about half compared to the sorghum grown as either a monocrop or as an intercrop with another potential host i.e. maize (Katumani Composite).

Cultivar differences in both sorghum and cowpea influence attack by stem borers. For example, infestation (expressed as the number of larvae per plant) was significantly higher on both the tolerant sorghum IS 18520 (2.28 larvae/plant) and the resistant IS 4660 (2.27/plant) intercropped with the cowpea ICV 2 when compared with the tolerant sorghum ICS 1 (1.67/plant) and ICS 2 (1.93/plant) intercropped with the same cowpea cultivar.

Intercropping sorghum (Serena) and maize (Katumani Composite) together increased stem borer attack on both. However, in spite of this knowledge, many farmers in Kenya would like to grow sorghum and maize together because, in the event of inadequate rains, they may still obtain some sorghum. In view of this, different inter-varietal combinations of sorghum and maize have been tested to determine whether suitable cultivars could be found. Such cultivars have been identified. For example, intercropping the tolerant sorghum (Serena) with the resistant maize (ICZ1-CM) significantly reduced the larval/pupal density from 0.60 to 0.37 per plant. Similarly, resistant sorghum (IS 4660) intercropped with unsuitable maize reduced larval/pupal density for the plant from 0.54 to 0.23 per plant.

Even intercropping different cultivars of sorghum influences their attack by stem borers. For example, the larval plus pupal density on the Serena/IS 4660 intercrop was almost as low (0.41/plant) as that on IS 4660 monocrop (0.38/plant) and significantly lower than that on Serena monocrop (0.51/plant).

11.2 Planting time

The date of planting is known to influence attack by various pests and this also applies to stem borer attack on sorghum and maize. Studies on Rusinga Island in western Kenya showed that the *B. fusca* and *C. partellus* infestation of early-planted sorghum started 70 DAE, whereas a crop planted 20 days later was attacked 28 DAE. Although by harvest time all plants of both sets were infested with the borers, the larval population density of *B. fusca* on the early-planted crop was much less than on the late-planted crop. Consequently, the loss in yield would also be less in the early crop.

12. PLANT RESISTANCE TO INSECT PESTS AS A COMPONENT OF IPM FOR CROP BORERS

The cultivation of crop cultivars that are resistant to insect pests has long been recognised as an important component of IPM (Figure 1), particularly for farmers in developing tropical countries. In order to take advantage of this in the management of crop borers of sorghum, maize and cowpea, the following activities were undertaken in the Project:

(i) Evaluation of crop cultivars overall, as well for the major components of borer resistance.

(ii) Elucidation of the mechanisms of borer resistance in different cultivars.

(iii) Elucidation of the genetic basis of borer resistance.

(iv) The development of cultivars which combine resistance with other desirable characters, especially yield, in collaboration with plant breeders of national and international agricultural research centres.

12.1 Evaluation of crop cultivars for resistance to crop borers

Evaluation of crop cultivars has been undertaken to compare the levels of overall borer resistance and its major components in these cultivars. This information complements that provided by plant breeding centres arising from their screening programmes. Finally, the evaluations undertaken in the project have identified two categories of cultivars. Firstly, those that have adequate resistance levels along with good yield and other desirable characters e.g. colour, taste etc. Secondly, those that have high levels of resistance though low yield and poor agronomic characters, but can be used as starting material for the development of resistant and agronomically good cultivars.

12.1.1 Crop cultivars evaluated. Two categories of cultivars of sorghum, maize and cowpea have been evaluated in this project:

(i) Those that have been reported to show resistance to the project target species in other geographical regions, but not in Kenya and neighbouring countries;

(ii) Those that have been reported to show resistance to other crop borer species, but not to the project target pests.

12.1.2 Development and standardisation of approach and methodology. Most reports on resistance levels to crop borers are based on widely divergent methods of screening and expressing resistance. Frequently, the results are not reproducible. Hence, there was an urgent need to standardise the approach and methodology for evaluating crop cultivars for both overall and major components of borer resistance. This standardisation has been achieved as summarised below. Evaluations are carried out in four stages:

Stage 1. Evaluation of cultivars planted in single rows under natural or artificial infestation.

Stage 2. Evaluation of cultivars found promising in stage 1, planted in multi-row plots under natural infestation.

Stage 3. Multi-locational evaluations in different agro-ecological zones of those cultivars that showed promise in stage 2.

Stage 4. Trial in farmers' fields.

Methods have been standardised for artificially infesting plants with adult females as well as larvae. For infestation with adult females, the cultivars are planted in radial rows in a cage so that each cultivar stands an equal chance of receiving oviposition. For larval infestation, the cultivars are planted in rows and the plants are artificially infested with eggs at the blackhead stage or with neonate first-instar larvae.

The parameters observed to be most consistent in expressing the major components of borer resistance in sorghum and maize plants are:

(i) Infestation levels (egg-population density i.e. no./plant, larval plus pupal density i.e. no./plant)

(ii) Damage levels (foliar lesions on 1–9 scale, percentage of plants with dead-heart and percentage of plant height affected by stem-tunnelling). The ratios of the values for these components for a tested cultivar to those of the reference cultivar, IS 18520 (Serena), are averaged to give the Overall Resistance/Susceptibility Index (ORSI). The lower the ORSI value, the greater the resistance. ORSI values are graded as follows:

<0.4	–	highly resistant (HR)
0.4–0.8	–	moderately resistant (R)
0.8–1.2	–	less resistant/tolerant (T)

1.2–1.6 – susceptible (S)
>1.6 – highly susceptible (HS)

12.1.3 Levels of resistance and its components in sorghum. About 500 sorghum cultivars obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Organization of African Unity/Semi-Arid Food Grains Research and Development (OAU/SAFGRAD) and farmers in Kenya have been evaluated under the project for *C. partellus* resistance as described above. As an illustration, the results of the evaluation of 20 cultivars under artificial infestation with *C. partellus* adults and larvae are shown in Figures 3 and 4. Note how variability in the dead-heart rating alone in cultivars IS 18363 and IS 2146 (common to both test sets) can affect the ORSI value. On the basis of these, as well as other evaluations, the following facts emerge:

(i) The sorghum cultivars that consistently show high or moderate resistance quality and good grain yield are:

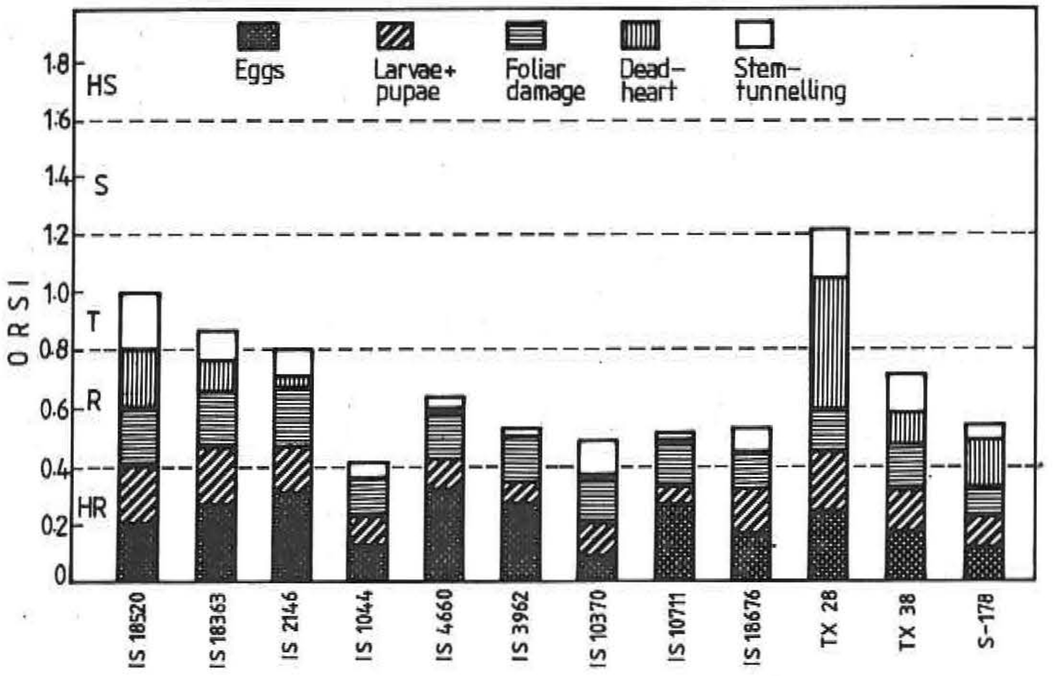

Figure 3. Overall resistance/susceptibility indices (ORSI) for 11 sorghum cultivars (set 1) based on ratios of each parameter for a cultivar to that of the reference strain IS18520.
(HS = highly susceptible, S = susceptible, T = tolerant, R = resistant, HR = highly resistant)

