STUDY WORKSHOP ON POST-HARVEST LOSSES OF CEREAL CROPS IN AFRICA DUE TO PESTS AND DISEASES

REPORT

UNITED NATIONS
ECONOMIC COMMISSION
FOR AFRICA (ECA)

THE INTERNATIONAL
CENTRE OF INSECT
PHYSIOLOGY AND ECOLOGY (ICIPE)

STUDY WORKSHOP ON ON-FARM AND POST-HARVEST LOSSES OF CEREAL CROPS IN AFRICA DUE TO PESTS AND DISEASES

REPORT

UNITED NATIONS
ECONOMIC COMMISSION
FOR AFRICA (ECA)

THE INTERNATIONAL
CENTRE OF INSECT
PHYSIOLOGY AND ECOLOGY (ICIPE)

TABLE OF CONTENTS

BACKGROUND

The importance of reducing food losses has been accepted as a matter of priority by the member countries of the United Nations. In the African context, the Lagos Plan of Action (1980) and the Africa Priority Programme for Economic Recovery recommended a drastic reduction of such losses as an important element in the global strategy of increasing food production and availability. In the past, laudable efforts to controlling crop pests have been made by most member countries. More recently, actions aimed at reducing post-harvest food losses have also been promoted.

Unfortunately, despite these efforts, food losses in Africa are still unacceptably high. The following elements are characteristic of the problems encountered which have contributed to this prevailing situation:

1. Reliable data on crop losses in cereal grains are scarce in Africa.
2. Most of the data, in particular for pre-harvest losses, are subjective and are difficult to relate to cultivars, growing conditions, climatic regions, farming practices, etc.
3. Scattered references to methodologies of crop loss assessment can be found in the published and unpublished literature, but the availability, practicability and reliability of these methods are not well known to the countries concerned.
4. Practical methodologies to determine the magnitude of the losses in connection with farming systems research are not available or have not been tested sufficiently. There is also a scarcity of methodologies concerning losses caused by locusts and other migratory pests.
5. There is a need for crop loss data but the collection of statistically reliable data through surveys and experimentation on a country wide or regional basis is generally very expensive and requires considerable manpower and infrastructure.

Data on pre- and post-harvest losses caused by arthropod and vertebrate pests and diseases:

- provide essential information to the decision-maker to assign meaningful priorities and resources to optimize investment in research and development.
- allow for rational decision-making on the need for pest control including the judicious use of pesticides.
- are very relevant to the development of pest control strategies and to the assessment of their effectiveness.

Based on these considerations, the United Nations Economic Commission for Africa (ECA) and the International Centre of Insect Physiology and Ecology (ICIPE) decided to hold the present Workshop with a view to:

(a) reviewing the present status of such losses in Africa;
(b) reviewing the methodologies for assessing and monitoring crop losses;
(b) planning future strategies for assessing and monitoring the losses, and applying these activities to agricultural development programmes aimed at increasing food crop production.

Summary and Recommendations

I. INTRODUCTION

1.1 Place of the Workshop within the ECA Programme of Activities

1. In conjunction with resolution 3362(S-VII) adopted in 1975 by the United Nations General Assembly calling for a drastic reduction of post-harvest food losses, and Lagos Plan of Action (1980) which urged African member States to promote and sustain action for reducing food losses both at the pre- and post-harvest stages, the ECA incorporated a series of activities into its regular programme designed to assist member countries achieve these goals. In doing so, the ECA benefited from the support of some donor countries, including Belgium and the Federal Republic of Germany. In close collaboration with the Food and Agriculture Organization (FAO), the Commission carried out several loss assessment studies at the subregional level and at national level at the request of member countries. Also, ECA planned to organize subregional seminars and workshops for the period 1986 to 1987. The first meeting of the series was organized at Lome (Togo) from 9 to 13 February 1987 and addressed experts in countries of the West African subregion.

2. The ECA reached an agreement with the International Centre of Insect Physiology and Ecology (ICIPE) for the implementation of a certain number of joint activities aimed at combating food losses. These include:

- the implementation of a pilot project on "Reduction of Food Losses through Insect Pest Management and Use of Small-Scale and Low-Cost Farm Equipment";
- the establishment of an "African Regional Pest Management Research and Development Network" (PESTNET); and
- the implementation of a Subregional Maize Research Programme for Eastern and Southern Africa.

Being an Africa-based institute for advanced research in insect science and its application, ICIPE has been able to achieve significant breakthroughs in fundamental research and develop strategies for the management of key insect pests of crops, livestock and vectors of human diseases within a relatively short period of time with regard to crop pests, ICIPE has developed control methods which are environmentally safe and both technically and economically feasible for the African resource-poor farmers. The Centre initially concentrated its research efforts on the insect pests of major African staple food crops including sorghum, maize and cowpea.

Based on the collaborative agreement and ICIPE's research experience on the assessment and reduction of on-farm food losses, the ECA decided to organize with the Centre, the present study workshop on "On-Farm and Post-Harvest Losses of Cereal in Africa due to Pests and Diseases". The workshop was to address mainly experts in these fields from member countries of the Eastern and Southern Africa subregion.

1.2 Objectives of the Workshop

3. The workshop aimed to bring together scientists from Eastern and Southern Africa, and experts from outside Africa involved in these research areas with a view to:

(i) reviewing the present status of food losses both at the pre- and post-harvest stages in Africa;

(ii) planning future strategies for assessing and monitoring crop losses; and

(iii) planning future strategies for assessing and monitoring such losses, and for applying these activities to agricultural development programmes aimed at increasing food crop production.

1.3 Organisation of the Workshop

4. *General*

Arrangements for the workshop were handled by ECA and ICIPE, and included defining the main themes, preparation of programme, selection of invited experts and establishment guidelines for the preparation of country papers. Both organisations contributed financially to meet costs related to organizing the meeting.

The workshop was held at the ICIPE Duduville International Guest Centre, Nairobi, Kenya from 11 to 16 October 1987. Twenty-nine participants actively took part in the meeting. These included representatives of member countries of the Eastern and Southern Africa subregion, invited experts from within and outside Africa and representatives of FAO, ICIPE and ECA. Crop loss reports and technical papers, followed by a discussion session, were given for the countries representated at the workshop. Two field visits, one to the ICIPE Mbita-Point Field Station and a second to the site of ECA/ICIPE project on "Reduction of Food Losses through Insect Pest Management and Use of Small-Scale and Low-Cost Farm Equipment", at Oyugis, were undertaken.

Programme

The programme of the workshop as drawn up and implemented is attached to this report as Annex I.

5. *Attendance*

The workshop was attended by 14 experts from 7 countries of the Eastern and Southern Africa subregion, namely Botswana, Ethiopia, Kenya, Malawi, Tanzania, Uganda and Zambia. Additional participants included 6 experts from the Overseas Development Natural Resources Institute (ODNRI, United Kingdom); 1 expert from the Gesellschaft fur Technische Zusammenarbeit (GTZ, Federal Republic of Germany); 1 expert from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); 1 expert from the International Red Locust Control Organisation for Central and Southern Africa; 1 expert from the East African Armyworm Project, Desert Locust Control Organization for Eastern Africa; 3 experts from the Food and Agriculture Organization (FAO); and 8 experts from ICIPE. Three ECA Staff members including the Director of the Joint ECA/FAO Agriculture Division also attended the workshop. The list of participants is attached to this report as Annex II.

1.4 Official Opening

6. The official opening ceremony of the workshop took place on Sunday 11 October 1987 and was presided over by the Honourable Minister for Research, Science and Technology of the Gorvernment of Kenya, Mr. W. Ndolo Ayah. Preceeding the Minister, Professor Thomas R. Odhiambo, Director of ICIPE and Dr. Samuel C. Nana-Sinkam, Director of the Joint ECA/ FAO Agriculture Division gave introductory remarks to the workshop.

7. Professor Odhiambo said the awareness of African leaders of the importance of crop protection and need to prevent post-harvest food losses, led to their commitment to support the Lagos Plan of Action in 1980. He noted that such support from African governmentsis fully justified by the great amount of food lost to pests and diseases which is as high as 60 per cent. He also mentioned that although losses vary greatly from one location to another, there is a need to find appropriate methods of loss assessment which would provide the basis for the adoption of feasible control strategies. The Director of ICIPE urged participating scientists to pursue efforts towards eradicating crop diseases and pests as they are part of the cause of Africa's food crisis. He also noted to participants that the present workshop which falls within the framework of the collaborative activities of ICIPE and ECA should present few, but practical recommendations which could lead to practical follow-up actions in favour of the African farmers and more particularly the resource poor ones.

8. Dr. Nana-Sinkam welcomed country representatives and invited experts on behalf of the Executive Secretary of ECA and the Director-General of FAO. He then gave a gloomy picture of Africa's food and agricultural sector and noted that the issue is so preoccupying that it was focussed in the Africa Priority Programme for Economic Recovery (APPER) and the United Nations Programme of Action for Africa Economic Recovery and Development (UN-PAAERD). The Director of the Joint ECA/FAO Agriculture Division pointed out that in the midst of food shortage, annual food losses in Africa are unacceptably high, particularly when ways of preventing them exist. He warned scientists, however, that successful research activities aimed at tackling this problem must be conducted whilst taking into account the specific requirements of the continent. He also pointed out that research for the sake of research will not contribute that much to solving the problem and that what is research aimed at attaining a practical objective. Dr. Nana-Sinkam continued by giving a brief on actions taken so far by African member countries, development agencies, international research centres and the United Nations system. He mentioned that FAO initiated several catalytic projects for the benefit of member states and that ECA, in conformity with the recommendations of the Lagos Plan of Action, undertook several related activities including studies and projects at the subregional level. The director ended his statement by expressing his satisfaction with the collaboration with the ICIPE which, he said, has, in a short period for a research institute, made significant breakthroughs in elucidating sound and economical methods of deviating some of the problems of African farmers.

9. The Honourable Minister, after welcoming participants to Kenya, noted that although agricultural technology brought about significant and rapid increase in productivity of various crops in most parts of the world, the impact of such technologies has been limited in Africa where the agricultural production has not been able to keep pace with the increasing demand of food for the growing population. He then mentioned that although there are a number of factors responsible for such a shortfall in the availability of food, one of the major constraints to boosting agricultural production in Africa has been the vulnerability of crops to pests and diseases, both at the pre- and post-harvest stages. He also observed that this vulnerability can even be worse in some cases where high yielding varieties are used. In view of the great importance of pests, great emphasis must be placed on their control. The Honourable Minister recalled that this workshop is part of the joint activities of the UN Economic Commission for Africa and ICIPE and that the efforts of both organizations to increasing food production and availability in Africa are laudable. He hoped that participating scientists will exchange vital information in this field and that deliverations will provide guidelines for future strategies of assessing, monitoring and controlling crop pests. Mr. Ayah then declared the workshop officially opened.

II. TECHNICAL THEMES DISCUSSED

The workshop included presentation of 10 technical papers on the following main topics:

(i) assessment of on-farm losses in main cereal crops including millet, sorghum, maize and rice;

(ii) assessment of on-farm losses caused by agents such as diseases, insect pests, birds and other vertebrate pests and soil pests;

(iii) assessment and control of post-harvest food losses with special reference to the status of the the greater grain borer, *Prostephanus truncatus* and to storage methods; and

(iv) FAO's experiences with crop loss assessment.

II.1 Assessment of On-Farm Losses in Main Cereal Crops

This topic was covered by four technical papers and each dealt with a specific crop.

II.1.1 On-farm losses in Millet

The paper was prepared and presented by Dr. Kenayo F. Nwanze, principal cereal entomologist at ICRISAT, Hyderabad, and the salient of his presentation includes the following:

The four major food millets in Africa are: pearl millet (*Pennisetum americanum* L.), foxtail millet (*Setaria italica* Beauv.), proso millet (*Panicum miliaceum* L) and finger millet (*Eleucine coracana* Gaertn.). Of these, pearl millet and finger millet are the most common types grown. Finger millet is relatively free of insect pests, and the most frequently occurring pest species of pearl millet are also pests of other crops. These include seedling pests, foliage insects, stemborers and panicale pests. There are few insect pests for which accurate data are available on crop losses in farmers' fields in Africa. On millet actual data are available for two pests, namely the millet stemborer (*Acigona ignefusalis*) and the head caterpillar (*Raghuva albipunctella*). This paper presents results from on-station research trials, on-farm pest surveys and on-farm trials. They are discussed under the following: (1) incidence ratio; (2) visual score paired analysis; (3) damage intensity loss ratio; (4) quantitative assessment (insecticide trials).

Incidence Ratio

In Senegal, Vercambre (1978) found that maximum panicle damage by *Raghuva* only reduced potential yields by 50-60 per cent even when 100 per cent of the panicles were infested. Studies by ICRISAT (1981, 1984) have permitted the mapping out of infestation rate and damage ratings for *Raghuva* and *Acigona* in Burkina Faso and Niger.

Visual Score Paired Analysis

Harris (1962) found that unbored stems could yield more than bored stems with associated attack by *Raghuva* as a result of better growth characteristics and healthy stems leading to higher yields. In a separate experiment yield loss was projected at 15 per cent. In trials at ICRISAT (1983), the highest yield loss due to *Raghuva* (14.9%) was recorded on an improved millet variety (CIVT) and the lowest (0.8%) was recorded on the local cultivar. In another set of village studies (ICRISAT, 1984) grain loss was due to *Raghuva* was estimated at 14 per cent.

Damage Intensity Loss Ratio

Vercambre (1978) estimated that 110,000 tones of grain were lost in Senegal in 1974 and Breniere (1974) reported a loss of 74,000 tones in Niger in the same year. Studies by Guevremont, (1983) in Eastern Niger showed that loss in grain weight due to *Raghuva* varied between 0.4 and 1.0 g for a mean yield of 34 g per panicle.

Insecticide Trials

Guevremont, (1982, 1983) recorded a yield loss of 6 per cent, calculated from yield differences between protected and unprotected crops, where almost 50 per cent of the panicles had *Raghuva* damage. Gahukar *et al.* (1986) have reported that in Senegal in 1981 and 1982 yield losses due to *Raghuva* varied from 3-82 per cent in Sine Saloum and 15-20 per cent in Louga. Correlations were established between egg or larval incidence, grain damage and yield loss. Studies by ICRISAT (1986) in Niger showed that estimated grain loss due to *Raghuva* varied between varieties: HKBtif, 41 per cent, CIVT 17 per cent and the local 8 per cent. For Acigona, the results showed that low levels of borer infestation resulted in an increase in yield. The data presented indicate a range of loss figures for both pests of millet, and indicate the need for standardization of methodologies for estimating losses on a regional scale. The paper also emphasizes the need to view crop loss assessment as a tool in pest control and a component within a crop management programme.

II.1.2 On-farm losses in sorghum

The presentation by Dr. K.V. Seshu Reddy, Senior Research Scientist at the ICIPE is summarized as follows:

Sorghum is an extremely important staple food for millions of people in many parts of Africa and other tropical countries. The grain yields of this crop on peasant farms are low. One of the major factors inducing instability in yields is insect pests. In Africa, the insect pests causing the most significant losses in sorghum are: the shoot fly (*Atherigona soccata*); several species of stem borers (*Chilo partellus, C. olichalcociliellus, Busseola fusca, Acigona ignefusalis, Sesamia calamistis, S. cretica, Eldana saccharina);* midge *(Contarinia sorghicola);* and a range of head bugs (*Calocoris angustatus, Erystylus* spp., *Agonoscelis pubescens, Creontiades pallidus, Calidea dregii, Campylomma* spp., *Spilostethus* spp.)

Sorghum, as a crop, has a low cash value and low yields, so insecticidal control in most instances is ruled out. However, studies on yield losses caused by the insect pests are scanty or non-existent in some countries. Therefore, yield loss assessment in sorghum forms an important tool in Integrated Pest Management (IPM), because it is the standard guide against which control strategies are tested and improved.

In assessing the potential yield losses by identified pests, a number of factors must be taken into consideration. These include: incidence and degree of infestation, stage of the crop when attack occurs, yield potential of crop due to agronomic and other related reasons, crop variety and the inherent capacity of the infested plants to overcome, tolerate or compensate for pest damage.