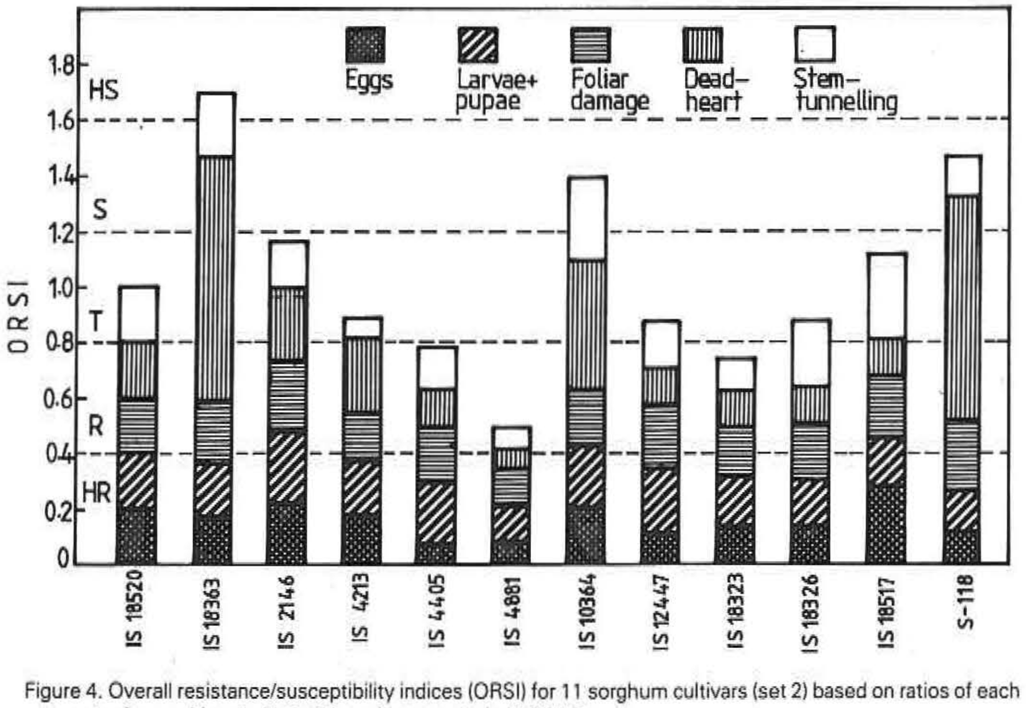

Figure 4. Overall resistance/susceptibility indices (ORSI) for 11 sorghum cultivars (set 2) based on ratios of each parameter for a cultivar to that of the reference strain IS 18520.

IS 1044, IS 4405, ICS 1, ICS 2 and accession nos. LRB 5, LRB 6, LRB 7 and LRB 8. The last six cultivars have been improved from materials obtained from different sources. All these cultivars are now suitable for cultivation and are in pilot trials (see later).

(ii) Some other cultivars show high resistance to *C. partellus* but are agronomically or otherwise poor: IS 12308, IS 2205, IS 4660. These are not suitable for cultivation, but provide good sources from which to develop resistant cultivars through appropriate breeding programmes.

12.1.4 Levels of resistance and its components in maize. Evaluations have been carried out on about 500 maize cultivars, mostly from the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) and also from the U.S. Department of Agriculture, Zambia, Mozambique and from some farmers in Kenya.

(i) Some cultivars that are borer resistant and have good yield as well as other desirable characters include: ICZ 1, ICZ 2, V 37 and KRN 1. These have been developed at ICIPE and are suitable for cultivation.

(ii) Other cultivars that are highly resistant but agronomically poor are: MP 701, MP 702, MP 704. These can be used as sources for developing resistant varieties to incorporate other desirable characters.

12.1.5 Levels of resistance in cowpea cultivars to the pod borer M. testulalis. Seven cowpea cultivars from IITA and 16 from different locations in Kenya have been evaluated. Of these, TVu 946 is the most resistant, followed by Vita 5, ICV 5, ICV 3, ICV 4 and ICV 13. The last four are from among the series ICV 1–ICV 14 developed at ICIPE. Another ICIPE cowpea cultivar, ICV 2, the most promising for cultivation since it combines some resistance with good grain yield and quality.

12.2 Multi-locational evaluation in different agro-ecological zones

Some of the cultivars that were found promising at our field station (MPFS) were tested in multi-locational trials at different national or regional agricultural research stations of the Kenya Agricultural Research Institute. These were inland at Alupe (Busia) and Katu-

Table 2. Ratio of the number of stem borer larvae plus pupae per 10 plants at harvest in four locations, for seven sorghum cultivars compared to that for the reference strain IS 18520

Sorghum line	MPFS	Lambwe East	Alupe	Katumani
IS 18520	1.00 (24.0 ± 6.8)*	1.00 (13.3 ± 1.6)*	1.00 (6.0 ± 1.5)*	1.00 (8.7 ± 3.3)*
IS 1044	0.72	0.91	0.47	0.49
LRB 9	1.17	1.04	2.13	1.69
LRB 7	1.83	1.62	1.42	0.64
LRB 5	1.44	1.02	1.60	0.89
LRB 3	1.26	1.50	1.98	0.72
LRB 4	1.50	1.87	2.42	1.30
LRB 8	1.74	1.96	2.60	1.38

*Number (mean ± s.e.) of larvae plus pupae per 10 plants of IS 18520.

Table 3. Ratio of percent stem length tunnelled, determined at harvest in four locations, for seven sorghum cultivars compared to that for the reference strain IS 18520

Sorghum line	MPFS	Lambwe East	Alupe	Katumani
IS 18520	1.00 (52.9 ± 3.9)*	1.00 (18.4 ± 3.2)*	1.00 (9.2 ± 2.6)*	1.00 (7.4 ± 4.5)*
IS 1044	0.18	0.48	0.17	0.39
LRB 9	0.85	1.10	1.49	1.18
LRB 7	0.73	1.38	1.62	0.65
LRB 5	0.92	0.65	1.39	0.89
LRB 3	0.61	1.14	1.52	0.74
LRB 4	0.46	0.89	1.15	0.91
LRB 8	0.64	0.83	1.33	0.99

* Percent stem length tunnelled (mean ± s.e.) in IS 18520.

Table 4. Ratio of grain yield for seven sorghum cultivars at four locations compared to the reference strain IS 18520. All the plants were covered by fish netting (28 mm mesh) to protect the crop from birds but allowing insects to pass through

Sorghum line	MPFS	Lambwe East	Alupe	Katumani
IS 18520	1.00	1.00	1.00	1.00
	(68.6 × 0.6)*	(81.0 × 3.5)*	(86.9 × 2.8)*	(8.4 × 8.4)*
IS 1044	1.21	0.82	0.49	2.24
LRB 9	1.40	1.33	0.99	2.25
LRB 7	1.40	1.47	0.91	1.85
LRB 5	1.15	1.13	0.98	4.13
LRB 3	1.33	1.15	1.12	4.95
LRB 4	1.40	1.27	1.03	3.76
LRB 8	1.33	1.30	0.64	2.36

*Grain yield, g/plant (mean ± s.e.) for IS 18520.

mani (Machakos), and at Kampi ya Mawe and Mtwapa on the Coast. Some evaluations were also carried out in farmers' fields at Lambwe East (South Nyanza).

The results with sorghum cultivars (Table 2-4) show that IS 1044, LRB 5 and LRB 8 performed well in respect of infestation, damage and final grain yield at most locations. These cultivars have therefore emerged as the most promising one for trials by farmers in their fields.

Similar trials with cowpea revealed that ICV 2 performed very well at most locations and is the most suitable cultivar so far for on-farm trials.

12.3 Mechanisms of resistance in the target crops to the crop borers

The aim of this study has been to elucidate the plant-related factors that determine the resistance or susceptibility of different crop cultivars. This information is most useful to plant breeders for developing pest-resistant varieties by incorporating resistance-imparting characters or eliminating susceptibility-imparting characters.

12.3.1 Approach and methodology developed. The approach developed involves a 2-stage investigation. The first stage examines the role of colonising responses of the insect in attacking certain cultivars and not others. The second stage examines the role of plant characters in governing the above responses and thereby the plant resistance or susceptibility. Special methods and devices have been developed for studying the various aspects mentioned above. The most important of these methods and devices are:

(i) A 3-sector chamber for measurement of oviposition responses to whole plants and their distance-perceivable characters (colour, smell, moisture) in the field or screenhouse.

(ii) A twin- compartment chamber, a wire-mesh tunnel and a glass tunnel for oviposition responses to volatiles.

(iii) A wire-mesh circular chamber for the role of contact plant characters in oviposition.

(iv) Glass tunnels for larval orientation (attraction/repulsion) to plants and their volatiles.

(v) A tray and a grid for larval orientation to plants in the field and to volatiles in the laboratory.

12.3.2 Factors governing plant resistance/susceptibility: role of colonising responses. Before identifying plant characters determining resistance or susceptibility, the stages in plant colonisation by the insect at which resistance is shown and the responses of the insect that contribute to the resistance/susceptibility must be identified. For this, the following colonising responses of *C. partellus* to selected susceptible, tolerant and resistant cultivars of sorghum and maize, and of *M. testulalis* to cowpea cultivars have been compared: oviposition, larval arrest/settling, attraction, leaf-feeding, stem-feeding and development.

Profiles of the colonising responses to different cultivars of each crop have been developed. These show the patterns, interaction and relative contribution of the responses to borer resistance or susceptibility in each cultivar. An illustration of these profiles is given in Figure 5 which shows the responses of *C. partellus* to seven cultivars of sorghum: susceptible IS 18363, IS 18463, IS 2146; tolerant IS 18520 (Serena); resistant IS 4660, IS 2205, IS 1044. The levels of response differ markedly from one cultivar to another. The lower the response level for a cultivar, the greater its resistance.

On this basis, it is clear that most of the responses of *C. partellus* to the sorghum IS 1044 are low and this accounts for its being the highest resistant cultivar among those studied. IS 4660 and IS 2205 elicit a few responses at a low level and others at medium or high level, and are classified as moderately resistant. IS 18363 elicits some responses at a very high or high level, some at a medium level, and is classified as susceptible to the borer.

The plant characters that determine the above responses of *C. partellus*, and thereby the resistance/susceptibility of these sorghum cultivars, may be biophysical or biochemical. Among the biophysical characters,

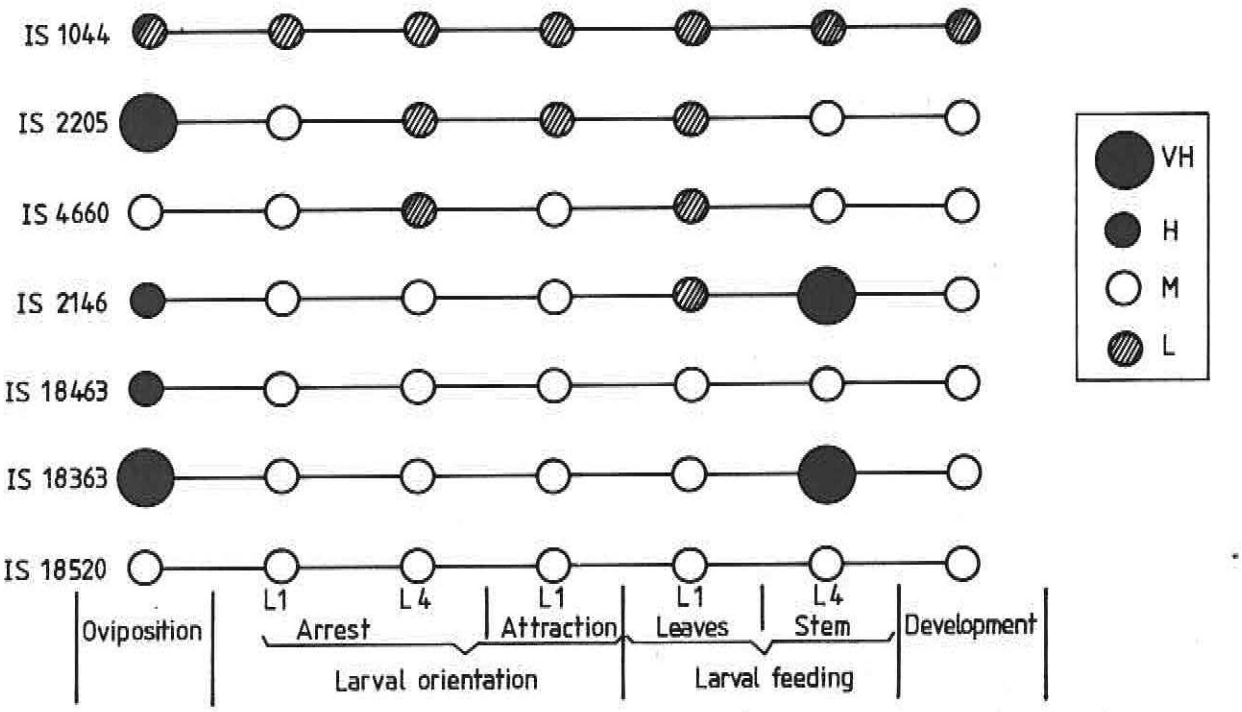

Figure 5. Profiles of seven colonising responses of *Chilo partellus* to seven sorghum cultivars. VH = very high, H = high, M = medium and L = low.

low moisture content and small diameter of the stem pith (as in IS 1044) are responsible for poor settling and growth of the larvae on a resistant cultivar. Among the biochemical characters, volatiles of sorghum plants are collected by a specially designed technique and contain nine major chemicals; the role of these chemicals is under study. Also certain non-volatile chemicals serving as gustatory stimuli (e.g. *p*-hydroxybenzaldehyde) have been identified as feeding stimulants which occur at lower levels in resistant than in susceptible cultivars.

Similarly, response profiles have been established which demonstrate the high resistance of the maize ICZ2-CM or MP 704 and the high susceptibility of the maize Inbred A to *C. partellus;* and the high resistance of the cowpea TVu 946 and high susceptibility of Vita 1 to *M. testulalis.* Studies on the role of plant characters have shown that a higher density of trichomes on maize leaves inhibits oviposition and can thereby contribute to borer resistance.

12.4 Genetics of plant resistance to crop borers

The aim of the study has been to elucidate:

(i) Modes of inheritance of different resistance components.

(ii) Types of gene action involved in the inheritance of these resistance components.

(iii) The most appropriate breeding strategies for improving or incorporating particular resistance traits into a cultivar.

12.4.1 Genetics of resistance in certain sorghum cultivars to Chilo partellus. The inheritance of borer-resistance in sorghum has been studied (results given in Tables 5 and 6) on the basis of crosses of highly resistant IS 1044 and highly susceptible IS 18363 with each other and with their progeny. The resistance appears to be polygenic. Additive gene effects were highly significant for all resistance components, i.e. leaf damage, dead-heart and stem-tunnelling. Dominance and epistasis gene effects were only important for leaf damage. Thus, as additive gene action is more important than non-additive gene action, it is expected that transgressive segregation for a higher level of resistance may result from a cross such as IS 1044 × IS 18363 through a recurrent selection programme.

Table 5. Generation means of different components of resistance of *Chilo partellus* in the cross IS 1044 (resistant) × IS 18363 (susceptible)

Generation	Leaf-feeding (1–5)	Dead-heart (%) (arcsine)	Stem-tunnel (%) (arcsine)
IS 1044 (P_1)	1.1	3.1	24.0
IS 18363 (P_2)	3.3	43.4	45.5
F_1	1.5	6.9	34.3
F_2	1.5	5.0	34.9
BC × P_1	1.2	7.0	29.7
BC × P_2	2.3	20.4	40.8

12.4.2 Genetics of resistance in certain maize cultivars to Chilo partellus. These studies (see Table 7) were based on crosses between the resistant (R) cultivars ICZ1-CM, ICZ2-CM and the susceptible (S) Inbred A. The inheritance of resistance in these cultivars is also polygenic, additive gene action being most important.