The quantitative losses caused by different insect pest species may be obtained through the following methods:

1. Estimation of losses through visual scores.
2. Comparison of yields from different fields having different degrees of infestation.
3. Comparison of the average yields of individual plants free from natural infestation by pests with that of the infested plants in the field.
4. Comparison of yields of sprayed (protected) and unsprayed (unprotected) plants.
5. Release of varying number of insects on plants enclosed in cages and correlate damage/yield with the insect density.

The studies on yield losses in sorghum caused by stemborers show that the age of the plant at the time of infestation and the larval density are important factors. The grain losses may vary from one species of stemborer to another, cultivar to cultivar and between seasons and locations.

For crop loss assessment studies, on national basis, the use of unprotected and insecticide protected plots at a number of locations on subsistence farmer fields, over a number of years, can indicate the extent of losses due to a range of pests. However, in order to assess the grain losses in sorghum caused by a single insect pest species, the cage method is best.

In Africa, there is an urgent need to study the extent of grain yield losses in sorghum, and in several other food crops. Also, the extension workers should be trained to recognize the pest population and crop growth stage at which they should recommend control measures.

II.1.3 On-farm losses in maize

The topic presented by Dr. J.K.O. Ampofo, research scientist at ICIPE, included the following main elements:

Maize is the most important cereal food crop in the Eastern and Southern Africa region. Production is however, limited by several constraints such as drought, low farm inputs and management, and ravages caused by pests and diseases. Yields per unit area are, thus, among the lowest in the world. Over 30 insect species and complexes are known to cause damage to maize plants in the field. However, objective and reliable assessment of losses in production caused by these pests is generally unavailable in the region. Information on crop losses is essential to monitor the effects of insect pests in maize production within the region for: (i) food and other policy planning; and (ii) to enable decisions concerning the allocation of resources to research for the management and control of the pests and other constraints limiting production to be made.

The types of damage caused by insect pests to field maize are variable and may lead to: (i) reduction in plant stand; (ii) reduction in the photosynthetic capacity of the plants; (iii) interference with water and nutrient uptake and translocation; (iv) tassel breakage or drying and poor fertilization; (v) stem breakage and ear drop; (vi) creation of openings for disease infection and actual transmission of disease; and (vii) tainting and reduction in the aesthetic value of the produce. These damage symptoms and their resultant effects depend on the size of the infestation, the attacking insect species and the plant growth stage attacked. Various methods have been proposed for the measurement of infestation, damage and the associated losses in yield caused by different insect pests. These include:

1. A comparison of yields from individual plants, plots or fields showing different degrees of infestation or damage with healthy plants, plots or fields from the same environment.
2. Controlled artificial infestation or prevention of attack to achieve different levels of damage in different plants and relating the yields to damage levels. Areas of low pest incidence, field cages and chemical insecticides have been used in combination with manual infestation to relate yield and damage levels.
3. The use of resistant and susceptible cultivars to obtain and relate the different levels of damage to yield.
4. Artificial simulation of insect damage and assessment of the effect on yield.

It is important to identify the pest or complex of pest insects within the location and assess their interaction with the crop. Usually insect pest induced losses in maize production result from the total effect of damage caused by different species. To isolate their individual effects under on-farm conditions may not be easy. However, we need to adapt the available methodologies for the assessment of these losses. Such methodology should be simple, flexible and suitable for use by educated field workers.

II.1.4 On-farm losses in rice

The paper covering this topic was prpared by Dr. M. Agyen Sampong, entomologist at the West Africa Rice Development Association (Regional Rice Research Station, Freetown) but was presented by Dr. Ampofo, ICIPE. The elements of the presentation included the following:

The rice plant is very versatile and is grown in various ecologies under both tropical and sub-tropical conditions. The major rice ecologies may be classified as upland, inland swamp, mangrove swamps, irrigated and deep water or floating. A wide diversity of insect pests attack the crop and their relative importance varies with the location, ecosystem and plant growth stage.

However, reliable and detailed information on the damage caused to the rice crop by insects in tropical Africa are rare. Most of the available data are estimates based on especially bad years or few affected locations, and references to heavy crop losses or serious pests abound in the literature. Cramer (1967) estimated that 33 per cent of the potential rice production in Africa is lost to pests, out of which 14 per cent was attributed to the insect pests alone. Neither insect pest populations nor crop losses are static. They vary with location, season, variety and farming system. The intensity and effect of damage caused depend on the crop growth stage. Young rice seedling succumb more easily to pest damages than older plants which may react to damage by compensatory growth or tolerance.

The importance of crop loss assessment has been to bring into focus the necessity to use good cultural practices and other pest management strategies to achieve better crop management for higher yields. Basically, two major steps are involved in the assessment of yield losses, namely the initial assessment of infestation or damage levels, and relating these to yield. Various methods have been proposed or used to assess insect pest infestation and damage levels in the rice crop. These include:

(i) Actual counts of insects per unit area;

(ii) Relative counts based on the number observed or collected per unit time;

(iii) Indirect counts whereby insect activity or symptoms of damage e.g. dead hearts or white/heads, are used to monitor their abundance within the area.

The level of infestation or damage is usually related to yield by the use of regression equations e.g. $Y = m - bx$ (where y = yield obtained, x = infestation or damage level, m = maximum or potential yield, b = rate of loss per unit increase of x). The variouse methods used to achieve this relationship include:

(i) A comparison of yields from individual plants showing different levels of natural infestation or damage;

(ii) Manipulation of infestation by the use of chemical insecticides or cages to achieve different levels of damage ; and

(iii) The use of resistant and susceptible cultivars (of similar yield potential) to relate infestation to yield.

The types of damage caused by insect pests to field maize are variable and may lead to: (i) reduction in plant stand; (ii) reduction in the photosynthetic capacity of the plants; (iii) interference with water and nutrient uptake and translocation; (iv) tassel breakage or drying and poor fertilization; (v) stem breakage and ear drop; (vi) creation of openings for disease infection and actual transmission of disease; and (vii) tainting and reduction in the aesthetic value of the produce. These damage symptoms and their resultant effects depend on the size of the infestation, the attacking insect species and the plant growth stage attacked. Various methods have been proposed for the measurement of infestation, damage and the associated losses in yield caused by different insect pests. These include:

1. A comparison of yields from individual plants, plots or fields showing different degrees of infestation or damage with healthy plants, plots or fields from the same environment.

2. Controlled artificial infestation or prevention of attack to achieve different levels of damage in different plants and relating the yields to damage levels. Areas of low pest incidence, field cages and chemical insecticides have been used in combination with manual infestation to relate yield and damage levels.

3. The use of resistant and susceptible cultivars to obtain and relate the different levels of damage to yield.

4. Artificial simulation of insect damage and assessment of the effect on yield.

It is important to identify the pest or complex of pest insects within the location and assess their interaction with the crop. Usually insect pest induced losses in maize production result from the total effect of damage caused by different species. To isolate their individual effects under on-farm conditions may not be easy. However, we need to adapt the available methodologies for the assessment of these losses. Such methodology should be simple, flexible and suitable for use by educated field workers.

II.1.4 On-farm losses in rice

The paper covering this topic was prpared by Dr. M. Agyen Sampong, entomologist at the West Africa Rice Development Association (Regional Rice Research Station, Freetown) but was presented by Dr. Ampofo, ICIPE. The elements of the presentation included the following:

The rice plant is very versatile and is grown in various ecologies under both tropical and sub-tropical conditions. The major rice ecologies may be classified as upland, inland swamp, mangrove swamps, irrigated and deep water or floating. A wide diversity of insect pests attack the crop and their relative importance varies with the location, ecosystem and plant growth stage.

However, reliable and detailed information on the damage caused to the rice crop by insects in tropical Africa are rare. Most of the available data are estimates based on especially bad years or few affected locations, and references to heavy crop losses or serious pests abound in the literature. Cramer (1967) estimated that 33 per cent of the potential rice production in Africa is lost to pests, out of which 14 per cent was attributed to the insect pests alone. Neither insect pest populations nor crop losses are static. They vary with location, season, variety and farming system. The intensity and effect of damage caused depend on the crop growth stage. Young rice seedling succumb more easily to pest damages than older plants which may react to damage by compensatory growth or tolerance.

The importance of crop loss assessment has been to bring into focus the necessity to use good cultural practices and other pest management strategies to achieve better crop management for higher yields. Basically, two major steps are involved in the assessment of yield losses, namely the initial assessment of infestation or damage levels, and relating these to yield. Various methods have been proposed or used to assess insect pest infestation and damage levels in the rice crop. These include:

(i) Actual counts of insects per unit area;

(ii) Relative counts based on the number observed or collected per unit time;

(iii) Indirect counts whereby insect activity or symptoms of damage e.g. dead hearts or white/heads, are used to monitor their abundance within the area.

The level of infestation or damage is usually related to yield by the use of regression equations e.g. Y = m− bx (where y = yield obtained, x = infestation or damage level, m = maximum or potential yield, b = rate of loss per unit increase of x). The variouse methods used to achieve this relationship include:

(i) A comparison of yields from individual plants showing different levels of natural infestation or damage;

(ii) Manipulation of infestation by the use of chemical insecticides or cages to achieve different levels of damage; and

(iii) The use of resistant and susceptible cultivars (of similar yield potential) to relate infestation to yield.

Each of these methods has its own advantages and drawbacks and a lot of consideration needs to be put into their use in the field, particularly in situations where farm practices vary.

II.2 Assessment of On-Farm Losses Caused by Main Agents

The papers on this theme dealt with specific loss agents including diseases, soil insect pests, armyworm, locusts and birds.

II.2.1 Cereal losses caused by diseases

The topic was covered by the presentation of Dr. K.N. Rao, Chief Technical Adviser/Plant Protection of UNDP FAO project on Maize Research and Extension in Zambia. The presentation is summarized as follows:

Crop loss assessment studies relative to plant diseases are very limited. International concern about the inadequacy of present loss assessment methods has been expressed in several workshops. Only by disease-loss appraisal is it possible to determine the economic loss due to different diseases and disease intensity. Disease loss appraisal, therefore, represents an essential step to implement pest or disease management schemes aimed at economic control.

Types of losses are characterised by a number of antitheses: actual-potential, incidental-regular, transitional-structural, recognised-hidden and direct-indirect.

Several principles are involved in the measurement of crop losses caused by plant diseases. These include: difference in yield between diseased and disease free

Table 1 - Important diseases of cereal crops in Africa for which crop loss appraisal is needed

Crop	Disease	Remarks
1. Maize	Maize streak virus Cob rots Leaf blights Leaf rusts Stalk rots	Rating scales available for most of the diseases
2. Sorghum	Head moulds Downy mildew Leaf blights Leaf stripe Sooty stripe *Cercospora* leafspot	Systematic crop loss assessments have not been done
3. Pearl millet	Downy mildew Ergot Smut Leaf spots	Systematic crop loss assessments have not been done
4. Wheat	Stem rust Leaf rust Head blight	Systematic crop loss assessments have not been done
5. Rice	Leaf blight Leaf blast Sheath rot	Systematic crop loss assessments have not been done

plants; the effect of single or a combination of pathogen infections; biological and ecological factors; losses due to diseases in perénnial plants; losses expressed in forms of value and variation of loss, from year to year.

Development of methods for estimating losses will take into account location, design and specification of field experiment, measuring yield and quality, disease assessment, development of rating scales and growth stages.

It is important to request FAO to co-ordinate the activities of member countries to initiate crop loss assessment studies for the above mentioned diseases in Africa.

II.2.2 Cereal losses caused by soil pests

The subject was covered by the presentation given by Dr. T.G. Wood, Overseas Development Natural Resources institute (ODNRI), United Kingdom). His presentation included the main following elements:

Soil pests are defined as those in which the damaging stage of the pests life cycle is found in the soil. In Africa the most important soil insect pests are termites, followed by the larvae of various beetles (particularly scarabs), and millipedes which are included here as they damage plants in a similar way to some insects.

The most important cereals in Africa are maize, sorghum and millet. Wheat and rice are becoming increasingly important. Attack by soil pests largely begins on the root system and yield losses result from plant mortality, lowered translocation of water and nutrients, increased susceptibility to pathogens, or lodging with subsequent damage to grain on the ground from various vertebrates, invertebrates and saprophytes.

Existing data is largely presented as "percentage of plants damaged" or "infested" and bears little relationship to yield loss, as this depends on the severity and timing of attack on the root system. Direct estimation of yield loss is time-consuming and few such studies have been made. However, methods are presented here for termites on maize which could be adapted for other pests and crops. Indirect estimates are more common and, in general, indicate that an integrated pest management approach to soil pests is required.

II.2.3 Cereal losses caused by armyworm

The paper covering this topic was prepared by Dr. D.J.W. Rose, M.J. Iles and M.A. Ward and presented by Dr. Rose, Leader, East Africa Armyworm Project, Desert Locust Control Organization for Eastern Africa. A resume of the paper included the following:

Armyworm, *Spodoptera exempta* (Wlk.) are notorious as serious pests of cereal crops and pastures, and sometimes as the indirect cause of cattle deaths. Their notoriety is reflected in popular names which describe characteristics of outbreaks - Mystery worms, because of their sudden appearance and disappearance; Hailworms, in recognition of their occurrence after major storms; and the African armyworm for its most dreaded characteristic, when hordes of caterpillars march out of infested grasslands to destroy adjacent cereals in only a few days. The publicity given to outbreaks of armyworm through newspaper headlines and radio has furthered its notoriety, so that like locusts, armyworm are well known to town folk and politicians as well as to the farming community. Consequently armyworm have developed a political importance which sometimes clouds the assessment of on-farm situations and subsequent control decisions.

Whilst there are many subjective accounts of the serious losses and damage that can be caused by armyworm, there is as yet very little hard data that can be used to forecast yield losses. Work done by Brown and Odiyo (1968) supports the view that the impressive outbreaks do cause serious losses. They began to build up the data necessary for developing action or economic thresholds by determining the feeding rate of the larvae. This was taken further by Brown and Mohamed (1972) when they considered the problem of crop response to armyworm damage. Crop loss trials by G.K.C. Nyirenda (unpublished data) set in farmers fields infested by armyworm gave maize yield losses of 75 per cent and 76 per cent for severely damaged plots, and 30 per cent and 45 per cent for partly damaged plots when fertilizer was not applied and slightly less loss if fertilizer was applied. Ward and Green (unpublished report, 1986) found that losses were greatest in very young wheat plants attacked less than 30 days after sowing, with final yield losses ranging from 30 per cent to 50 per cent. This preliminary work has indicated that control of armyworm infestations is often justified at the farm level, considering that the cost of control with one application of a recommended insecticide (2.4 per cent Cypermethrin at one litre per hectare) is only 0.8 per cent of the value of a high yielding crop of maize. It has also been shown that the effect of damage to cereals is related to their age at the time of attack. Very small plants and those with developing leaf areas are most vulnerable. Those at an in between stage are better able to withstand the attack and recover. The time of armyworm upsurges in relation to the growing season, the severity of defoliation and availability of water and nutrients have a major impact on extent of losses.

Two investigations have been made by agricultural economists to assess the impact of armyworm on a national and regional basis - K. Gubbins (unpublished report, 1981) on behalf of ODA, British Government; and R. Purcell for the EEC (unpublished report, 1986) Their assessments were based on records of cereal yields, distributions of outbreaks between and within countries over twenty years, and the frequencies and intensities of armyworm attack and damage. Both reports concluded that armyworm research and control programmes were justified. Purcell developed a method for obtaining national estimates of crop losses for Tanzania, Kenya, Ethiopia and Uganda using a crude scoring method incorporating frequency and intensity of attacks in each country.

It is recognized that more critical methods are now needed to obtain better estimates of losses, and of the improvements in yields that may be obtained with armyworm control. These are needed at the farm level for the development of criteria for control decisions; and at the national and regional level for improvement in the development in time and space of human and material resources for control operations.