Table 6. Estimates of gene effects in a six-parameter genetic model for stem borer resistance in the sorghum cross IS 1044 × IS 18363

Resistance components	*m*	*d*	*h*	*i*	*j*	*l*
Leaf-feeding (1–5)	1.5**	1.1**	0.2	1.0*	2.2**	–0.6**
Dead-heart (%) (arcsine)	5.0**	13.4*	18.3**	34.8**	20.1**	–29.3
Stem-tunnelling (%) arcsine)	34.9**	11.1**	0.9	1.4	21.9**	–4.3

*Significant at 5% level; **significant at 1% level.
m= mean effects
d=additive gene effects
h=dominance gene effects
i=additive × additive gene effects
j=additive × dominance gene effects
l=dominance × dominance gene effects.

Table 7. Generation means of measurements of resistance to *Chilo partellus* in three crosses of maize

Generation	Resistance components		
	Leaf-feeding (1–9)	Dead-heart (%) (arcsine)	Stem-tunnelling (%) (sq. root of $n + 0.5$)
Cross 1			
ICZ1-CM (P_1)	3.6	5.1	3.9
Inbred A (P_2)	4.9	27.3	4.6
F_1	3.6	11.6	4.1
F_2	4.7	20.2	4.2
BC × P_1	3.8	5.7	3.8
BC × P_2	4.1	17.1	4.3
Cross 2			
ICZ2-CM (P_1)	4.1	13.6	3.1
Inbred A (P_2)	4.9	27.3	4.5
F_1	3.5	5.1	4.0
F_2	4.6	16.0	4.0
BC × P_1	3.9	9.0	4.0
BC × P_2	4.1	15.8	4.3
Cross 3			
ICZ2-CM (P_1)	3.6	13.6	3.1
ICZ1-CM (P_2)	4.1	5.1	3.9
F_1	3.3	0.7	2.3
F_2	4.2	14.4	3.4
BC × P_1	3.8	14.3	3.1
BC × P_2	3.9	13.4	3.5

But, unlike sorghum, non-additive gene action (dominance and epistasis) is involved only in the inheritance of dead-heart resistance and this resistance is dominant. Recurrent selection would, therefore, be appropriate for increasing the level of resistance. Heterosis breeding (R × S and/or R × R) can be exploited in F_1 crosses showing good combining ability for yield and borer resistance.

12.4.3 Genetics of cowpea resistance to the pod borer Maruca testulalis. On the basis of crosses of the highly resistant TVu 946 and the susceptible ICV 5 with each other and with their progeny, the pod borer resistance in the cowpea was found to be polygenic. Additive gene action was predominant. The heritability, genetic coefficient of variability and genetic advance in respect of resistance traits were low and suggested slow progress in the selection process. On the basis of these results it is expected that diallel selective mating and single seed descent methods would be effective in increasing the borer resistance levels.

13. BIOLOGICAL CONTROL AS A COMPONENT OF IPM FOR CROP BORERS

Efforts to develop strategies for effective utilisation of natural enemies for crop borer control have concentrated on their parasitoids and pathogens.

13.1 Parasitoids

The studies have concentrated on indigenous rather than on imported parasitoids.

13.1.1 Incidence of parasitoids of crop borers. A list of parasitoids isolated from *C. partellus* on sorghum and maize and *M. testulalis* on cowpea in different parts of Kenya during the course of the project are listed in Table 8. Those found to have potential for use in biological control of *C. partellus* are *Trichogramma mwanzei* on eggs, *Apanteles sesamiae* on larvae, *Pediobius furvus* and *Dentichasmias busseolae* on pupae. For *M. testulalis,* the most important parasitoid is *Tetrastichus sesamiae* on larvae and pupae.

The incidence of these parasitoids has been found to vary with the fluctuations in the population density of the host and the phenological stage of the crops. For example, on both maize and sorghum, the attack of pupal parasitoids of *C. partellus* starts when the plants are 7–8 weeks after emergence (WAE), reaches a peak 10–12 WAE and then declines (Figure 6). However, even at peak levels, the incidence of these parasitoids is quite low, so effectiveness is likely to be reduced. Unlike these pupal parasitoids, the parasitisation of the eggs of *C. partellus* by *T. mwanzei* in Coast Province is quite high, sometimes up to 100%. The parasitisation of the larvae and pupae of *M. testulalis* is also quite low, about 5% in western Kenya.

In view of the above, two strategies are being developed for IPM of crop borers i.e. inundative release of mass-reared parasitoids at appropriate times during the cropping season and augmentation of the natural population of the parasitoids. For both strategies to be effective, it is essential to have adequate information on their biology, ecology, reproductive potential, population dynamics, etc. and to culture them on a large scale. These aspects have been under study on the present project for some years. The greatest progress towards the use of parasitoids as a component of IPM has been made in respect to *T. mwanzei.*

13.1.2 Trichogramma mwanzei: *the egg-parasitoid. Occurrence.* Trichogrammatid parasitoids of *C. partellus* eggs have been found on Rusinga Island (near the ICIPE Field Station at Mbita); in the Lambwe Valley (about 20 km from the field station) and at Mtwapa near Mombasa on the coast. The coast species, *T. mwanzei,* can be collected much more regularly and in greater numbers than

Table 8. Hymenopteran parasitoids of *Chilo partellus* and *Maruca testulalis* isolated in Kenya, plus one dipteran (Tachinidae)

Host	Stage attacked	Parasitoid	Family	Locality
Chilo partellus	egg	**Trichogramma mwanzei*	Trichogrammatidae	Mtwapa
	"	**Trichogrammatoidea lutea*	"	Rusinga I.
	"	*Trichogramma exiguum*	"	Lambwe E.
	"	*Telonomus thestor*	Scelionidae	Mtwapa
	"	*Telonomus nephele*	"	Mtwapa
	larva	*Apanteles sesamiae*	Braconidae	Mbita
	"	*Bracon* sp.	"	"
	"	*Euvipio rufa (?)*	"	"
	pupa	*Hyperchalcidia soudanensis (?)*	Chalcididae	"
	"	**Pediobius furvus*	Eulophidae	"
	"	**Dentichasmias busseolae*	Ichneumonidae	"
Maruca testulalis	larva	*Apanteles* sp.	Braconidae	"
	"	*Bracon* sp.	"	"
	"	*Chelonus* sp.	"	"
	"	Unidentified species	"	"
	pupa	**Tetrastichus sesamiae*	Eulophidae	"
	"	*Antrocephalus* sp.	Chalcididae	"
	"	*Bracon* sp.	Braconidae	"
	"	*Braunsia* sp.	"	"
	"	Unidentified species	Tachinidae	"

*Most promising as bio-control agents.

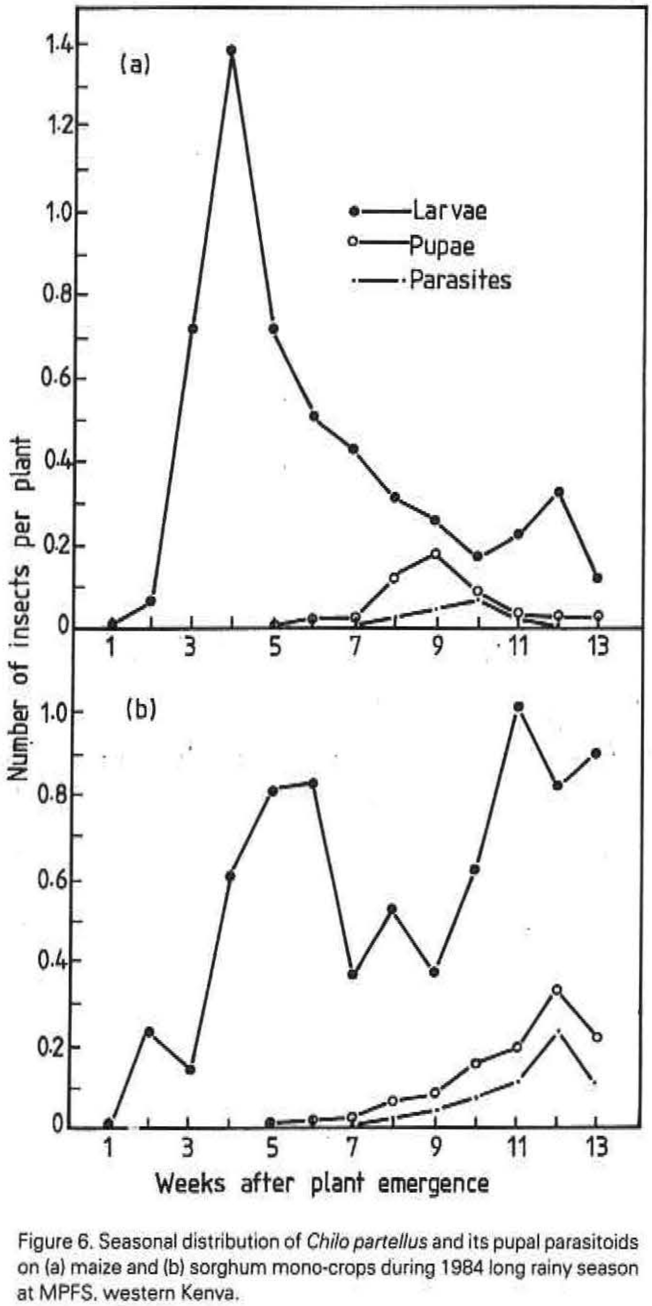

Figure 6. Seasonal distribution of *Chilo partellus* and its pupal parasitoids on (a) maize and (b) sorghum mono-crops during 1984 long rainy season at MPFS, western Kenya.

the others. In view of this, and of its easy laboratory multiplication, subsequent studies have been confined to this species.

Life cycle and production. Laboratory investigations show that *T. mwanzei* completes its life cycle from egg to adult in 8–9 days at 25–28°C and 65–75% r.h. The mean number of adults developing in each *Chilo* egg is 1.9 (range 1–4).

Host preference. The preferences of *T. mwanzei* for the following lepidopterous eggs were studied to determine which is the most suitable for mass culture purposes. *Chilo partellus* eggs are most preferred, the overall mean number of progeny being 24.3 per female *T. mwanzei* in these tests. The next best host is *B. fusca* followed by *E. saccharina. Bombyx mori* eggs are unsuitable for the purpose.

Effect of age of host eggs on progeny production. The eggs of *C. partellus,* when parasitised on the first or second day, yielded maximum progeny (34.6 and 32.1 per female, respectively). This number declined with egg age until day 5, when parasitisation produced no progeny.

Effect of maternal age on progeny production. Maximal progeny production was achieved when *C. partellus* eggs were parasitised by one-day-old *T. mwanzei* females. Thereafter, progeny production declined until it was only 1–2 per female after day 4.

Effect of food sources on longevity and progeny production. Tests showed that maximum survival (4.5 days) and progeny production (30.4 per female) were obtained when the adults were fed on 20% honey or 20% sucrose solution. The nectar from various flowers was no better than distilled water.

Biotic potential. Life-tables have been constructed and show that the net reproductive rate is 49.6, indicating a fairly high potential for use as a bio-control agent.

Rearing. The foregoing information has been most valuable in developing techniques for mass culture of *T. mwanzei* for bio-control of *C. partellus.*

13.1.3 Field release of T. mwanzei *for stem-borer control.* The information presented above has served as

Table 9. Effect on infestation of *Chilo partellus* of releasing batches of 3000 *Trichogramma mwanzei* adults four times at weekly intervals on 20 × 20 m plots of sorghum and maize in farmers' fields in western Kenya

Location	Crop	No. larvae + pupae per 100 stalks at harvest		Reduction in borer population on treated plot
		Untreated plot	Treated plot	
Wasaria (Rusinga)	Sorghum[1]	166	14	91.6
Kodiera (Kanyamwa)	Maize[1]	11	4	63.6
MPFS	Maize[2]	22	5	77.3
Oyugis	Maize[2]	16	5	68.8

1 Long rains, 1988
2 Short rains, 1988

the basis not only for rearing *Trichogramma* on a medium scale, but also for testing it in the field.

Dispersal of T. mwanzei *released in the field.* When the parasitoids were released in 10 × 10 m plots of sorghum in farmers' fields on Rusinga Island, the parasitisation of *C. partellus* eggs was maximal (60–97%) at a distance of 1 m from the release point. With increasing distance, the parasitisation of eggs declined until at 5 m it was 10–40% less. Thus the dispersal pattern from the release point can achieve a fairly high percentage of parasitisation of *C. partellus* eggs.

Effects of T. Mwanzei *release on damage to sorghum by C. partellus.* For this experiment, four batches of 3000 *T. mwanzei* adults each were released in successive weeks in 20 × 20 m plots of sorghum or maize at four sites in western Kenya. The results (Table 9) show that this release resulted in a reduction of borer populations by 63–92% as compared with the untreated plots. These tests clearly demonstrate the effectiveness of *T. mwanzei* for the bio-control of *C. partellus,* and identify it as a prime candidate for inclusion in any IPM package for cereal stem borer control.

13.2 Pathogens

Pathogenic micro-organisms have long been known to cause disease and mortality in insect pests in various parts of the world. Some of these pathogens have also been used for bio-control of insect pests. The possibility of using pathogens for the control of crop borers in this project has been investigated.

13.2.1 Incidence of pathogenic micro-organisms infecting crop borers. Surveys in different parts of Kenya revealed widespread and fatal infections in both larvae and pupae of crop borers. Details of the pathogens recovered from the diseased insects are summarised in Table 10. Most of the bacteria recovered from the insects were *Monococcus* sp. which are non-pathogenic, but a few were *Bacillus* spp. which hold promise as bio-control agents. Similarly, some of the fungi infecting the borers were saprophytic and non-pathogenic whilst others were pathogenic, including *Aspergillus* spp. and *Beauveria* spp. The viruses included granulosis and nuclear polyhedrosis viruses. The protozoans that were isolated were Microsporidia and included *Nosema* and *Vairimorpha.* The nematodes recovered from the larvae included a member of the genus *Panagrolaimus. Nosema, Panagrolaimus, Bacillus thuringiensis* and *Beauveria* have been taken up for detailed studies in this project. The most progress towards practical application of these micro-organisms for bio-control of crop borers has been made with *Nosema.*

13.2.2 Nosema *sp. for bio-control of crop borers.* This pathogen was originally observed infecting the natural populations of *M. testulalis* as well as *C. partellus,* the former being a major host. Since then, a culture has been maintained in the laboratory on *C. partellus* larvae.

Culture and production. Suitable methods of culture and production for experimental as well as field application were developed. The most satisfactory culture method is given here. Cadavers of *C. partellus* larvae killed by *Nosema* infection provide the pathogen for culture. The cadavers are macerated in distilled water which is then filtered through muslin cloth several times to obtain a purified suspension of *Nosema* spores. The concentration of spores in the suspension is determined in a Neubauer counter chamber and adjusted to 1×10^7 ml. Of this suspension 0.5 ml, serving as the inoculum, is placed in a glass petri dish. Third or fourth-instar *C. partellus* larvae, reared on an artificial diet, are dipped into the inoculum for 2–3 sec and then transferred to another petri dish containing the larval diet. Generally 10 larvae can be kept in each dish. When the larvae die, their cadavers are again macerated in water to prepare a suspension of *Nosema* spores as before. The spore yield varies from 1.3×10^6 to 4.9×10^8 spores per larva. The third instar is the most appropriate stage for spore production.

This method can be adapted either for small scale production at rural community/village level or for large scale production. The culture can be maintained in re-usable plastic containers. A team of three persons is adequate to handle the culture operations, mainly the preparation of larval diet and harvesting the infected dead larvae. As many as 1000 larvae per day can be produced. These larvae, with a mean yield of 10^7 spores per larva, will yield the material for 1000 litres of inoculum per day at a concentration suitable for spraying to control *C. partellus.*

Table 10. Pathogens infecting *Chilo partellus (Cp), Eldana saccharina (Es), Busseola fusca (Bf)* and *Maruca testulalis (Mt)* larvae sampled from sorghum and cowpea at different phenological stages

Pathogens	Host	No. sampled	No. infected	% infection[1]
Bacteria	*Cp, Bf, Mt, Es*	243	189	77.8
Fungi	*Cp*, Bf, Mt*	240	46	19.2
Viruses	*Mt*, Cp*	231	3	1.3
Protozoa	*Mt*, Cp*	241	19	7.9
Nematodes	*Cp*, Es, Bf*	241	7	2.9

[1]N.B. There were some multiple infections.
*Major host.