Two of the authors M.J. Iles and M.A. Ward, have recently collaborated in a programme of work started by the Ministry of Agriculture and entomologists in Tanzania. Initial findings have been published in two reports (M.J. Iles, 1987; M.A. Ward & S. Green, 1987) and the scientific papers which will be produced with the Tanzanian scientists will mark the beginning of intensive studies to evaluate losses caused by this migrant pest. Because armyworm is a migrant, it is difficult to select in advance crops which will be attacked in order that the usual methods of crop loss assessment may be applied. Techniques being developed are based on visits to farmers who are representative of the different regions and farming practices. In making surveys, careful thought is given to the data base used e.g. importance of subsistence and cash crops, varieties and regions, sample selection, and the data to be collected for analysis. Consideration is also being given to approaches which include broad based surveys, together with more intensive surveys where several visits per year are made to co-operating farms, and crop loss case studies where this is possible to arrange.

The authors will welcome any suggestions and comments which may be useful in improving the value of the proposed study and its extension to other parts of Eastern and Southern Africa.

II.2.4 Cereal losses caused by locusts

This topic was dealt with by Dr. A.C.Z. Musuna, International Red Locust Organization for Central and Southern

Africa. The main elements of presentation included the following:

This paper briefly describes four different locust species that have great potential to cause damage to agriculture and pasture in the Eastern, Central and Southern Africa regions. Particular reference is made to the Red Locust (*Nomadacris septemfasciata Serville*) and the African Migratory Locust (*Locusta migratorioides* R & F) which mostly feed on monocotyledonous plants. Reference is also made to the Brown Locust (*Locusta pardalina Walker*) and the Desert Locust (*Schistocerca gregaria Forskal*). There were frequent reports of damage to cereal crops by the red locust during the most recent plague of the 1930's. However, since that time little data on yield loss have become available owing, primarily, to the fact that locust infestations have mostly been irregular and confined within their natural breeding areas, away from crop land. The control methods that are currently used to safeguard crops are summarized. The paper provides general background information that should enable evaluation of locust incidence in the region and assessment of consequent cereal crop production losses.

II.2.5 Cereal losses caused by birds and rodents

The paper was presented by Dr. C.C.H. Elliot, Project Manager, FAO/UNDP Crop Protection Project, Kenya. The summary of his presentation includes the following:

(i) The methods for, and the problems of recognizing bird and rodent damage are described. For birds, the methodology for assessing the damage, and the necessary statistics for determining sample design and sample size exist. Damage is measured either by visual estimation of the percentage loss (sorghum, maize, millet) or by weighing/comparing/damaged/ undamaged spikes/panicles (wheat/rice). Sampling usually involves randomly selected transects. A system is also available for assessing bird damage over large areas at district, regional or even countrywide levels involving aerial surveys of crop hectarage and ground teams sampling damage levels at randomly selected points.

(ii) For rodents, the methodology is less well established but damage in the field is usually quantified in terms of the percentage of rows of cereal destroyed at germination (maize) or by the number of cut stems compared to uncut stems in sample quadrants (wheat, barley).

(iii) Manpower and resources for bird control do not often extend beyond the control operation to damage assessments. As a result, the necessity for and success of bird control has to be evaluated in terms of diminishing farm complaints or expressions of farmer gratitude rather than objectively in terms of crop saved or cost-effectiveness. It is suggested that in the long run, emphasis must inevitably switch to damage assessments as the economic pressures on Africa continue to increase.

II.3 Post-Harvest Food Losses

The theme was illustrated by four presentations which covered post-harvest losses in general, the specific case of the greater grain borer, and the relation of such losses to storage methods.

II.3.1 Assessment of Post-Harvest Losses due to Pests

The topic was illustrated by an example of stored maize in traditional granaries in Togo, presented by Dr. C.U. Pantenius, expert of GTZ and supervising a storage project in Niger. The presentation included the main following elements:

One of the most urgent problems of many countries in the Third World is an insufficient food supply. In the past, the majority concept to increase food production was to enlarge acreage or increase yield by any means, but the reduction of losses after harvest was almost neglected. More recently, however, loss reduction programmes after harvest have gained priority to many governments and international organizations. Nevertheless, the level of post-harvest losses in the different storage systems which can be reduced by economically reasonable methods is still not clear. In stored maize for example, estimations of loss range between 1 and 100 per cent. The enormous variability of local post-harvest situations and unreliable loss assessment methods are the main reasons for the lack of information. During a two year research project on traditional maize granaries in Togo, three methods of loss assessment were studied which are discussed by the FAO: the Count and Weight Method, Standard Volume/Weight Method and the 1000-Grain Mass Method. In general, between 80 and 90 per cent of the overall losses were caused by insect feedings. Besides *Prostephanus truncatus* (Horn), the most important storage pests were *Sitophilus zeamais* (Motsch.), *Tribolium* spp. and *Cathartus quadricollis* (Guer.). Best results were obtained by the Count and Weight Method. The significantly highest losses of dry weight (12-13%) were found after 6 months in stored hybrids. At the same time, local varieties appeared much more adapted to traditional storage methods, exhibiting losses of only 3 per cent under the same conditions. Lowest level of losses (<1%) were observed in regularly smoked granaries in the mountain regions. The mean losses of dry weight during the primary season were found to be 6.4 per cent after 6 months, while after a storage period of 4 months during the secondary season, losses were as high as 8 per cent. In Togo, *P. truncatus* was observed for the first time in spring 1984. Becauseof the different damage *P. truncatus* causes on corn, a newly developed Sample Weight Method was examined in an additional test. After 6 months of observation this dangerous pest caused serious losses of up to 30.2 per cent.

II.3.2 Current status of the greater grain borer, Prostephanus truncatus in Africa

The presentation of Dr. P. Golob, Tropical Development Research Institute (TDRI, United Kingdom) provided elements on the damage caused by the greater grain borer which is becoming a real threat for stored maize and cassava in Eastern Africa. The summary of this presentation includes the following:

Since the first reported observation in Tanzania in 1981, the larger grain borer (LGB) has spread from a small area in the north west of the country to 17 of the 20 regions. Only in the extreme south, along the Mozambique border, has the pest not been found. It has also become established in Kenya, Burundi, Togo and Benin.

LGB can cause very high weight loss in farm stored maize and dried cassava, commodities on which it is able to breed. After 5 months storage during the dry season in Western Tanzania, mean losses of 9 per cent were found, as compared to expected losses of less than 1 per cent LGB-free areas in East/Central Africa.

Application of 0.5 per cent permethrin dust at 2.8 ppm provides excellent protection for one year against LGB when applied to loose maize grain. However, the storage of shelled maize predisposes towards the development of *Sitophilus* species which can result in high losses being sustained by farmers as this beetle is not controlled by permethrin. A cocktail of permethrin and pirimiphos-methyl, applied at 3.3 and 17.7 ppm successfully controls all storage pests and is currently being used in an extensive control campaign in Tanzania.

A multi-donor funded control and containment campaign, co-ordinated by FAO, has been in operation in Tanzania since 1984. The programme is comprised of a training element for agricultural staff, and several field extension campaigns which assist with insecticide distribution and with the dissemination of information to farmers. The primary objectives of the programme are to reduce farm storage losses and to contain LGB within the areas it is now found. In some regions, where LGB is relatively isolated, attempts are being made to eradicate it.

II.3.3 Storage methods in relation to post-harvest losses in cereals

This subject was dealt with by Dr. J.A. McFarlane, Tropical Development Research Institute (Storage Department) and Dr. Alfred Richter, ECA expert in post-harvest food losses. The first paper concentrated losses in relation to management of storage systems and the second paper focussed on losses in relation to the conditions of storage. The following summary outlines the main elements discussed.

Storage method encompasses the patterns and periods of storage as well as the particular storage techniques which may be used. Storage management, in its broadest sense, is therefore a major determinant of post-harvest losses in stored cereals, affecting the magnitude of losses and their susceptibility to reduction. Key issues are the location and scale of grain storage which, in most developing countries, involves both rural domestic storage and larger-scale "buffer" storage at district centres, commonly near towns.

Various storage techniques are described and discussed against the background of available information on storage losses and with regard to the common patterns and periods of storage. The importance of long-term development planning for cereal crop production and utilisation is stressed with reference to enhanced storage management, including storage logistics and crop pricing policies, as a major factor in storage pest management and the reduction of storage losses.

An outline of the different natural storage conditions prevailing in different subregions of Africa and the variety of storage problems encountered due to more, or less, successful attempts to create and to run centralized public storage is given.

Details are also provided on suitable grain types for low loss stores attempts and storage problems experienced with other types of grain such as modern maize varieties, groundnuts and pulses.

Factors contributing to good storage performances in traditional systems and factors reducing performances are outlined.

The problems created by cereal banks and other communal storage are emphasized. The paper concludes that food security must be promoted at the farmer and village level, as the big centralized storage attempt to produce food security is too expensive for low income groups which includes almost the entire rural population.

Some loss figures of some selected PHFL projects are given and some basic storage parameters are indicated in the attached tables.

II.4 FAO's Experience with Crop Loss Assessment

Between 1977 and 1981 the United Nations Food and Agriculture Organization undertook several projects related to crop losses at the pre-harvest stage. Following the adoption of aresolution by the UN General Assembly in 1975, FAO implemented a number of catalytic projects at the national and regional level in Africa. Through these activities, the Organization gained experience in food loss assessment and a recent evaluation of these activities called for a re-orientation of their scope. Elements of this experience presented by Dr. G.G.M. Schulten, senior entomologist, Plant Protection Service is hereunder summarized.

Crop loss can be defined as the difference between the attainable yield, if crops were to be completely protected from adverse biotic factors, and the actual yield.

Crop loss can also be defined as the difference between the economic yield, which gives the highest return on investment, and the actual yield.

The economics of crop losses concern the actual losses and the costs of current control measures. The cost of actual losses is difficult to assess: if more were produced prices might decrease and if less were produced prices might increase. Nevertheless, in calculations, some illustrative figure has to be adopted for if loss data are to be used for management decisions, some average crop price is required. Depending on the situation, losses can also be calculated as the costs which have to be made to import and distribute the lost commodity.

In calculating the potential benefits of a loss reduction programme, all costs which have to be made to reduce losses (inputs and its distribution, extension, training and research) should be taken into consideration.

Justifications for loss assessment given in the literature are:

- to create an awareness on existing pest problems
- to stress the need for crop protection
- to provide data for the decision-maker to assign meaningful priorities and resources to obtain investment in research and development
- to obtain data that allow for rational decision-making on pest control

It should be kept in mind, however, that in specific cases the actual losses sustained are only a small part of the potential losses which may occur in the absence of control measures. Also, considerable efforts and funds need to be used to establish and maintain Plant Quarantine Services to prevent the introduction of pests with a high loss potential.

When considering crop losses and their reduction, it should never be forgotten that yield is limited by production constraints of many kinds, among them inadequate agronomic practices, lack of fertilizer, improved seeds, etc. Pests are only one of the many constraints which may reduce the farmer's yield and income.

FAO's experience

In the last 20 years FAO was twice involved in large-scale loss assessment activities. Special attention to pre-harvest loss assessment was given in the period 1969-1981 and to post-harvest loss assessment from 1975 till 1982. Both activities showed a similar pattern.

The need for data on losses was recognised and much effort was made to collect, develop and publish loss assessment methodologies. Losses were determined in various crops, followed by low emphasis on large-scale collection of loss data for problem identification. Nowadays, loss assessment is largely limited toproblem solving and monitoring activities, making full use of the experience and methodologies developed earlier.

Pre-harvest losses

A symposium on crop losses was held in Rome in 1967. It was concluded that a well planned investigational programme was required which through field experimentation and surveys, would increase the accuracy of crop loss estimation. FAO prepared a manual for loss assessment studies (published in 1971 and followed by two supplements in 1977 and 1981) which included descriptions of recommended methodologies.

The methodology advocated emphasized:

(a) the establishment of a pest/yield relationship; and
(b) regular statistically executed surveys to determine pest severity at a regional or national level.

The established methodologies have been proven to be very useful but are now mainly used for an appraisal of the magnitude of the losses in a defined crop production or pest control programme, or as a research tool e.g. in the development of varieties.

Post-harvest losses

Initially, much importance was attached in the Prevention of Food Losses Programme (PFL) to the statistically reliable assessment of losses in the post-harvest system. The objective of the assessment was problem identification and monitoring of progress in loss reduction.

Much importance was attached to randomized surveys and sampling, but due to many constraints (funds, manpower, time) practically all surveys should be rated as non-randomized.

In practice, however, the non-randomized surveys were found to be sufficient to identify where losses in the various components of the post-harvest system were of such magnitude that there was a good chance to reduce them.

A range of methods have been developed to measure losses in the various components of the post-harvest system of crops (from yield losses in the mature crop till primary processing). The developed methodologies are now largely being used for problem solving and monitoring in post-harvest projects. It should be mentioned here that the justification for post-harvest projects is not only the reduction of losses but also as a method of increasing food production. As a result of changes in agricultural practices and attitudes such projects can, for example investigate the need for mechanised threshing or shelling to remove labour constraints; the introduction of small mills to reduce the workload for women; the development of adequate drying and storage systems to prevent aflatoxin contamination; the construction of small warehouses; and the training of personnel to improve marketing, etc.

III. OVERVIEW OF COUNTRY REPORTS

For the preparation of country papers, ECA and ICIPE prepared guidelines which were forwarded to member countries attached to the letters of invitation to participate in the workshop. Country representatives were expected to provide basic information on:

- Food production patterns of country main staples and respective self-sufficiency ratios;
- Brief description of Government Food Security policy;
- Importance of crop pests and diseases with indication of magnitude of losses if data available;
- Strategies adopted to reduce such losses;
- Importance of losses in stored products and their magnitude if data available;
- Strategies adopted to reduce post-harvest food losses;
- Brief of role of national and international organizations in support of national efforts to reduce food losses;
- Planned projects aiming at improving the prevailing situation.

The country papers hereunder summarized include 7 papers which were presented during the workshop and two papers on Angola and Somalia which were forwarded to the organizers by their authors, Mr. Domingos Lopes Da Silva, Chief, Department of Statistics, Ministry of Agriculture, Luanda, Angola and Dr. Mahad Abdi Farah of the Central Agricultural Research Station, Afgoi, Somalia. The paper on Zambia, although it reflects the situation, was not prepared by a country representative but by experts stationed in that country, namely Dr. Marcelo Dougnac and Mr. Bernard Mtouga.

BOTSWANA

The unfavourable climate encountered in Botswana enables only a limited range of crop types to be grown. This has consequently resulted in crop pest management research and practices being neglected. However, with the launch of a number of new initiatives to improve arable farming, pest management and produce protection have now to be seriously considered if food grain production is to be significantly increased.

The programmes initiated include the Pendamatenga Project, the Arable Lands Development Programme, Accelerated Rainfed Arable Programme and it is envisaged that the Irrigated Agriculture Development Project will soon be undertaken.

A number of serious pests have been identified and investigated such as the quelea, locusts, and the armyworm. Lesser investigated pest species include the stalk borers, bugs and aphids. Post-harvest pests such as moths and weevils should also be investigated.

Very little information has been collected on the magnitude of losses caused by these pests mainly due to lack of expertise and personnel.

The government has intervened by setting up the plant protection section whose policy is currently under consideration. The formation of the National Post Production System to investigate, among other things, food losses in this area is a step towards redressing the situation. Upgrading of certain facilities to cater for arable farming requisites also provides better incentives for crop farmers.

Liaison with non-governmental organisations, parastatals and the private sector is being promoted to facilitate easy access to information and products required for increased food production. Although the idea is for the government to initially handle the supply of requisites to producers, it is hoped that ultimately, as the arable sector develops , the private sector will take over with government legislation guiding their operations. Assistance in technical advice and equipment will be made to a certain level.

Technical co-operation will be strengthened regionally and internationally through existing channels like the SADCC, FAO, etc. Training of staff has just started and we hope to have a strong unit in five years time.

The most important storage pests of cereal grains are the maize weevil, the rice weevil, the grain weevil, moulds, rodents and birds. The overall potential losses in stored cereal grains in a storage period of one year can reach 16 - 20 per cent. The Agricultural Marketing Corporation (AMC), a government agency, is constructing modern warehouses in order to properly store food grains and reduce food losses. FAO and the Ministry of Agriculture will launch a comprehensive, post-harvest study so that storage food losses can be reduced.