Bio-control potential of Nosema: *screenhouse trials.* The possibility of using *Nosema* as a bio-control agent for *C. partellus* on sorghum and maize was tested by applying the pathogen to sorghum plants in a screenhouse. The plants were arranged in three groups. Group 1 were infested with *C. partellus* eggs and sprayed with a semi-purified aqueous suspension of *Nosema* spores (1.5 × 10^6 spores/ml), using a hand sprayer at the rate of 1.0 ml per plant. The plants in group 2 were infested with larvae but were not sprayed with *Nosema* suspension. The plants in group 3 were non-infested, non-treated controls. The results (Figure 7) showed that the damage to sorghum plants (incidence of dead-hearts) infested with larvae and treated with *Nosema* was greatly reduced, and the development of heads of grain was consequently much greater than in the infested untreated plants. Foliar application of *Nosema* has thus been demonstrated to have major potential as a control agent for *C. partellus.*

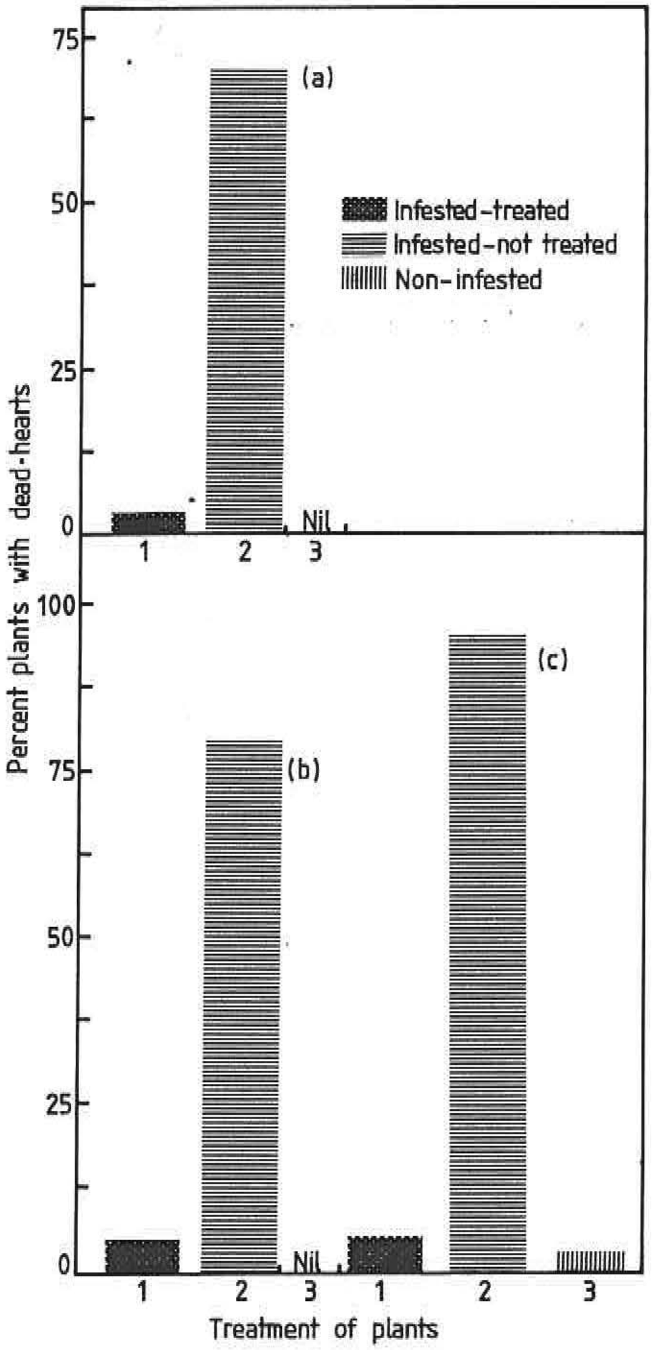

Figure 7. Incidence of dead-hearts in sorghum infested with first-instar *Chilo partellus* larvae (a) 40 days (b) 51 days and (c) 90 days after plant emergence, with and without treatment with *Nosema* sp.

Factors determining the effectiveness of Nosema *for controlling* C. partellus. Solar radiation is known to inactivate various microbial pest control agents, usually by the action of the u.v. component. The effects of solar radiation on *Nosema* were investigated by exposing pathogen-treated plants to sunlight for periods of varying duration. Sorghum plants were infested with first-instar *C. partellus* larvae introduced into the leaf funnel, and all were showing foliar damage (at a score of 1) by the third day. They were then inoculated with *Nosema* at 08.00, 10.00, 12.00, 14.00, 16.00 and 18.00 hours.

Further foliar damage was stopped in most of the plants by the application of *Nosema*. Dead-heart formation remained high only in the infested non-inoculated controls, where 23.3% plants were damaged by the fifth week after infestation. The highest level of dead-heart formation in the *Nosema*-inoculated plots at this time was 11.2% in the rows treated at 10.00 h. There were no differences in the reduction in the number of larvae per plant although they were treated at different times of day. Even treatment at midday did not reduce pathogen activity. These results indicate that exposure of *Nosema* to sunlight is not important in limiting its effectiveness.

The timing of application of *Nosema* has been tested both before and after the infestation of sorghum plants with borer larvae. When the pathogen was applied to the plants after larval infestation, damage was low if *Nosema* was applied within seven days of infestation. But if pathogen application was further postponed plant damage increased, particularly 11 days after infestation. The development of heads or grain was highest if the pathogen was applied no later than 1–7 days after infestation.

When the pathogen was applied to the plants before infestation with larvae, there was a significant reduction in the damage and yield loss according to the timing of application. If *Nosema* was applied at the egg stage of *C. partellus,* the damage to treated plants was much less than that on untreated plants. Subsequently, the formation of heads/grain on the *Nosema*-treated plants was 98.3% compared to 64.9% on untreated plants, thereby increasing the yield by about one-half.

The application of *Nosema* spores to sorghum plants before infestation with *C. partellus* larvae also reduced plant damage, provided the pathogen was applied less than 3 days prior to infestation. However, a greater time-gap increased the damage. Consequently, the formation of heads and grain was also reduced (Table 11).

It is clear, therefore, that the timing of *Nosema* application to plants is important. The correct timing can be judged by monitoring *C. partellus* populations in the fields through pheromonal or light traps.

Table 11. Success in formation of heads in sorghum plants inoculated with spores of *Nosema* sp. and infested with first-instar *Chilo partellus* larvae on different days after inoculation

Days after inoculation	Fully formed	Partly formed	Not formed	Chaffy head
Control*	51.4[a1]	37.1[a]	8.6[b]	2.9bc
1	44.4[a]	44.4[a]	11.2[b]	0.0c
3	31.6[a]	37.1[a]	25.7[ab]	5.6[abc]
5	5.6[b]	16.7[a]	69.4[a]	8.3[abc]
7	0.0[b]	25.0[a]	62.9[a]	12.1[abc]
9	0.0[b]	22.2[a]	65.7[a]	12.1[abc]
11	3.6[b]	25.0[a]	36.1[ab]	35.3[ab]
13	0.0[b]	28.6[a]	29.8[ab]	41.6[a]
19	39.5[a]	50.0[a]	6.7[b]	3.8[abc]
Control**	47.7[a]	37.2[a]	2.8[b]	12.3[abc]

* Pest-free plants.
** Plants infested at 19 days, but not inoculated.
[1] Numbers in each vertical column followed by the same letter are not significantly different by Duncan's Multiple Range Test ($P > 0.05$).

13.2.3 The nematodes Panagrolaims *sp. for the biocontrol of crop borers.* Insect-eating nematodes are important biological control agents against crop borers because of their ability to seek out and destroy their insect prey in stem tunnels or within pods. The application of entomophagous nematodes like *Neoplectana carpocapsae* as a tool in IPM of certain insects of orchard crops has already started.

An indigenous nematode strain was isolated from stem borers at MPFS. Laboratory bio-assays revealed that all three target crop borers *(C. partellus, B. fusca* and *M. testulalis)* were susceptible to the nematode. Furthermore, limited small-scale spray applications of the nematode on sorghum plants artificially infested with *C. partellus* under screenhouse conditions showed the crop can be protected from stem borer damage and yield loss.

To examine the possibility of using this nematode as a component for the management of stem borers, studies were undertaken on the distribution of the nematode in western Kenya and the development of techniques for mass production in artificial media.

Distribution of Panagrolaimus *sp. in western Kenya.* The initial phase of this work has been limited to the Lake Victoria Basin area of Kenya where the nematodes were isolated from 25% of all sample plots, but especially from moist soils containing a high percentage of sand or organic matter (30% and 35% respectively), rather than loams and clay soils (10–15%). Nematodes were usually found in the upper layers of the soil at depths of less than 40 cm. The work will eventually be expanded to embrace the rest of the ecological zones of Kenya.

Mass production of Panagrolaimus *in artificial media.* The conventional method of multiplying the nematode in its insect prey is both tedious and uneconomical for practical application. An artificial diet has been developed on the Project and evaluated for production of the nematode. It contains beef liver (20 g), technical agar (0.5 g), sodium chloride (0.5 g) and water (100 ml). This diet has been found to be very convenient and cost-effective for the artificial production of the nematode.

13.2.4 Bacillus thuringiensis *for bio-control of crop borers.* Several strains of *B. thuringiensis* are known to be effective bio-control agents for various insect pests. However, little is known about these bacteria and their activity against the major crop borers in Kenya. Hence the study of such bacteria has been pursued in order to develop and evaluate methods for bacterial control of these pests. The study was initiated with *C. partellus* and emphasis has been on the indigenous rather than the exotic or commercial strains of bacteria.

Surveys throughout Kenya have yielded 62 new bacterial isolates which have been provisionally identified as *B. thuringiensis* strains. Tests of pathogenicity to *C. partellus* larvae have revealed four strains that are even more toxic than 38 exotic strains which were also tested.

Screenhouse tests with these toxic *B. thuringiensis* strains were conducted by spraying bacterial formulations on the sorghum plants 24 h after infesting with *C. partellus* neonate larvae. Damage to the treated plants was reduced in varying degrees relative to untreated infested plants. In addition, treated plants showed a corresponding reduction in yield loss. Two *B. thuringiensis* strains, collected in Mombasa and Busia, were particularly effective in protecting the plants and reducing damage to a minimum. Further work is therefore justified to exploit their use as bio-control agents.

14. INSECT MASS REARING

It was essential to have large cultures of the target crop borers, particularly *C. partellus* and *M. testulalis,* available for experiments to further the research and development activities on IPM components described above. This also opened the way for mass breeding of *T. manzei* on *C. partellus* eggs.

The diet that has been developed for the mass production of *C. partellus* is simple and effective (with 70–80% recovery) and its ingredients are available locally. The composition is given in Table 12. The methodology for rearing *M. testulalis* on natural as well as artificial diets has also been successfully developed. These diets for mass production of crop borers for experimental use could be used by the national programmes.

Table 12. Composition of the artificial diet developed for *Chilo partellus*

Ingredients	Quantity
Fraction A	
1. Bean powder	137.00 g
2. Sorghum leaf powder	50.00 g
3. Brewer's yeast	10.0 g
4. Vitamin E capsules	1.30 g
5. Ascorbic acid	3.25 g
6. Sorbic acid*	1.25 g
7. Methyl-*p*-hydroxybenzoate*	2.00 g
8. Benlate*	1.25 g
9. Distilled water	625.0 ml
Fraction B	
10. Agar	12.75 g
11. Distilled water	500.0 ml
Fraction C	
12. Formaldehyde 40%*	2.5 ml

* Antimicrobial compounds.

15. PILOT ON-FARM TRIALS OF IPM COMPONENTS IN KENYA

Research and development of two IPM components for the management of stem borers on sorghum — that is intercropping sorghum or maize with cowpea, and the use of stem borer resistance in selected sorghum or maize cultivers — has reached a stage when they can be combined and tested on farmers' fields under their own management.

The pilot trials are being conducted in collaboration with ICIPE's Social Science Interface Research Unit and extension staff of the Ministry of Agriculture. On the basis of surveys, 50 resource-poor small-scale farmers were identified in western Kenya, 25 each in the Kendu Bay and Oyugis Divisions (see Figure 8). Each farmer has adopted the farming practices and cropping patterns recommended:

(i) Sorghum, as shown in Table 13.

(ii) Maize cultivar V 37 monocrop; KRN1 monocrop; maize V 37 intercropped with cowpea ICV 2; KRN 1 intercropped with ICV 2; maize hybrid monocrop.

During the long and short rainy seasons of 1988, these cropping patterns demonstrated the advantages of intercropping, as well as the use of selected sorghum or maize

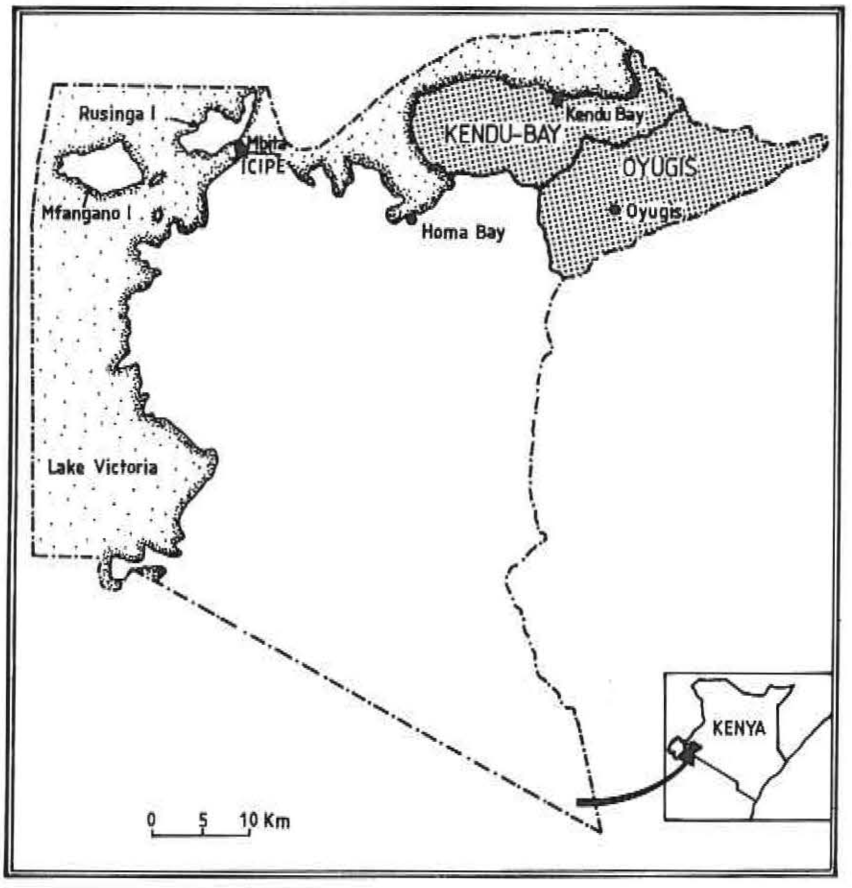

Figure 8. Map of Kenya showing the location of ICIPE, Mbita and project sites, (Kendu-Bay and Oyugis).