There are UNDP and Belgian assistance projects which comprise training, supply of equipment and strategic studies. These and similar assistance projects can enhance an effective work programme towards reducing losses in food crops both in the field and in storage.

Cereal insect pests in the field

Wheat and Barley

The area under wheat and barley in Ethiopia was 722,000 and 872,000 hectares respectively during the 1985/1986 growing season.

The prevalent insect pests in these crops could be categorized as shoot and root (soil borne insect pests) attacking insect pests. The shoot attacking insect pest is commonly called shootfly (*Delia armabourgi*) and belongs to the order Diptera. It attacks wheat, tef, maize and some grasses but its effect is more pronounced on barley than on the other crops.

The soil borne insect pests (root attacking insect pests) belong to one order, Coleoptera and their common names and families are as follows:

(a) Sand weevil or snout beetle (Curculionidae)
(b) White or Chafer grub (Scarabaedae)
(c) Click beetles or wire worms (Elateridae)
(d) Brown beetles (Tenebrionidae)
(e) Shiny dark beetles (Tenebrionidae)

Maize and sorghum

The area under maize and sorghum cultivation during the 1985/86 crop season was about 1.5 million hectares.

The major insect pests in these crops are stalk borers, which include *Busseola fusca* (Fuller) and *Chilo partellus* (Swinhoe). *B. Fusca* occurs from 1235 to 2600m above sea level, while *C. partellus* was found to be most important at altitudes below 1500 m. Sorghum shoot fly (*Atherigona varia soccata*) is another important insect pest in sorghum. Other sporadic insects pest include the African migratory locust, *Locusta migratoria migratorioides;* the desert locust *Schistocerca gregaria* and armyworm *Spodoptera exempta*.

Cereal insect pests in warehouses

The important stored grain pests are mainly beetles and moths. The biting and chewing mouth-parts of these insects enable them to feed on hard and dry stored agricultural products . The larvae and adults of various beetles and also the caterpillars of several moths can cause heavy damage under both tropical and temperate climatic conditions. There are many stored grain insects in Ethiopia. The major pests are: Sitophilus oryzae, Sitophilus zeamais, Sitophilus granarius, Tribolium castaneum, Tribolium confusum, Sitotroga cerealella, Ephestia cautella, Ephestia kuehniella, and Acanthoscelides objectus.

Even though there is no reliable data that would indicate the extent of stored losses in Ethiopia by insect pests, it is assumed to be 5 to 10 per cent (MacFarlane 1968).

Conclusion and Recommendation

There are many insect pests in cereal crops both in the field and in the stores in Ethiopia. Even though it is difficult to quantify the damage inflicted by these pests, a conservative estimate of crop loss of about 10-15 per year as a result of the feeding action of the pest species can be assured. This quantity would have been sufficient to feed about 2,000,000 people for a year. To overcome this problem, it is first necessary to be able to generate information on the biology, loss assessment, economic threshold level, economic injury level and other relevant parameters affected by these insect pests. To do this it is high time, to place highly qualified people on this subject and, to give financial and material support in order to carry out basic and fundamental research.

KENYA

Introduction

Kenya is a country of enormous contrasts in topography, climate and soils. Almost half of the total area is near desert and only about one fifth of the total area is suitable for arable agriculture. Broadly there are several agro-ecological These are:

(i) Humid
(ii) Sub-humid
(iii) Semi-humid
(iv) Transitional
(v) Semi-arid
(vi) Arid

It is in Zone I, II, III, IV where maize, wheat, barley, sorghum, bananas, beans, cassava and potatoes are grown.

Government Food Security Policy

It is a declared Kenya Government Policy to be self-sufficient in major food crops. This has been spelt out in the 1981 Sessional Paper No.4 on National Food Policy. One of the major challenges facing the country is the current high population increase. This issue has been addressed in another Sessional Paper No.4 of 1982 on Development Prospects and Policies in which it is proposed to restructure the agricultural sector to enable it to play its major role in being the backbone of the economy. Sessional Paper No.1 of 1986 on Management of Economic Growth gives added emphasis on the role agriculture should play in economic development. Concrete action to boost food production has been taken by the government through the management of producer prices, provision of seasonal credit, construction of additional storage facilities, training of extension personnel and provision of necessary facilities to enable them to perform their duties. Appropriate action has also been taken in the area of procurement and distribution of agricultural inputs through the co-operative system.

On-Farm Losses in Cereals

The contribution of pests and diseases to crop losses is not well documented and methodologies for estimates are yet to be developed under farmers' field conditions. However, it is known that a wide variety of pests and diseases affect various individual crops. The magnitude of economic losses seem to vary with time and place as well as within varieties. No recent studies on magnitude are available. The maize stalk borer, armyworm and cutworms are recorded as being the major maize pests. Rodents, too cause on-farm damage.

Pesticides are commonly used in the country to combat incidences of pest infestations.

Post-Harvest Losses in Cereals and their Products in Storage

There is a large range of diseases and pests that cause post-harvest losses. It is estimated that post-harvest losses due to diseases and pests in maize range between 6-16 per cent in the country. Once again the methodologies for assessment need to be refined further. Rodents, maize weevils, and grain borers are considered important pests. Chemical control is currently the single most effective method for control.

Role of National and International Organisations in Reducing Losses

National organizations should shoulder the prime responsibility to design appropriate methods to assess crop losses and to take positive action to control such losses. The Ministry of Agriculture through the National Agricultural Laboratories and the Crop Protection Branch carry out these functions. Other organizations in the country like co-operatives and parastatals through their distribution network complement the Ministry's efforts.

The international community do also have an important role to play through the support they can, and do give to national efforts. This country receives such assistance from a number of international organisations.

Future projects in this area of crop protection are many, particularly in the area of culture control, crop resistance biological control, and improved use of pesticides.

MALAWI

Cereals contribute the largest percentage to carbohydrate providing staples in Malawi. Maize, rice, sorghums and millets are considered to be of major importance and are grown extensively. Of these however, maize is the most important, providing well over 70 per cent of th carbohydrate requirement. Cassava and sweet potatoes are some of the non-cereal crops contributing substantially to the country's energy needs. Malawi has, during years of favourable weather produced enough grain to feed its population, and has even exported surplus grain at times.

A wide range of plant diseases, pests and weeds contribute to the low crop yields and high losses in storage which farmers experience. The government, through the Research Department, has provided recommendations for farmers to follow in order to reduce such losses. Most of the recommendations, however, lack quantified information on the actual losses incurred as a result of these pests and diseases. In these times of economic strain there is need for recommendations to be economically viable, thus an economic analysis must be carried out for each control measure and reviewed from time to time.

It is in light of this that we consider this workshop of great significance to the future of cereal production in Malawi.

TANZANIA

Tanzania's physical and climatological conditions allow for diversified crop production. More than 85 per cent of the population is involved in agriculture which contributes 50 per cent of Tanzania's gross domestic product (GDP).

Most of the crops grown are rainfed and grown under small scale farming schemes, though contribution by parastatals in wheat, rice and beans production in large estates is also significant. The most important staple food is maize. Sorghum and cassava are important in areas with less reliable rainfall. Beans, rice, wheat and bananas are also becoming predominant staples. In the 1985/86 season, the production of maize was just over 2 million tons, sorghums and millets 1 million tons, rice 0.5 million tons, cassava about 2 million tons, wheat 71 thousand tons, bananas 736 thousand tons and beans 438 thousand tons. The country was self-sufficient in maize only.

The improvement of the marketing system by setting attractive producer and consumer prices and efficient utilization of storage and transport facilities are among several measures adopted in implementing the Government Food Security Policy. Availability of farm inputs and incentive goods, together with prompt payment to farmers is expected to encourage more food production. Creation and maintenance of strategic Grain Reserves are considered essential so that imports are carried out only when it is necessary.

Improvement of the infrastructure in the subsistence sector, and making available production inputs and loans to farmers may increase food production. No accurate estimates of crop losses have been documented, but it is generally accepted that pests may cause up to an average of 5 per cent loss of grain in the field.

Actual yield losses, however, vary between crops, individual pests and also between seasons. Several insects and diseases damage crops, but their losses may not be apparent like those caused by *Quelea* birds, the locusts, or armyworms, which occur in large outbreak numbers. Rodents are also important pests of both on-farm and post-harvest crops. Among the post-harvest insects, the larger Grain Borer *Prostephanus truncatus* (Horn) has become the most serious pest on unshelled (on-cob) maize causing losses of an average of 9 per cent in less than 6 months of storage.

Pest control measures in the field include cultural, chemical and biological methods. After harvest most of the grain is stored in traditional storage structures which do not offer full protection against pest infestation and other factors responsible for the deterioration of stored grain.

Improvement of storage structures and transportation system is considered important in reducing post-harvest losses. National and international organizations have played very important roles in the country's attempt to reduce crop losses by field and post-harvest pests.

Strengthening of plant protection and crop improvement research should go together with improvement of extension services so that farmers may be assisted in dealing with pest problems.

Construction of warehouses, rehabilitation of the transport system and other measures which will encourage the farmer to produce commercially will be emphasized in future projects.

UGANDA

Uganda occupies an area of about 240,000 sq km with a population of about 15 million people. The area suitable for crop farming is estimated to be 4.5 million hectares. Over 90 per cent of the population derive their livelihood from agriculture.

The country's food production patterns are varied depending on agricultural practices, soil types, rainfall, altitude and customary dietary differences. A wide range of food crops are produced in Uganda. The main staples are bananas, finger millet, sorghum, sweet potatoes, maize and cassava. Legumes grown for a source of vegetable protein to supplement the starchy staples are beans, field peas, groundnuts, cow peas, pigeon peas and simsim. Rice, wheat and irish potatoes are also produced.

The country is self-sufficient in all of the food crops except wheat which is imported. There are however, localized food deficient areas in the country brought about by poor internal marketing and distribution programmes.

The country's Food Security Policy is embodied in a document titled "Towards a National Food Strategy" designed in 1982-1984. The policy aims at being self-sufficient in food production for local consumption and having surpluses for export. The Produce Marketing Board is the government body charged with the buying, storage and export of specified produce. However, co-operative unions and private traders are licensed by the Produce Marketing Board as their agents. Some licensed agents also buy produce and sell it to private millers and processors. It should be noted that the Produce Marketing Board's storage capacity of 68,000 metric tonnes does not constitute a strategic reserve. A lot of farm produce is retained on the farm for consumption, seed and local trade.

The cereals produced in Uganda include maize, finger millet, sorghum and rice. Some wheat is also produced. These are attacked by insects, diseases, rodents, birds and other mammalian vermin. Actual figures on losses caused individually by these agents in the field are not available. This is because sufficient studies on loss assessment in this respect have not been done in Uganda.

A very heavy toll is exacted on cereals in storage due to damage by insects, rodents, mites, fungi and poor storage structures and practices. The amount of losses caused by each of these agents has not been quantified but they are known to be high.

Since 1962 there has been no assessment of post-harvest losses. Some information is available on losses in maize. Information on the magnitude and timing of damage in the various cereals, and losses exacted by individual agents, is not available. However, the government has devised some strategies for reducing on-farm and post-harvest food losses. These include two ongoing projects funded by FAO on "Re-establishment of Applied Research and Extension Activities on the Prevention of Post-harvest Losses" and "Vertebrate Pest Project". Other programmes projected by the Government are the proposed training programmes for warehouse management, and stock maintenance; construction of warehouses for medium-term storage; the rehabilitation of existing storage capacity; and establishment of warehouses for long-term storage for the country's strategic reserves. The above programmes need international funding. The government has also approached FAO to fund the Plant Protection Service and improve traditional storage structures.

ZAMBIA

In Zambia, subsistence farming is the largest sector involved in agricultural production. Small-scale commercial farming represents a small fraction of the total farming community. Large scale farming is almost insignificant. The levels of food production in all sectors are very poor. The insufficient food production consequently leads to seasonal shortages and uneven food distribution.

In order to involve the farmer in agricultural research, a farming system perspective has been established in the country. In this approach, priorities in research are established by a multidisciplinary effort in which all factors affecting the farmer's decisions are considered. Disciplines such as agronomy, economy, sociology, anthropology, nutrition and extension are represented in a joint research programme.

The contribution of social scientists to such a research programme is very important and the work of the biological scientists is often dependent on the results obtained from the socio-economic work. In most cases, studies on crops originate, and are analysed, on the basis of economic and nutritional implications. However, in order to achieve a better understanding of production constraints, more attention should be given to the biological factors affecting the system as crop losses occur due to an interaction of many factors.

When pests and diseases have been identified as a limiting factor, crop losses should also be established. Ultimately, control measures should also be developed. Specific production constraints should be identified which influence the farmer to make decisions. The assessment will help in understanding farmer's practices.

During experimentation, it has been observed that pests and diseases play an important role in affecting the final crop yield obtained. It is thus very necessary to give proper attention to the damage caused, and methods of its prevention. Agro-ecologicalfactors will enhance the scope of the biological scientist in any farming systems research team. This will assist in developing more appropriate technologies suitable for the small-scale farming communities.

ANGOLA

Despite the fact that petroleum is the mainstay of Angola's economy (80 per cent of total export revenues in 1981), the agricultural sector remains the base of the country's socio-economic development. Eight million hectares out of a total land area of 124.7 million hectares are under arable production. Before 1975, Angola was a net agricultural exporter and maize, cotton and sisal were the most important export products after coffee. Since independence, there have been considerable and regular food shortages and a thriving black market due to insecurity and rural exodus brought about by war resulting in a shortage of farm labour, particularly in the surplus production regions. The considerable war efforts also prevented the country allocating adequate resources for agricultural development. The agricultural sector consequently declined significantly and coffee production went from 200,000 tons in the 1970's to 30,000 tons in 1981; cereals production declined from about 650,000 tons in 1969-71 to 320,000 tons in 1981. In the meantime, cereal imports increased to about 270,000 tons in 1985.

Since 1975, Angola has adopted a centrally-planned economic and agricultural development policy based on setting up state farms and production co-operatives in place of the large plantations owned by colonial settlers. The main food crops include maize, cassava, rice and wheat. For 1985, the total production was 332,000 tons cereals, 227,000 tons for vegetables, 1,950,000 tons for cassava, 40,000 tons for potatoes and 180,000 tons for sweet potatoes, according to an FAO estimate. Due to lack of trained manpower and to the generalized insecurity problem in production areas, statistical information on agriculture is still very scarce and unreliable.

A food security policy formulated in 1986-90 five-year development plan is based on the development of main staples and the diversification of export crops. Also, it was realized that a rapid transition from a subsistence agriculture to a more monetarized commercial system of agriculture had to be made. For this purpose, the country formulated several development projects mainly supported by the European Economic Community. These included support programmes to rural producers through the provision of basic inputs such as seeds and fertilizers. Also, the Agricultural Development Stations (ADS) became active in a number of areas to support peasant producers.

Due to the lack of qualified personnel and an institutional frame, it is still difficult, if not impossible, to measure the losses resulting from operations at sowing, harvest, transport, storage and distribution. However, in 1982 it was verified that the losses in maize production were nearly 40 per cent, mainly due to problems in harvest organization, installation of silos and dryers and the irregularity of rains. All these factors, in addition to the political-military situation, impede the harvest operations.

Angola's cereal production is insufficient to cover the population needs. Losses are verified mostly in central warehouses an d during transportation. The lack of stocks further emphasized that a strategy for loss reduction be determined. Efforts are being madeto reduce crop losses through the regional organization SADCC in the context of its projects related to food security, namely project No.7 on Reduction of Post-Harvest Losses.

Apart from the above mentioned support from SADCC, Angola has not been the object of international technical assistance towards reducing food losses from institutions like FAO, ECA, UNDP, UNEP, etc., nor from bilateral agencies like USAID, GTZ, etc., or non-governmental organizations. Angola's government recognizes the need for international aid in this field and will be pleased to benefit from it, especially in the domain of technical training.

SOMALIA

The most important crops in Somalia are maize, sorghum, sesame, cowpeas, banana and various vegetables. They are used either for local consumption or for export. All are cultivated on small-scale farms and as a consequence, yields of the various crops are low.

The government has liberalized pricing and domestic marketing of most agricultural crops, particularly cereals, and has reduced the role of public agricultural marketing agencies such as the Agricultural Development Corporation Agency (ADC). It has introduced an auction system for the sale of the same important commodities thus modifying the earlier pricing of such concessional commodities by the national agency for trade. The government's agricultural inputs to supply agencies have continued to heavily subsidize prices e.g. ONAT the tractor hire service agency.

Crop losses due to pests and other factors have not been quantified. Losses are not always proportional to the quantity of food grain involved. The cereal crops growing in Somalia are attacked by an unusually large range of field pests. Damage by these pests is greater in rainfed areas than irrigated areas. The major pest species responsible for potentially serious losses in both quality and quantity in Somalia include stemborers and shootfly. Important storage pests include *Sitophilus* spp. and *Tribolium* spp. Losses due to stemborers at harvest time amounted to approximately 30 per cent at Agfoi and Badawo. (Personal communication, Ali-Nur).

There are ongoing efforts by national and international organizations to reduce these losses.

IV. FIELD VISITS

The workshop programme included field visits to the ECA/ICIPE project site at Oyugis and to the ICIPE Mbita-Point Field Station on Thursday 15 October. Out of a total of 39 participants, a group of 15 visited Oyugis and another 15 visited the field station. Two ECA staff joined the Oyugis group and one joined the field station group.

At Oyugis, the group met with the field staff (the National project officer and six technicians) attached to the ECA/ICIPE project and was briefed on the objectives and on-going activities of the project. Following this briefing, the group visited four farmers involved in the pilot project and had discussions with them. After one year of the implementation phase of this project, it is amazing to note the increased awareness of participating farmers of crop pests problems and how they have adopted the first set of control methods including use of resistant varieties and appropriate agronomic practices. The group of visiting experts also appreciated the level of knowledge of the field technicians and their consciousness in performing their task. Pending thepreparation of the technical annual report which will assess the actual results from the proposed methods in terms of yield, at this stage of maturing crops, it is clearly noticeable that the fields of participating farmers are in a better condition than those cultivated traditionally. Also, visiting experts found the pilot project a good example of interface between researchers and farmers.

The visit to the ICIPE Mbita-Point Field Station gave the opportunity to country representatives and experts from outside Africa to be familiar with the ICIPE research programmes and some of the results obtained. The group was briefed on the main research components including crop pests, livestock pests and vectors of human diseases. More particularly, briefing and discussions were related to the crop pests management research programme which includes plant resistance to insect pests, bionomics and applied ecology, biological control and insect mass rearing technology.

V. CONCLUSIONS AND RECOMMENDATIONS

Workshop Review

The workshop covered a wide range of invertebrate and vertebrate pests and pathogens that attack seeds, seedlings, roots, foliage, stems, panicles, seed heads and stored grain. Weeds were not discussed as loss agents.

Various methods of loss assessment were discussed and they can be listed in order of increasing technical difficulty and accuracy.

1. Assessment of percentage of plants infested.
2. Assessment of intensity of damage.
3. Comparison of yield of attacked and unattacked plants.
4. Pesticide trials - comparison of treated and untreated plots and stored grain.
5. Assessment of yield in caged and uncaged plants.
6. Artificial simulation of damage.
7. Different post-harvest loss assessment methods were also discussed, including the use of volumetric grain and cob count.

With adequate methods, 1,2,3,4 and 7 described above could be adopted on farmers fields; methods 5 and 6 are more appropriate to research stations.

Recommendations

Participants to the workshop made the following recommendations based on conclusions reached during discussions which followed the presentation of technical and country papers.

A. General

Because of the high cost of assessing food losses as indicated above, it is recommended that:

1. Initial appraisal of losses at a country-wide or regional basis can be made by the use of "indirect data": These consist in particular of:
   - expert opinions of knowledgeable persons and experiences obtained in crop improvement projects, farming systems research, etc.
   - distribution surveys of pests, diseases and weeds.
   - data on losses which were found in pesticides trials, on-farm demonstrations, etc.

It is recognized that these data would need careful interpretation but this source of information should not be neglected.

2. Loss assessment, in the first place, should be conducted in conjunction with specific loss reduction activities and their evaluation such as the effectiveness of pesticides, resistant varieties or other crop management practices used at the farm level. It is recommended that crop loss assessment and related research are primarily conducted in conjunction with current national projects directed at increasing farmers' production, revenue and security of national and individual food stocks.

3. Where possible, existing information should be verified by crop loss assessment in small plots at farmers' fields, as indicated in 2 above.

4. Crop loss assessment studies based on specifically designed surveys and experiments for countries and regions should be conducted whenever possible and with specific objectives in mind. The need for co-ordination to be established by the ECA/FAO was emphasised.

5. Data on crop losses and loss assessment, and value of losses financially or for food security methodologies, should be readily available at the national level. Each country should locate such data bases at Ministries of Ágriculture, Plant Protection Services, universities or research institutions, depending on the local situation.

6. It is also recommended that ECA and FAO continue to sensitize member countries on the importance of reducing food losses as one of the major components of increasing agricultural production and the availability of food in the continent.

B. Methodologies

It is recommended that a manual be prepared for crop loss assessment in cereal grains in Africa. This manual should provide background information and short but practical descriptions of suitable methodologies. Literature references connected with each method should be provided with a brief description of their advantages and disadvantages. The manual will describe a range of yield loss assessment techniques and indicate their suitability:

(a) For extension workers to use as a guide for pre- and post-harvest loss assessment and to appraise its applicability in their extension programmes.

(b) For research and development specialists to use in damage assessment trials.

Loss assessment is not a static but a dynamic subject, and the manual should be regularly updated, taking into account feed-back information from the extension workers and researchers.

The workshop further agrees that there was a need for further research on loss assessment methodology and in particular to develop practical methods allowing rapid appraisals to be made at the farm level.

C. Extension

The necessity for information about crop loss assessment and the proposed technologies/management transfer to address problems being passed between research organizations and extension agencies is recognised. It is hoped that countries and international agencies alike should consider the means of achieving this and make additional provision for the dissemination of information.

D. Practical Projects

Member states are urged to initiate or continue to promote practical projects aimed at preventing and reducing food losses, both at the pre- and post-harvest stages. It is recommended that research institutions involved in related activities undertake, in collaboration with national agricultural departments, on-farm trials involving extension workers and farmers themselves. This process will not only test the feasibility of the proposed methods at farm level but will also create a mechanism of interaction between researchers and the end users.

In countries where such projects are already completed or on-going, results must be made widely available to national and international institutions and agencies involved in related activities.

E. Training

There is a need for training in loss assessment, in particular in relation to loss reduction activities and pesticide use. It is therefore recommended that workshops are organized:

- at national level to train field personnel.
- at international level to train senior professional personnel.
- at international level to sensibilize decision makers for the need for crop loss assessment as a tool for increasing agricultural production and to make them more aware of the uses which should be made with such data.

F. Implementation of the Recommendations

To implement the recommendations:

(a) First priority is the preparation of the manual. **ECA and FAO are therefore requested to seek funds to prepare the manual.** Funds are needed for institutional/author's contracts to prepare various chapters, and for its printing and distribution. For the preparation of the manual, a working group should be formed consisting of members of institutions/organizations which have a particular knowledge on the assessment of losses caused by arthropods, diseases, weeds, storage pests and the strategic/economic ramification of the losses. The activities of the working group must be co-ordinated by one institute. The time frame for the preparation of the manual should be within one year after the necessary funds have become available.

(b) To facilitate the dissemination and exchange of information and experiences between countries, the participants urge ICIPE to strengthen the PESTNET system and diffuse the Bulletin providing highlights of activities under the system as widely as possible. PESTNET Bulletin should be used to promote the exchange of information among scientists involved in the assessment of both pre- and post-harvest losses and national concerned institutions.

(c) Other recommendations can be taken up in parallel to the preparation of the manual, depending on the availability of funds and national priorities. It is expected that the manual will stimulate in-country seminars, workshops and training programmes with the objective of reducing crop losses.

It was recognized that any recommendation in the field of crop loss assessment and/or of reducing such losses cannot reach the objectives outlined without appropriate government agricultural policies. Consequently, it was recommended that ECA and FAO request African member countries to set up agricultural policies conducive to the objectives of increasing food production and assuring food security, through the assessment and reduction of food losses.

LIST OF PARTICIPANTS

Annex II

ECA/ICIPE REGIONAL STUDY WORKSHOP ON "ON-FARM AND POST-HARVEST LOSSES OF CEREAL CROPS DUE TO PESTS AND DISEASES
Nairobi, Kenya, 10-17 October 1987

List of Participants

Country Representatives

BOSTWANA

Mr. Rapula G.S. Ksotlele
Post Harvest Officer
Ministry of Agriculture
P/Bag 003
Gaborone
Botswana

ETHIOPIA

Dr. Tadesse Gebremedhin
Head, Crop Protection Department
Institute of Agricultural Research (IAR)
P.O. Box 2003 Addis Ababa Ethiopia

Mr. Fulassa Sori
Pesticide Application Senior Expert
Ministry of State Farms Development
P.O. Box 5765
Addis Ababa
Ethiopia

KENYA

Mr. Matthias Ochieng' Were
Deputy Director of Agriculture
Ministry of Agriculture
P.O. Box 30028
Nairobi
Kenya

Mrs. Margaret Katunge Kimoli
Agricultural Research Officer II
National Agricultural Laboratories
P.O. Box 14733
Nairobi
Kenya

Mr. Patrick Wanyonyi Wekesa
Agricultural Research Officer II
National Agricultural Laboratories
P.O. Box 14733
Nairobi
Kenya

MALAWI

Mr. Defrea Verson Kampani
Senior Agricultural Officer
Pest Control
Ministry of Agriculture
P.O. Box 30134
Lilongwe 3
Malawi

Mr. Cuthbert Martin K. Chimbe
Commodity Team Leader (Crop Storage)
Department of Agricultural Research
P.O. Box 30134
Lilongwe 3
Malawi

TANZANIA

Mr. Juma A. Saidi
Senior Research Entomologist
Tropical Pesticide Research Institute
P.O. Box 3024
Arusha
Tanzania

Mr. Juma M. Katundu
Scientific Officer
Tanzania Agricultural Research Organization
P.O. Box 9167
Dar-es-Salaam
Tanzania

UGANDA

Mr. Silim Moh'd Nahdy
Scientific Officer (Entomologist)
Storage Entomology
Kawanda Research Station
Ministry of Agriculture
P.O. Box 102
Entebbe
Uganda

Mr. Enson K. Kato
Agricultural Officer
Ministry of Agriculture
P.O. Box 102
Entebbe
Uganda

ZAMBIA

Mr. Bernard Mdoka Mtonga
Farming Systems Agronomist
Adaptive Research Planning Team
Luapula Regional Research Station
P.O. Box 710129
Mansa
Zambia

Invited Experts

Dr. Richard John Cooter (observer)
Head of Physiology and Behaviour Section
Department of Applied Ecology
ODNRI, College House
Wrights Lane
London W8 5SJ
U.K.

Ms. Judy Walker
ODNRI
College House
Wrights Lane
London W2
U.K.

Dr. Johnson Glynn Holt
ODNRI
College House
Wrights Lane
London W2
U.K.

Dr. Tom George Wood
Overseas Development Natural Resources Institute (ODNRI)
Wrights Lane
London W2
U.K.

Mr. John Antony McFarlane
Overseas Development Natural Resources Institute (ODNRI)
Storage Department
Slough
England

Dr. Peter Golob
Overseas Development Natural Resources Institute (ODNRI)
Storage Department
Slough
England

Dr. Derek J.W. Rose
Leader, East African Armyworm Project
Desert Locust Control Organization for Eastern Africa
P.O. Box 30023
Nairobi
Kenya

Dr. Kanayo F. Nwanze
Principal Cereals Entomologist
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru P.O.
Andhra Pradesh 50234
India

Mr. Austin C.Z. Musuna
Chief Scientific Officer
The International Red Locust Control Organization for Central and Southern Africa
P.O. Box 240252
Ndola
Zambia

Dr. Pantenius Christian Ulrich
Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ)
Dag-Hammarskjold-Weg
6236 Eschborn W-Germany

Dr. M. Agyen Sampong
Director, Mangrove Swamp Rice Research Station
West African Rice Development Association
P.M.B. 678
Freetown
Sierra Leone

FAO Experts

Mr. Gerard G.M. Schulten
Senior Officer (Entomologist)
Plant Protection Service
Food and Agriculture Organization
Via Terme di Caracalla
Rome
Italy

Dr. Kolli N. Rao
Chief Technical Adviser/Plant Protection
UNDP/FAO Maize Project
P.O. Box 30563
Lusaka
Zambia

Mr. Roger William Vinita
Project Leader, Prevention of Food Losses Project
C/O FAO
P.O. Box 521
Kampala
Uganda

Mr. Valentine R.J. Ndibalema
Agricultural Research Officer
FAO LGB Control Programme
P.O. Box 2
Dar-es-Salaam
Tanzania

Dr. Graham H.G. Martin
Chief Rodent Consultant
FAO/UNEP Kenya Project
Kenyatta University
Department of Zoology
P.O. Box 43844
Nairobi
Kenya

ICIPE Experts

Dr. D.L. Haynes
Deputy Director
ICIPE
P.O. Box 30772
Nairobi
Kenya

Prof. Kailash Narain Saxena
Programme Leader
Crop Pests Research
ICIPE
P.O. Box 30772
Nairobi
Kenya

Dr. Zerubabel M. Nyiira
Senior Principal Research Scientist
ICIPE
P.O. Box 30772
Nairobi
Kenya

Dr. K.V. Seshu Reddy
Senior Research Scientist
ICIPE
Mbita Point Field Station
P.O. Box 30
Mbita
Kenya

Dr. James K.O. Ampofo
Research Scientist
ICIPE
P.O. Box 30772
Nairobi
Kenya

Ms. Esther Bonitatibus
Scientific Officer
ICIPE
Mbita Point Field Station
P.O. Box 30
Nairobi
Kenya

Dr. Henry F. Magalit
Senior Research Scientist (Biostatistician)
ICIPE
P.O. Box 30772
Nairobi
Kenya

Mr. Munene wa Macharia
Postgraduate Student ARPPIS,
ICIPE
P.O. Box 30772
Nairobi
Kenya

Economic Commission for Africa

Dr. Samuel C. Nana-Sinkam
Director
Joint ECA/FAO Agriculture Division
United Nations Economic Commission for Africa
P.O. Box 3005
Addis Ababa
Ethiopia

Dr. Halidou Ouedraogo
Economic Affairs Officer
United Nations Economic Commission for Africa
P.O. Box 3005
Addis Ababa
Ethiopia

Dr. Alfred Richter
Expert Food Loss Reduction
United Nations Economic Commission for Africa
P.O. Box 3005
Addis Ababa
Ethiopia

ANNEX I

PROGRAMME OF WORK

THE REGIONAL STUDY WORKSHOP ON "ON-FARM AND POST-HARVEST LOSSES OF CEREAL CROPS IN AFRICA DUE TO PESTS AND DISEASES": NAIROBI, KENYA, 11-15 OCTOBER 1987

VENUE: Duduville International Guest Centre, Nairobi

PROGRAMME

Sunday, October 11, 1987

All day	Registration
18:30	**Reception and Official Opening** Introductory Remarks by Professor Thomas R. Odhiambo, Director, ICIPE Introductory Remarks by Dr. S.C. Nana-Sinkam, Director, Joint ECA/FAO Agricultural Division ECA, Addis Ababa Opening address by the Chief Guest, Hon. W. Ndolo Ayah, MP Minister for Research, Science and Technology, Kenya.