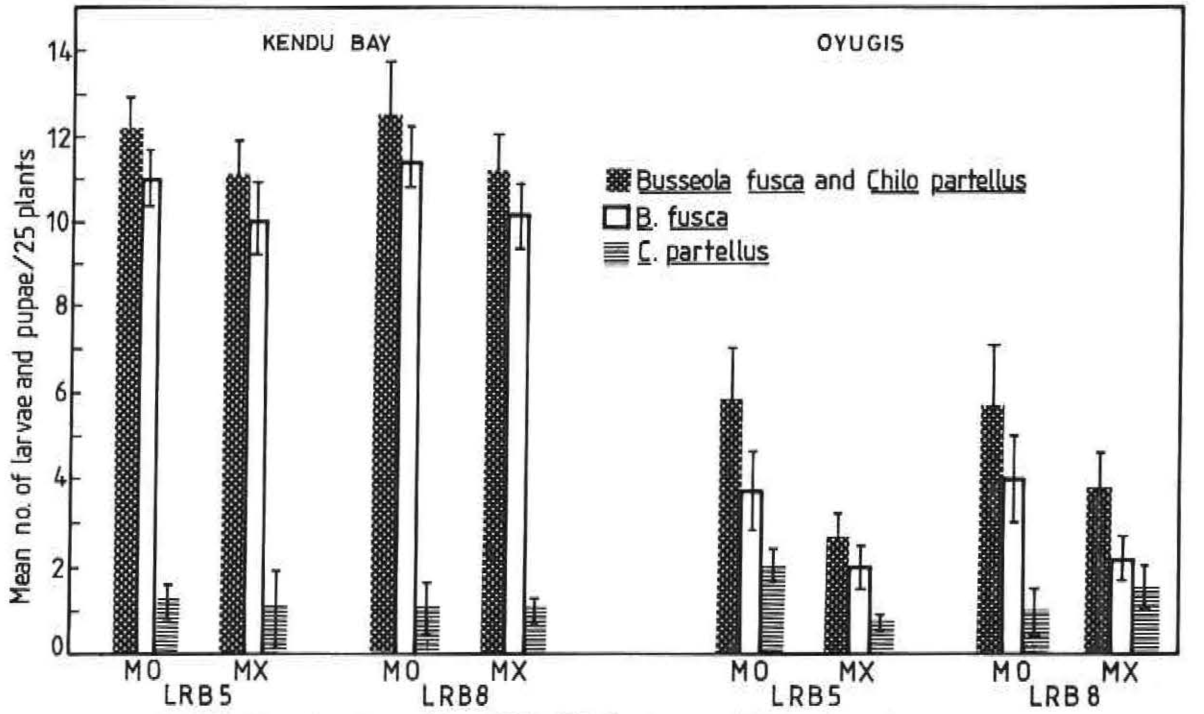

Figure 9. Effect of sorghum cultivars (LRB 5, LRB 8) and cowpea (ICV 2) and cropping patterns on infestation by stem borers in farmers' fields in Kenya (bar equals ± 1 s.e.; Mo, monocrops; Mx, intercrops).

cultivars, in keeping the borer attack low and increasing the grain yield.

Illustrating the results of these trials for sorghum, the population density of the larvae plus pupae of *B. fusca* plus *C. partellus* on LRB 5 and LRB 8 monocrops was almost equally lower than that on farmers' own sorghum at both Kendu Bay and Oyugis (Figure 9). This density was significantly reduced on intercropping each of the two cultivars with the cowpea ICV 2 in Oyugis (Figure 9). But in Kendu Bay such an intercropping effect was not marked. The results were similar in respect of the percentage of sorghum plants damaged by the two stem borer species (Figure 10).

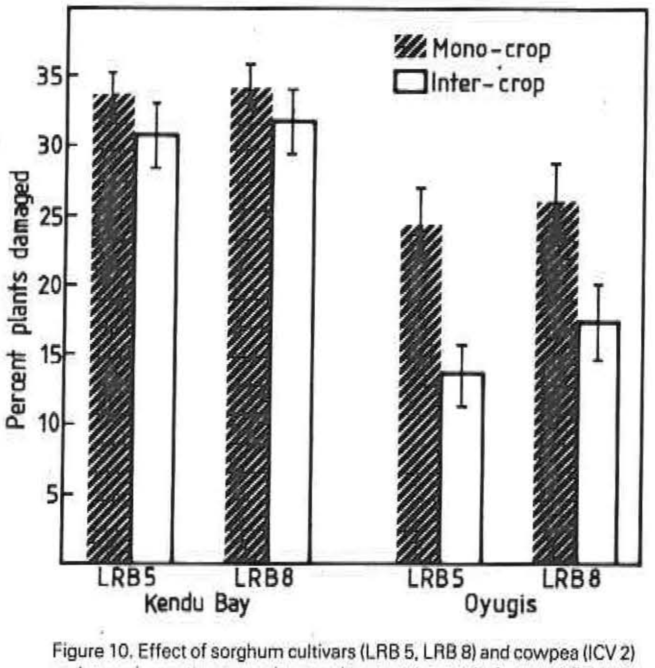

Figure 10. Effect of sorghum cultivars (LRB 5, LRB 8) and cowpea (ICV 2) and cropping patterns on damage by stem borers in farmers' fields in Kenya (bar equals ± s.e.).

The effects of the two IPM components on the sorghum grain yield were also quite evident (Table 13). The increase in the yield (Table 14) of both the sorghum cultivars as monocrops, over the farmers' own sorghum monocrop, varied from 13.4% for LRB 8 in Oyugis to 53.0% in Kendu Bay for LRB 5. Intercropping these sorghum cultivars with the cowpea ICV 2 resulted in a further increase in the grain yield over that of the farmers' own sorghum monocrop by 21.7% for LRB 8 in Oyugis to 62.0% in Kendu Bay for LRB 5. Cowpea intercrops of LRB 5 and LRB 8 also gave additional yields ranging from 5.4% to 17.4% relative to the monocrops of the same cultivars.

These trials thus demonstrate on sorghum the effectiveness of the two IPM components, in combination, for reducing the incidence of stem borer attack and the yield losses they cause. Also, these trials provide a basis for extending our work in the same area and the details of this are now being developed. Extension of this package to Zambia and Somalia has commenced and further country extensions are planned.

Table 13 Mean (± s.e.)sorgum grain yield (g/25m^2) showing advantage of using ICIPE's IPM components in farmers' field trials in two divisions in western Kenya. including an intercrop with cowpea (ICV 2) (long rainy season 1988)

Crops grown	Oyugis (6)*	Kendu Bay (16)*
Farmers' own mono crop	4045 ± 877	3176 ± 271
LRB 5 mono crop	5103 ± 677	4857 ± 472
ICV 2 mono crop	325 ± 65	742 ± 160
LRB 5 intercrop	5992 ± 741	5140 ± 485
ICV 2 intercrop	277 ± 57	437 ± 85
LRB 8 mono crop	4589 ± 566	4579 ± 464
LRB 8 intercrop	4924 ± 604	5119 ± 515
ICV 2 intercrop	192 ± 37	321 ± 56

*No. of farmers participating in the trial.

Table 14 Percentage increase in sorghum grain yield showing advantage of using ICIPE's IPM components in farmers' field trials in two divisions in western Kenya, including an intercrop with cowpea ICV 2 (long rainy season 1988)

	% grain yield increase	
Factor	Oyugis(6)*	Kendu Bay(16)*
LRB 5 mono crop over farmers' mono crop	26.2	53.0
LRB 5 intercrop over farmers' mono crop	48.1	62.0
LRB 5 intercrop over mono crop	17.4	.5.4
LRB 8 mono crop over farmers' mono crop	13.4	44.2
LRB 8 intercrop over farmers' mono crop	21.7	61.2
LRB 8 intercrop over mono crop	7.3	11.8
Intercropping advantage (land equivalent ratio, LER)		
LRB 5	1.9	1.6
LRB 8	1.7	1.6

*No. of farmers participating in the trial.

16. TRAINING

Considerable training has been undertaken at postdoctoral, doctoral and technologist levels. In addition, training of national extension staff has also occurred where joint trials have been instituted e.g. in Kenya, Somalia and Zambia. A list of nationals trained is shown at Appendix I.

APPENDIX I

TRAINING

Countries whose nationals have received training during the project

A. Post Doctoral Research Fellows

Cameroon	1
Ghana	2
India	1
Sierra Leone	1
Vietnam	1
Uganda	1
	7

B. Masters Programme

M. Phil. in Insect Science specializing in biological control; four classes (1985–1988)

Cameroon	1
Kenya	5
Nigeria	3
Sierra Leone	2
Tanzania	1
Uganda	1
	13

C. Doctoral Programme

West Germany	1
Kenya	8
Malawi	1
Sudan	1
Tanzania	2
Uganda	5
Zambia	1
	18

D. Training: scientists

Ghana	1
Ivory Coast	1
Nigeria	1
	3

E. Training: technicians

Mozambique	1
Somalia	1
Uganda	3
Zambia	1
	6

APPENDIX II

COLLABORATING INSTITUTIONS

International

Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Mexico

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

International Institute of Tropical Agriculture (IITA), Nigeria

International Rice Research Institute (IRRI), Philippines

National

Kenya

Mozambique

Somalia

Tanzania

USA

Zambia

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