Monday, 12 October 1987

08:00 – 09:00	Registration (Cont'd)

Chairman: Dr. D.L. Haynes, Ag. Director, ICIPE

09:00 – 09:25	Objectives and scope of the workshop by Dr. S.C. Nana-Sinkam, Director, Joint ECA/FAO Agriculture Division, ECA, Ethiopia
09:25 – 09:30	Workshop logistics by Professor K.N. Saxena, ICIPE, Nairobi.
09:30 – 10:00	Group Photography Coffee/Tea break

Country Reports (20 min. report presentation: 10 min. discussion)
Chairman: Dr. S.C. Nana-Sinkam, ECA, Ethiopia

10:00 – 10:30	Kenya
10:30 – 11:00	Ethiopia
11:00 – 11:30	Uganda
11:30 – 12:00	General discussion
12:00 – 14:00	Lunch

Technical papers (45 min. paper presentation: 15 min. discussion)
Chairman: G.G.M. Schulten, FAO, Rome

14:00 – 15:00	Assessment of on-farm losses in milles due to insect pests K.F. Nwanze
15:00 – 16:00	Assessment of on-farm losses in sorghum due to insect pests K.V. Seshu Reddy
16:00 – 16:30	Coffee/Tea break
16:30—17:30	Assessment of on-farm losses in maize due to insect pests J.K.O. Ampofo

Tuesday, 13 October 1987
Country Reports
Chairman: Mr. M.O. Were, Deputy Director, Ministry of Agriculture, Kenya

09:00 – 09:30	Tanzania
09:30 – 10:00	Zambia
10:00 – 10:30	Coffee/Tea break
10:30 – 11:00	Malawi
11:00 – 12:00	General discussion
12:00 – 14:00	Lunch

Technical Papers
Chairman: Professor K.N. Saxena, ICIPE, Nairobi

14:00 – 15:00	Cereal losses caused by armyworm in Eastern and Southern Africa D.J.W. Rose
15:00 – 16:00	Assessment of on-farm losses in rice due to insect pests M. Agyen-Sampong (Presented by Dr. Ampofo, ICIPE)
16:00 – 16:30	Coffee/Tea break
16:30 – 17:30	Cereal losses caused by locusts in Eastern and Southern Africa A.C.Z. Musuna

Wednesday, 14 October 1987
Chairman: Dr. K.F. Nwanze, ICRISAT, India

08:30 – 09:00	Botswana

Technical Papers
Chairman: Dr. P. Golob, ODNRI, U.K.

09:00 – 10:00	Assessment of on-farm losses in cereals due to insect pests T.G. Wood
10:00 – 11:00	Assessment of on-farm losses in cereals due to birds and other vertebrate pests C.C.H. Elliot
11:00 – 12:00	Assessment of on-farm losses in cereals due to diseases K.N. Rao
12:00 – 13:00	Assessment of post-harvest losses in cereals due to pests and diseases C.U. Pantenius
13:00 – 13:30	General Discussion

Thursday 15 October 1987

Field visit by air (See information sheet) item ... 15)	Group A - ICIPE's Mbita Point Field Station Group B - Pilot Project on Reduction of Food Losses at Oyugis

Friday, 16 October 1987
Technical Papers
Chairman: Dr. C.U. Pantenius

08:30 – 09:30	Current status of the greater grain borer, *Prostephanus truncatus* in Africa P. Golob
09:30 – 10:30	Storage methods in relation to post-harvest losses in cereals J.A. Mcfarlane
10:30 – 11:00	Coffee/Tea break
11:00 – 12:00	Storage methods in relation to post-harvest losses in cereals A. Richter
12:00 – 13:00	FAO's experience with crop loss assessments G.G.M. Schulten
13:00 – 14:30	Lunch
14:30 – 16:00	General discussion and recommendations Chairman: Dr. S.C. Nana-Sinkam Co-Chairman: Prof. D.L. Haynes Rapporteurs: Dr. A. Richter Dr. J.K.O. Ampofo
16:00 – 16:30	Coffee/Tea break
16:30 – 17:30	General discussion and recommendations (cont'd)
17:30	Concluding remarks by Dr. S.C. Nana-Sinkam

The Assessment of On-Farm Losses Due to Birds and Rodents in Eastern Africa

C.C.H.Elliott

Introduction

Most scientists and many decision-makers in agriculture would agree that a rational pest control strategy cannot be developed unless there is a clear idea of how much damage pests are causing to the various crops. It is therefore surprising to find that in the case of birds and rodents, there is little in the way of good statistical data on damage levels. It should be necessary for there to be sound information on how serious are the losses due to birds and rodents, so that governments can assess what sort of inputs they should make towards solving or limiting the problem. Damage assessment data could also be used to evaluate the degree of success achieved by bird or rodent control teams. This review will show that for birds the methodology for damage assessment exists but that for rodents it has not yet been developed, though a method similar to that of birds is likely to be needed. What is lacking is the manpower and resources necessary to carry out such assessments. At present all available resources are used up in control operations.

The Recognition of Bird and Rodent Damage

The crops discussed here are mainly the cereal crops — maize, sorghum, millet, wheat and rice. Birds can damage other crops in eastern Africa including horticultural crops such as fruit and tomatoes, oil crops such as sunflower and they sometimes cause fouling to stored crops. Rodents also cause losses to horticulture, as well as forestry, groundnuts, coconuts, sugarcane, stored crops,even farm machinery and habitations but for them as for birds, this paper concentrates on the cereals.

Many farmers automatically assume that their crops are being attacked if they see large flocks of small birds in their fields. Often they are right but sometimes their anxiety is misplaced. The flocks may be of species which cause little or no damage such as waxbills and mannikins (Estrildidae). On other occasions notorious pests such as the Red-billed Quelea (*Q. quelea*) may be feeding entirely on preferred weed seeds such as those of lovegrass *Setaria* sp. or may be gorging themselves on insects such as those of armyworm or American bollworm.

Careful observation through binoculars will soon show if the crop itself is being attacked. Other signs will depend on the crop concerned. Maize cobs are peeled back by weaverbirds and pieces of grain removed. Sorghum grain is normally broken so that inner white colour shows up. For rice, millet and wheat, birds remove the whole grain and mandibulate off the husk. Serious bird-damage is usually evident from the scattering of bits of husk and grain scattered on the ground between the plants. Birds killed for samples will have pieces or whole grain in their gizzards but the careful observer will have to be sure that such grain has not been picked up from the ground in fields already harvested. Sometimes the damage that birds do is compounded by grain being knocked to the ground but not eaten. This is typical of rice and wheat where harvesting is delayed until the crop is extra dry and prone to shattering. At milky stage birds often nip the grain and suck a little from each one.

Bird damage can be confused with insect damage especially when large insects such as grasshoppers chew chunks off millet heads or through eating the pollen, cause the grain to abort. Grain shattering due to wind can be incorrectly blamed on birds.

Rodent damage is much more easily overlooked than bird damage because most of it takes place at night. Often farmers only complain about rodent damage when rodent populations reach plague proportions and they are literally tripping over them. The most common forms of rodent damage in eastern Africa are the removal of germinating seeds especially of maize, requiring the farmer to replant, the cutting of the stems of wheat or barley just above ground level and the attacking of stored grain on the farm. Recognizing that it is rodents that have done this is not necessarily easy since lack of germination can be due to a variety of causes and other vertebrates also remove seeds. There should, however, be other tell-tale signs of rodent activity such as burrows, and well-worn tracks from nearby rough pasture or grassland. In storage, rodent problems will be most obvious if stores are visited at night. Rodents also damage ripe grain and here in Kenya, they can cause significant losses to maize which has been stooked before harvesting.

Methods of Damage Assessment — Birds

For birds, two main methods have been used, the visual estimation of percentage lost from an individual cereal head and cut samples of the crop in which the weight of damaged and undamaged heads is compared.

The visual method is used mainly on maize, millet and sorghum where the weight of an individual head is substantial. Estimating the percentage grain damaged or removed is done by eye. Staff can be trained to do this using simulation cards or actual grain heads in which the number of grain removed and remaining has been counted precisely. Staff can also be tested for their 'observer bias' since most people have a regular tendency to overestimate or underestimate and field data can be appropriately adjusted. Devices have been developed for measuring the length of a maize or millet cob and to divide them into quarters, to make the percentage loss easier to estimate.

The weighing method is suitable for the small spikes of wheat and rice. The method assumes that the birds attack the crop randomly, not choosing any particular size or shape of spike. Samples are taken from the field, as described below, and the weight of damaged spikes is compared to that of undamaged spikes. A simple calculation is then done to determine the percentage loss. The method has the advantage that it is relatively objective since it does not depend on the ability to judge percentages visually.

The problem in making damage assessments comes in the design of sampling procedures that achieve statistical respectability while not exceeding the availability of trained manpower. The design is difficult because bird damage is so localised and irregularly distributed. One field may be seriously damaged while the next may be untouched. Within fields themselves, damage may be concentrated around the edges or near patches of bush that the birds find convenient as perches. Elaborate statistics are available to help calculate if sample size is sufficient and the often high statistical variance is the major factor in this. The most important aspect is the random selection of sampling sites and of sampling transects or strata.

The basic method usually used to assess bird damage in a single field is to proceed through a field in a broad zig-zag, stopping at 20 paces exactly and sampling 5 heads either by cutting them (wheat or rice) or by the visual percentage method. The five heads are selected randomly with the eyes shut. A minimum of 40 stops is made in one field giving a data base minimum of 200 sampled heads. If the object is to assess the damage over a whole farm, then the fields are numbered and selected randomly, and as many of them are assessed as possible in the time available. Damage assessments can either be made just before harvest if the idea is to assess total pre-harvest losses, or if they are to serve as a measure of pest control effectiveness, assessments need to be made at the time of control and again just before harvest.

When bird damage assessment is directed at areas larger than a large farm, such as a large area of subsistence farmers or a District, Province or even over a whole country, it becomes much more difficult to design a statistically valid protocol. Because of the effort, time, and man-power, very few such estimates have been made. One was done on the lowland sorghum crop of the Awash Valley, Ethiopia (Jaeger and Erickson, 1980). They toured the area by vehicle, and on reaching a sorghum-growing valley, they estimated the total cropping area and then stopped at fixed intervals across it, taking sampling transects first to one side of the road, then to the other. The method was very rough but it did provide some indication of the levels of bird damage over hundreds of thousands of hectares.

Since then, FAO engaged a consultant, D. Otis of the Denver Wildlife Research Centre, Colorado, USA to help refine large-scale bird damage surveys (Otis in prep.). He identified two prerequisites for effective large-scale surveys. The first was an accurate map of crop distribution and of all motorable roads within the target area. It is surprising that even in countries so advanced agriculturally as Kenya, it is difficult to find an accurate presentation of crop distribution and total hectarage. The hectarage in a district is also not necessarily a static figure and will change according to developing agricultural trends and rainfall patterns. The second prerequisite is the availability of trained manpower. There is no point in developing a design requiring 100 people and 40 vehicles if only 10 and 3 are available. Because of these short-comings a method was developed of estimating the hectarage of a particular crop and it was successfully tested on sorghum in Singida, Tanzania. It used an aircraft flying at 200 km/hr at 100 m altitude. An observer records every 15 seconds whether a small circle drawn on the window looks on to the target crop or not. A recorder records positive or negative. The aircraft flies along randomly chosen parallel transects across the target area. The data provide an estimate of crop hectarage.

A ground-team divides all the motorable roads through the target area into 2 km sections and gives each a number. These numbers are randomly selected and at each one selected left and right transects off the road are made over a 500 m × 500 × 500 line. Patches of the target crop encountered at 50 m stopping points are evaluated for damage and head size within a 1 m circle.

The above method has been proposed as a suitable statistical method for large-scale bird damage assessment but only the crop distribution part has so far been tested. It seems likely that it would produce satisfactorily accurate estimates but the inputs would be high.

Methods of Damage Assessment — Rodents

I have not uncovered any methodology on rodent damage equivalent in detail to that available for birds. Clearly a similar method would be likely to be appropriate. Small-scale assessments over a few hectares have concentrated on the number and percentage of rows of sown maize that have had to be replanted. Sometimes these have been extrapolated to larger areas (Taylor, 1968). Taylor used another method for the standing crop, counting the number of cut stems compared to standing stems in metre square quadrats. It appears that largescale surveys incorporating some level of statistical validity have not been attempted. The same can apparently be said for rodent losses to stored grain on the farm.

Damage levels recorded

Only the local surveys of bird damage in individual fields and farms meet reasonable levels of statistical exactitude. These show that in areas of some tens, occasionally hundreds of hectares, birds can cause serious damage, sometimes even the total loss of the crop. Some examples of recorded damage levels are as follows:

- In Nakuru, Kenya in 1953 a yield of 1000 bags of wheat was recorded where 7000 was expected, due to birds (Plowes, 1955)
- 40 ha of dwarf sorghum was wiped out at Filabusi, Zimbabwe (Plowes, 1955)
- 150 ha of sorghum was completely destroyed at Jebel Simsim, Sudan (Bruggers *et al.*, 1984)
- 354 t of rice (12.7% of the crop) was lost at Bongor, Chad (Elliot, 1979)

- 15.2% was lost over 4200 ha of wheat, near Nakuru in 1978 (FAO, 1981)
- 31% of 122 ha of sorghum was destroyed by birds at Wanle Weyn, Somalia (Bruggers, 1980)

A number of efforts have been made to quantify bird damage over larger areas, even over countries, but these have not followed all the procedures outlined above and have many statistical weaknesses (see Elliott in prep.). The evidence indicates that if losses due to birds are set against national cereal production, then that loss is likely to be less than 5% or even lower. However, as well as these direct losses, birds have an indirect impact on cereal production through the anxiety they cause which can often discourage farmers from expanding areas under cultivation or adopting new varieties. The severe local losses which birds actively cause also have to be combatted.

For rodents, the local records are fewer but some of them are striking, as shown below:
- in 1969, 50-60% of the wheat crop was destroyed by rodents in the Sudan (Hopf *et al.*, 1976)
- 34% of the stems of the wheat were cut by rodents near Kitale, Kenya (Taylor, 1968)
- during the 1962 rodent outbreak in Kenya, 20% of the maize had to be replanted (Taylor, 1968)
- the Ministry of Agriculture, Ethiopia reported that in a normal year 5% of grain production is lost to rodents, the level rising to 20% in a bad year. (Hopf *et al.*, 1976).

On a national scale, rodent damage has seldom been objectively assessed. The evidence seems to suggest that the 'normal year' levels of damage may accumulatively be more important than the damage caused in 'bad years', since the latter only seem to occur once every five years or so, if the experience in Kenya is anything to go by (Gatimu and Martin in prep.). Rodent damage in storage on the farm is also likely to be important nationally.

Discussion

After many years of working with pest birds in Africa, I have witnessed numerous efforts to incorporate damage assessments as part of the routine operation of bird control. The methodology has progressed steadily to the extent that at whatever level assessments should be made, whether local or national satisfactory methods now exist. Yet I think it is true that in no country in Africa are damage assessments carried out as a routine either in relation to updating the definition of the problem or in relation to assessing control effectiveness. It seems that all the resources available must be channelled into control and that no funds or time are left over for damage assessments. The authorities in most countries are therefore only able to assess the success of control operations by the diminution of complaints or the expression of gratitude by farmers. While this may have political significance so that some have classified certain bird species such as the Quelea as agro-political pests, such a measure of success can hardly be called objective nor does it evaluate cost-effectiveness.

I think that the time will come when market forces will necessitate that bird control, and rodent control if the latter becomes a more general activity, will have to be evaluated in terms of economics and cost effectiveness. At such a time, damage assessments will need to become a routine part of crop protection activities. Probably it will be necessary to create special teams trained specifically in this activity whose only job will be to monitor damage levels as part of an on-going effort to improve strategies and make control operations as economic as possible.

References

Bruggers, R.L. (1980). The situation of grain-eating birds in Somalia. Proc. 9th Vertebrate Pest Conf., Fresno, Calif. **9:** 5-16.

Bruggers, R.L., Bohl, W.H., Bashir, S.El., Hamza, M., Ali, B., Besser, J.F., DeGrazio, J.W., and Jackson, J.J. (1984). Bird damage to agriculture and crop protection efforts in the Sudan. *FAO Plant Prot. Bull.* **32:** 2-16.

Elliott, C.C.H. (1979). The harvest time method as a means of avoiding quelea damage to irrigated rice in Chad/Cameroun. *J. Appl. Ecol.* **16:** 23-35.

Elliott, C.C.H. (in prep.) The pest status of the quelea. In Bruggers, R.L. and Elliott, C.C.H. (Eds.) The Ecology and Management of the African Red-billed Quelea. Oxford Univ. Press.

FAO (1981) An assessment of the bird pest problem in Sudan, Ethiopia, Somalia, Kenya and Tanzania. Unpubl. Int. Rep. FAO/UNDP, Rome Italy.

Gatimu, J.M. and Martin, G.H.G. (in prep.). Rodent problems and management in Kenya. Proc. European Plant Prot. Org., Sept. 1987.

Hopf, H.S., Morley, G.E.J. and Humphries, J.R.O. (1976). Rodent damage to growing crops and to farm and village storage in tropical and sub-tropical regions. Centre for Overseas Pest Res./Trop. Products Inst., Lond., U.K.

Jaeger, M.M. and Erickson, W.A. (1980). Levels of damage to sorghum in the Awash Basin of Ethiopia and the effects of the control of quelea nesting colonies (1967-1979). Proc. 9th Vert. Pest Conf., Fresno, Calif. **9:** 21-28.

Plowes, D.C.H., (1955). Queleas in Southern Rhodesia CCTA/CSA **55(121):** 1-13.

Taylor, K.D. (1968). An outbreak of rats in agricultural areas of Kenya in 1962. *E. Afr. agric. For. J.* **34:** 66-77.

Assessment of On-Farm Losses in Cereals Due to Diseases

K.N. Rao

I. Introduction

Plant diseases were studied initially because they were causing economic losses to plants. However, very few people have attempted to systematically estimate the losses they are causing. This information is important to impress upon the administrators, donors and practical men, who are allocating large sums of money to carry on the work for an efficient disease management. International concern about the inadequacy of methods used for assessing diseases and estimating losses resulted in FAO's sponsoring a symposium on Crop Losses in 1967, which recommended development of more precise methods, so that the limited expertise available could be deployed in the most efficient way. In a world conscious of pollution, loss estimates may achieve new significance by providing evidence that will justify or condemn the use of fungicides to control epidemics. To develop rational and economic control measures, whether by breeding resistant cultivars or by using fungicides, it is not sufficient to state that disease causes a loss, the magnitude of the loss must be evaluated so that it can be related to the gain obtained. Only by disease loss appraisal is it possible to determine the economic loss due to different amounts of diseases. Disease loss appraisal therefore represents an absolutely essential step because until economic loss can be measured, it is not possible to implement disease or pest management schemes aimed at economic control (James, 1974).

II. Types of Losses

Before going into study of actual estimates of losses it is essential to know what are the types of losses that we encounter due to diseases. Types of losses are characterized by a number of anti-theses: actual-potential, incidental-regular, transitional-structural; recognised-hidden; direct and indirect.

(a) Actual and Potential Losses: The first anti-thesis is "actual" versus "potential" loss (Klemm 1940). The actual loss consists some or all of the following elements: (i) loss of quantity and/or quality produce; (ii) extra costs of harvesting and/or grading; (iii) costs of disease.

These elements lead to: (iv) decreases in monetary return of labour and investment; (v) decrease in economic activity of rural population; (vi) increase of prices paid by consumers.

Potential losses are the losses which may occur in the absence of control measures. The importance of potential losses can be evaluated by studying the history of catastrophies caused by plant diseases (Chester, 1950; Large, 1950; Ordish, 1952; Stevens, 1934; Zadoks, 1967).

(b) Incidental and Regular Losses: Incidental losses occur only once or at irregular intervals. In the latter case they are due to exceptional weather conditions over a prolonged period favouring the build-up of an epidemic (e.g. the devastating 1932 epidemic of black stem rust, *Puccinia graminis,* on wheat in Eastern Europe) or to the appeareance of new areas of the pathogen (e.g. the 1950 epidemic of black stem rust race 15 B of wheat in Northern America).

Regular losses occur each season in more or less equal amounts. In many countries brown leaf rust of wheat (*Puccinia recondita*) is the cause of regular losses. Observers may be so used to regular losses that these are no longer recognised. Nevertheless, the long term average of regular losses may be at least as high as that of incidental losses.

(c) Transitional and Structural Losses: Transitional losses occur when growers change over from one farming system to another. This type of loss is of a temporary nature. Transitional loss will disappear, rapidly or after many years, when a new equilibrium has been established, sometimes at the expense of great research costs.

There are many examples of transitional losses (Barnes, 1964). Introduction of victoria resistance in commercial oat varieties of USA produced severe losses caused by the hitherto unknown fungus *Cochliobolous (Helminthosporium)* victoriae.

In contrast to transitional losses, structural losses are unavoidable in a given agricultural situation. An example is the loss of bananas caused by sigatoka leaf spot, *Mycosphaerella musicola,* in the humid tropics. Transitional losses are restricted to annual crops and the products of perennial crops.

(d) Direct and Indirect Losses: The last anti-thesis is between 'direct' and 'indirect' losses. Direct losses are losses of quantity and quality of the product and, in addition losses of yielding capacity. Indirect losses are actual losses in the economic and social field occurring as a consequence of plant diseases. (i) **Direct Losses:** Direct losses can be divided into two groups: Primary and Secondary Losses. **Primary Losses:** The primary losses are pre- or post- harvest losses of plant products due to plant diseases. They occur all along the line from seed storage through germination, growing and harvesting to handling and storage of the harvested product. Primary losses can be losses in quantity or in quality. Loss of quantity alone is exemplified by loose smut (*Ustilago tritici*) of wheat. Economically, the primary loss consists of some of the following elements: (i) Reduction of quantity of marketable products per hectare; (ii) Reduction of market value per unit of product; (iii) Costs of disease control; (iv) Extra costs of harvesting; (v) Extra costs of grading; (iv) Costs of replanting (vii) Loss due to the necessity of growing substitute crops yielding smaller monetary returns than the customary one.

All of these elements result in a loss of income or an increase in expenditure at the farm, during storage, shipment and retailing, or in customer's kitchen.

- **Secondary Losses:** Secondary losses are losses to the yielding capacity of future crops. The cumulative effect of soil, seed or tube-borne diseases in annual crops is well known. The eye spot disease (*Cercosporella herpotrichoides*) of wheat is soil borne and its accumulation can be interrupted only by a wide rotation. From the economic point of view, such losses are losses of capital invested in soil, seed or tree, sustained at farm level. (ii) **Indirect Losses:** Indirect losses are the economical and social implications of plant diseases beyond their immediate agricultural effects. They occur in various sections of society and they can be classified accordingly.

- **The farmer's losses:** At the farm level, loss of income or capital impoverishes the farmer and, eventually forces him to give up farming.
- **Losses to the rural community:** When farmers suffer as a group, the whole community life of the rural community and its dependent industries is retarded. Returns on invested capital decrease and unemployment occurs.

III. Principles of Measuring Crop Losses Caused by Plant Disease

(a) Variation In Types of Measurement: The effects of plant disease can be measured as reduction in yield of a commercial crop, including commercial nursery. This reduction can result either from direct infection of plant parts to be harvested, or from infection of other parts of the plant.

(b) Differences in Yield Between Diseased and Disease-Free Plants: These differences in yield between diseased and disease-free plants varies from complete loss to no loss when compared with expected maximum yield.

(c) Loss of Combination of Pathogen: Loss resulting from a disease caused by a single pathogen is a relatively simple relationship that can be measured by comparing the difference in response between diseased and disease-free plants. The relationship becomes more complicated when more than one pathogen is involved in a disease complex. Several things may happen when more than one pathogen occur on the plant at the same time. There may be additive or synergistic effects can be seen.

(d) Biological and Ecological Factors: There are critical places and times in the measurement of plant disease loss that are dictated by certain biological and ecological factors. Susceptibility of host, virulence of pathogen, time of infection, soil type and condition of weather, and presence of vectors are the factors involved. The amount of plant disease loss usually is influenced by an interaction of two or more of these factors.

(e) Perennial Plants: In annual plants, the loss from plant disease can occur only on the crop produced from the year the plant was grown and can be attributed only to disease that occurred in that year; whereas in case of perennial plants once disease attacked, there would be a yearly loss until the plant is removed.

(f) Expressed in Terms of Value: The loss is expressed in percentage, the value is not the same to the grower and processor or a delivery man. The value of the produce gets reduced in the ownership levels.

(g) Variation from Year to Year: The loss in yield varies from year to year even though one may say a particular one is a normal year. It is important to add or subtract exceptions to each of these normal years.

IV. Development of a Method for Estimating Losses

(a) Location, Design and Specification of Field Experiments:
Ideally, identical experiments should be conducted in all geographical areas where the crop is important, over a 3 year period, using the major cultivars under the range of conditions found under normal farming practices. Some experiments have featured paired plots, or isogenic lines, and the disease loss is calculated as the difference in yield between the two treatments expressed as a percentage of the yield on the healthy plot. However, this design is inferior to the multiple treatment experiment.

(b) Measuring Yield and Quality: When suitable experimental specifications to detect a given yield difference between treatments have been chosen, yield and quality should be estimated by the same harvesting techniques and grading systems used by the farmers.

(c) Disease Assessment: Diagnosis and assessment of plant diseases are important functions of plant pathologists. Diagnosis of the more common diseases is based on identification of pathogen and/or symptoms using methods universally known and accepted.

V. Problems in Expressing Crop Losses

The major purpose of expressing crop losses is to provide facts and economic intelligence to aid in decision making regarding the most economical ways of increasing crop production. With this objective in mind, it is difficult to generalize any one method of expressing crop losses. Each method has unique advantages. Selection of any one method of expressing crop losses will depend on the specific purpose to be served.

Despite the problems involved, it is strongly recommended the full use of costs and returns analysis as guides to decision making on a regional and national basis. The analysis of costs and returns not only will provide valuable economic intelligence for decision making, but also will put crop losses in a better perspective. Techniques for controlling crop losses are only a potentially important part of the improved production packages for increased crop production.

Conclusion

The importance of crop loss assessment in decision making was fully illustrated. Types of losses caused by various plant diseases were discussed before determining the principles of measurement and methods of estimating losses. It is generally recognised that no single method of estimating losses can be regarded as perfect. However, combination of various methods to suit a specific purpose is the most ideal. The analysis of costs and returns as a guide to decision making on a regional and national basis, is suggested as single best method of crop loss assessment, provided price elasticities are taken into consideration.

References

Barnes, E.H. (1964). Changing plant disease losses in changing agricultural phytopathology **54:** 1314-1319.
Chester, K.S. (1950). Plant disease losses: Their appraisal and interpretation. Exp. Sta Coll. Agric., Bull. No. 677: 1-21.
James, C. (1974): Assessment of plant diseases and losses. *Ann. Rev. of Phytopath.* **12:** 27-48.
Kelmm, M. (1940). Enterverluste, Schadensschatzung und Pflanzenshutzstatistik. *Rorschungsdienst* **10:** 1309-1313.
Large, E.C. (1950). The advance of the fungi. 3rd Edition. Jonathan Cape, London.
Ordish, G. (1952). Untaken harvest. Constable, London.
Stevens, N.E. 1934. Records of agricultural projects known to have failed through plant diseases. *Plant dis. Reptr.* **18:** 7-16.
Zadoks, J.C. 1967. International dispersal of fungi. *Neth. J. Plant. Path.* 73, Suppl. 1: 61-80.

Assessment of On-Farm Losses in Maize Production Due to Insect Pests

J.K.O. Ampofo

Introduction

Maize is the most important cereal food crop in the eastern and southern Africa region. Production is however, limited by several constraints such as drought, low inputs and management and ravages by pests and diseases. Yields per unit area are, thus, among the lowest in the world (CIMMYT, 1987).

The low yields are attributed partially to damage by insect pests. However, objective and reliable assessment of losses in maize production due to these pests are lacking in several countries in the region. Losses are often cited as 'considerable' (eg. Rose, 1972), serious (Atkinson, 1980). In some cases the insect is merely noted as damaging (eg. Jarvis *et al.* 1984) or a 'limiting factor' in maize production (Lynch and Guthrie, 1980).

Accurate information about losses is essential: (i) to monitor the effects of insect pests on maize production in individual countries for food and other policy planning. (ii) to make decisions concerning the allocation of resources to research for the management and control of the pests and other constraints limiting production. (iii) as a basis for judgment on the importance of insect pests in maize production and stimulate action against them (Walker, 1983).

Over 30 insect species and complexes are known to cause damage to maize plants in eastern and southern Africa (Table 1). However, only about seven: *Busseola fusca* Fuller, *Chilo partellus* (Swinhoe), *Sesamia calamistis* (Hampson), *Eldana saccharina* (Walker), *Cicadulina* spp., *Spodoptera exempta* (Walker) and termites are consistently reported to cause economic damage.

Various methods for the assessment of losses caused by the different maize pests have been devised and used by a number of maize researchers (eg. Walker 1983, 1987; Chiarappa 1971, Judenko 1973). It is the objective of this paper to briefly review the methodologies available presently.

Types of damage caused by the major insect pests of field maize.

The maize crop in eastern and southern Africa is attacked by insects throughout its life cycle. The damage resulting from these attacks can be categorized according to the plant stage attacked and the effect on the plant.

i. Crop establishment - attack on germinating seeds and seedlings reduce plant stand. ii. Reduction in photosynthetic area of leaves as a result of foliar feeding. iii. Interference with water/nutrient uptake and translocation by root on stem damage. iv. 'Dead heart' formation and plant death resulting from damage to the growing point. v. Tassel drying or breakage resulting from severe tunneling in the peduncle. This may lead to poor pollen

Table 1. Insect pest species of maize in eastern and southern Africa

Classification	Common name	Scientific name	Plant part attacked
Consistent pests (generally widespread)	Maize stem borer	*Busseola fusca* Fuller	Folliage, stem and ear feeder
	Spotted stem borer	*Chilo partellus* (Swinhoe)	"
	Coastal stem borer	*Chilo orichalcociliellus* (Strand)	"
	Sugarcane borer	*Eldana saccharina* (Walker)	"
	Pink stem borer	*Sesamia calamistis* (Hampson)	"
		Cicadulina spp.*	Sap sucker and disease vector
Sporadic pests	Armyworm	*Spodoptera exempta* (Walker)	Foliage, stem and ear feeder
	Locusts	*Locusta m. migratorioides* (R & F)	Foliage feeder
		Nomadacris septemfasciata (Serv)	"
	Grasshopper	*Homorocoryphus nitidulus* Walker	Ear feeder
Common pests of minor importance	Earworm	*Heliothis armigera* (Hubner)	Ear feeder
	False codling moth	*Cryptophlebia leucotreta* (Geyer)	Ear feeder
	Cutworms	*Agrotis segetum* (Schiff)	Stem feeder
		A. ipsilon (Hufnagel)	Stem feeder
	Maize leaf aphid	*Rhopalosiphum maidis* (Fitch)*	Sap sucker/disease vector
		Peregrinus maidis Ashmead *	Sap sucker/disease vector
	Termites	*Microtermes* spp. *Macrotermes* spp.	Stem feeders
		Allodontermes spp. *Odontotermes* spp.	Foliage feeder
	Grasshoppers	*Zonocerus* spp.	

*Sap feeder of no direct economic importance but transmit diseases that may cause economic loss.

development and poor fertilization. vi. Stem lodging and ear drop as a result of extensive stem or shank tunneling. vii. Creation of openings for pathogens and transmission of disease. vii. Loss in aesthetic value of the crop as a result of damage to the ears of e.g. sweet maize.

Measurement of damage due to insect pests

The damage resulting from insect attack may vary according to season, variety as well as the plant growth stage. There is generally a direct relationship between the level of infestation and the extent of damage and various methods are available for the measurement of the parameters involved (Walker 1981, 1987).

These may be broadly distinguished as (i) the extent of the infestation eg. the percentage of plants attacked. This parameter considers the distribution or spread of the attack; i.e. the percentage of plants harbouring the insect or showing symptoms of attack and (ii) the severity of the attack, this may be assessed in actual numbers of the insect per plant or on rating scales eg. aphids/plant or the extent of foliar damage caused by borers on a 1 - 9 scale (Guthrie *et al.*, 1961) where 1 = no foliar damage and 9 = severe foliar damage Table 2. Severity of earworm damage may be measured by the revised centimeter scale where 0 = no damage , 1 = silk damage, 2 = ear tip damage to a depth of one centimeter and 3 − n = damage increased by 1 unit for each additional centimeter depth of penetration (Widstrom, 1967). The severity of stem tunnelling may be measured as the length of stem, or percentage of stem length tunnelled.

The actual loss caused by a particular insect is reflected by the total effect of the two parameters i.e. the extent and severity of infestation. A widely spread infestation or damage of low intensity may result in no loss as maize plants can tolerate low levels of damage. Similarly a few severely damaged plants in a plot may not result in any significant yield loss on plot basis; the neighbouring plants may compensate by producing more yield than normal as a result of the reduced competition from the damaged plants (e.g. Flynn and Reagan, 1984). The relationship between the two parameters is therefore an important consideration in the measurement of the damage caused by insect pests and the net effect on yield production.

Relations between yield and infestation

Crop loss has been defined as the reduction in the quantity and quality of yield (Singh and Khosla, 1983). Field losses (L) due to insect attack (i) are usually expressed as the percentage reduction in the potential maximum or pest free yield (m) and the relationship is expressed as:

(1) $L = m - b_i$ for a single causative factor.

(2) $L = m - b_i i_i - b_2 i_2 \ldots\ldots bnin$; for multiple causative factors ($b_i\, b_2 \ldots. bn$) where b is the rate of loss per unit increase with the attack level by a causative factor (i).

The percentage loss is calculated as:

$$(3)\ L\% = \frac{Ym - Yi \times 100}{Ym}$$

Where Ym and Yi are the potential maximum yield and yield under infestation, respectively.

The loss caused by the different factors may be sorted out using multiple regression analyses.

Methodologies used in the assessment of losses

Assessment of losses under natural infestation. Natural infestations have been used by various workers to relate plant damage to yield. For this method plants showing various levels of infestation are compared for yield or yield/infestation regressions drawn or damage (e.g. borer damage) are selected and labelled and their final yields are compared with yield from unattacked plants from the same field or environment. This is usually referred to as the "analytical method" (Judenko, 1973)

Table 2. Scale for scoring *C. partellus* damage to whorl stage maize plants.

Visual rating of damage	Numerical score	Resistance reaction
No damage	0	Immune (or escape)
Few pin holes	1	Highly resistant
Few shot holes on a few leaves	2	Resistant
Several shot holes or small holes on a few (< 50%) leaves	3	Resistant
Several (> 50%) leaves with shot holes or small lesions (< 2 cm long)	4	Moderately resistant
Elongated lesions (> cm long) on a few leaves	5	Moderately resistant
Elongated lesions on several leaves	6	Susceptible
Several leaves with long lesions or tattering	7	Susceptible
Most of the leaves with long lesions or severe tattering	8	Highly susceptible
Plant dying as a result of foliar damage	9	Sensitive to damage

or the "paired plant" method (Le Clerq, 1967). This method avoids the confounding effects of insecticide and other protective measures which may affect crop growth and yields. It however, has the disadvantage of healthy plants competing with less healthy ones. This may be overcome by using 'paired plots' i.e. plots in similar environments with different levels of attack to eliminate the effect of competition from adjacent plants.

Artificial infestation or prevention of attack. Artificial infestation or removal of egg masses (Mohyuddin and Attique, 1978) (or other stages of the pest) may be used to achieve different levels of attack/damage. The yields from unattacked (control) plants are then compared with yields from attacked plants.

It is sometimes difficult to control infestation from the natural populations or contamination from other pests within the environment. In such situations protective cages (Kalode and Pant, 1966) may be used to prevent contamination. Plants within the cages may be exposed to different levels of artificial infestation. The method may also be used to control infestation at different stages of plant growth (e.g. Ampofo, in press). A problem associated with this method is that the cages may decrease the amount of light and air movement (Way and Banks, 1968) or trap heat and influence the relative humidity within (Ampofo, in press). Also certain natural enemies may multiply faster within the cages than in the open field.

Use of chemical insecticides to obtain differences in infestation. This is probably the most common approach to control the level of infestation. The type of insecticide or the concentration and number of applications can be varied to achieve different levels of infestation/attack (e.g. see Walker, 1960). Yields from the different treatments are then compared as described above.

The problems associated with the use of chemical insecticides include (a) a direct effect on plant growth and yield performance, (b) the effect of non-target organisms eg. nematodes, pollinators etc. and (c) interplot interference of pest movement. Judenko (1973) has reviewed the effect of insecticides on the yield of various crops including maize.

Simulation of insect damage. Artificial damage may be used to simulate attack by the different pest species and their effect and yield by comparison to undamaged plants. Parts of the foliage may be removed to imitate the damage caused by armyworms, cutworms etc. (Brown and Mohamed, 1972, van Huis, 1981) or whole plants can be removed to imitate the 'dead heart' damage caused by stem borers. This method has the advantage of precision in the level of damage caused, and the time or crop growth stage at which the damage caused is also controlled. Insect damage to plants however, is not precisely controlled and the results obtained from simulated trials may not have a direct field application.

Use of insect resistant and susceptible cultivars. Insect resistant and susceptible cultivars may be used to obtain different levels of infestation and damage. The yields from these cultivars may then be compared. The general assumption here is that yield differences between cultivars are minimal or known and are taken into account in the comparisons. This method has been used by Patch (1943) Kalode and Pant (1966) and Ampofo (1986) to estimate losses in maize due to insect pests.

The method, however, suffers disadvantages: (i) There are usually inherent differences in yield potential among cultivars. (ii) Some cultivars are tolerant to attack and damage by certain pests and produce good yields even when attacked. These factors may confound the assessment of yield losses using this method.

The above discussion summarizes some of the methodologies available for the assessment of field losses in maize production caused by insect pests. The methodologies have been reviewed further by Chiarappa (1971), Walker (1983, 1987). Results from the different methods are, however, not readily comparable. Some of the methods are complicated and cannot be readily applied by the average field worker. There is need for simplification and standardization to enable a single method to be used by workers in the region. The results from such a method will be easier to compare and generate information on the overall losses caused by the various pests within the region. This will help foster collective action within the region for pest control.

References

Ampofo, J.K.O. (1986). Maize stalk borer (Lepidoptera: Pyralidae) damage and plant resistance. *Environ. Entomol.* **15:** 1124-1129.

Ampofo, J.K.O. (in press). The expression of maize resistance to the spotted stem borer (Lepidoptera: Pyralidae) in relation to plant age at infestation. *ACTA Phytopathologica* (Hungarian Academy of Sciences).

Atkinson, P.R., (1980). On the biology, distribution and natural host-plants of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) of Ent. Soc. Sth Afr. **43:** 171-194.

Brown, E.S. and Mohamed, A.K.A. (1972). Relation between simulated armyworm damage and crop loss in maize and sorghum. *E. African Agric. Forestry J.* **37:** 237-257.

Chiarappa, L. (1971). Crop loss assessment methods: FAO Manual on the Evaluation and Prevention of Losses by Pests, Diseases, Weeds. FAO and CAB. 123 pp.

CIMMYT, (1987). 1986 CIMMYT World Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries.

Flynn, J.L. and Reagan, T.E. (1984). Corn phenology in relation to natural and simulated infestations of the sugarcane borer (Lepidoptera: Pyralidae) *J. Econ. Entomol.* **77:** 1524-1529.

Guthrie, W.D., Dicke, F.F. and Neiswander C.R. (1961). Leaf and sheath feeding resistance to the European corn borer in light inbred lines of dent corn. *Ohio Agric. Exp. Sta. Res. Bull.* 860. 38 pp.

Jarvis, J.J., Guthrie, W.D. and Robbins, J.L., 1984. Evaluation of maize plant introduction for resistance to black cutworm larvae. *Maydica* **26:** 219-225.

Judenko, E. (1973). Analytical method for assessing yield losses caused by pests on cereal crops with and without pesticides. *Tropical Pest Bulletin* **2:** 5-31.

Kalode, M.B. and Pant, N.C. (1966). Studies on the susceptibility of different varieties of sorghum, maize and bajra to *Chilo partellus* under yield and cage conditions. *Indian J. Entomol.* **28:** 448-464.

Lynch, R.E. and Guthrie, W.D. (1980). Relative susceptibility of corn hybrids to european corn borer damage. *Maydica* **25:** 117-126.

Le Clerq, E.L. (1967). Methodology for disease measurement related to assessment of losses. In Background Papers Prepared for the FAO Symposium on Crop Losses, Rome 2-6 October, 1967, Rome, FAO pp. 11-48.

Mohyuddin, A.I. and Attique, M.R. (1978). An assessment of loss caused by *Chilo partellus* to maize in Pakistan. *PANS* **24:** 111-113.

Patch, L.H. (1943). Survival weight and location of European corn borers feeding on resistant and susceptible field corn. *J. Agric. Res.* **66:** 7-19.

Rose, D.J.W. (1972). Pests of maize and other cereal crops in the Rhodesias. *Rhodesia Agric. J. Bull.* 2163.

Singh, D. and Khosla, R.K. (1983). Assessment and collection of data on pre-harvest foodgrain losses due to pests and diseases — FAO economic and social development paper no. 28.

van Huis, A. (1981). Integrated pest management in the small farmers' maize crop in Nicaragua. Ph.D thesis, Agricultural University, Wageningen, 221 pp.

Walker, P.T. (1960). The relation between infestation by the maize stalk borer, *Busseola fusca* and yield of maize in East Africa. *Ann. Appl. Biol.*, **48:** 780-786.

Walker, P.T. (1981). The relation between infestation by lepidopterous stem borers and yield in maize : methods and results. *Bulletin, Organisation Europeene et Mediterraneene four la protection des Plantes.* **11 (2):** 101-106.

Walker, P.T. (1983). The assessment of crop losses in cereals. *Insect Sci. Applic.* **4:** 97-104.

Walker, P.T. (1987). Methods of studying the relation between different insect population levels, damage and yield in experiments and surveys. In Teng P.S. (ed) Crop Loss Assessment and Pest Management. The American Phytopathological Solicity, St. Paul Minn. U.S.A.

Way, J.M. and Banks, C.J. (1968). Population studies on the active stages of the black bean aphis on its winter host. *Ann. Appl. Biol.* **62:** 177-197.

Widstrom, N.W., (1967). An evaluation of methods for measuring corn earworm injury. *J. Econ. Entomol.* 60: 791-794.

Assessment of On-Farm Losses in Millets due to Insect Pests

Kanayo F. Nwanze

Introduction

The millets in general constitute a major food source in the warmer regions of the Old World, particularly in southern Asia and Africa where they provide sustainable yields under extreme environmental and biotic stress conditions. The four major food millets in these regions are: pearl millet (*Pennisetum americanum* L.), foxtail millet (*Setaria italica* Beauv.), proso millet (*Panicum miliaceum* L.) and finger millet (*Eleucine coracana* Gaertn). Of these, pearl millet and finger millet are the most commonly grown. Pearl millet covers an estimated 26 million ha of cultivated land in Africa and India. In West Africa where it constitutes the major staple crop in the Sahelian zone, over 12 million ha of the crop is grown. Almost the entire production of finger millet is confined to Africa and Asia. India produces over 50% of the total world production and most of the rest is produced in central Africa (Cameroon), eastern Africa (Uganda and Tanzania) and southern Africa (Zimbabwe, Malawi and Zambia) where, depending on the country, it makes up between 20-60% of the total area grown to millets.

Finger millet is relatively free of insect pests and although it may harbour a range of pest species, the need for their control is much less a problem when compared to pearl millet. For the same reason the literature on finger millet is rather scarce. The range of insects that attack the millets is perhaps relatively narrow when compared to other cereal crops such as rice, wheat, corn and sorghum and the most frequently occurring species are also pests of other crops. These include: (a) Seedling pests: - shoot flies, *Atherigona* spp. - leaf beetles, *Lema* spp; *Chaetocnema tibialis* Illig.
(b) Foliage pests: several species of armyworms, *Spodoptera* spp.; hairy caterpillars, *Amsacta moloneyi* Druce; and aphids, *Rhopalosiphum maidis* Fitch.
(c) Stem Borers: - *Acigona ignefusalis* Hmps., *Eldana saccharina* Walker and *Sesamia calamistis* Hmps.
(d) Panicle pests:- midge, *Geromyia penniseti* Felt.; - earhead caterpillars, *Raghuva albipunctella* De Joannis, *Heliothis armigera* Hbn. and *Eublemma gayneri* Rothsblister beetles, *Cylindrothorax westermanni* Mkl., *Mylabris holosericea* Klug, *Psalydolytta fusca* Oliv.

Gahukar (1984) and Ndoye and Gahukar (In press) have provided comprehensive lists of the pests of millet in West Africa. Some species such as grasshoppers and locusts, although not specifically confined to millet, cause spectacular losses and are often more important than the more frequently occurring species listed above.

There are few insect pests for which accurate data are available on crop losses in farmers' fields in Africa. In most cases, the evidence provided is only one indicating levels of pest infestations as opposed to actual losses (Davis, 1982). Among the several species that are reported to attack pear millet, actual data on losses are available for only two, namely *Acigona ignefusalis* and *Raghuva albipunctella*. The FAO manual on crop loss assessment methods (FAO, 1971) does not list millet nor any of its major pests. Only two cases are provided on a related crop — sorghum: midge and greenbug. This paper provides information from on-station research trials, on-farm pest surveys and on-farm trials that have been used in West Africa to assess damage and/or losses due to attacks by *Acigona* and *Raghuva*. It also discusses areas where future emphasis is needed.

Assessment Methods

Crop damage from an insect attack may not always result in yield loss and the intensity of damage is not often proportional to the incidence of a pest. To distinguish between the different methods of measurement, in this paper crop loss assessment methods are discussed under: (1) incidence ratio (2) visual score paired analysis (3) damage intensity loss ratio (4) quantitative assessment (insecticide trials).

(1) Incidence ratio:

The incidence ratio technique is a quick and easy method for assessing crop damage by pests. However it does not give actual loss values sustained by a crop but an indication of the presence or the frequency of occurrence of a pest in an area. It is usually expressed in percentages derived from actual counts of individual insects (usually crop infesting stages, such as larvae) or of damage symptoms. However, the incidence ratio becomes a vital tool in crop loss control where economic thresholds have been established for an insect on a crop in a particular area. It also serves for comparisons of pest infestations between zones and between years.

Example 1 (ICRISAT, 1981, 1984)

ICRISAT, conducted a series of pest surveys from 1980-1983 in Burkina Faso and Niger. The surveys involved a total of 379 farms and observations were made on *Acigona* and *Raghuva* incidence.

Fields were selected at random at 10-40 km intervals. The incidence of *Acigona* was assessed by splitting millet stems and examining for borer damage. Usually up to 25 stems/farm were sampled. For Raghuva, 150-250 randomly selected panicles per farm were observed for the presence of the characteristic spiral damage. A total of 2727 stems and 37,689 panicles were observed.

The following ratios were developed:

Acigona:

(a) % infested stems =

$$\frac{\text{no. of stems borer damage} \times 100}{\text{total number of stems sampled}}$$

(b) % tunnelled internodes =

$$\frac{\text{no. of tunnelled internodes} \times 100}{\text{total number of internodes of stems sampled}}$$

Raghuva: (c) % infested panicles=

$$\frac{\text{no of panicles with } \textit{Raghuva} \text{ damage} \times 100}{\text{total no. of panicles sampled}}$$

In Burkina Faso, the highest stem borer incidence was observed in the wetter southern Sudanian Zone of Bobo Dioulasso (Table 1), whereas *Raghuva* incidence was highest the drier northern Sahelian Zone. Infestations of pearl millet by *Raghuva* were not observed in the southern parts of Burkina Faso. In Niger, both *Acigona* and *Raghuva* incidence were most severe in the districts of Niamey (east at Filinque) and Maradi. Stem borer damage at Dosso was also high. The studies also showed a decline in stem borer and *Raghuva* infestation from 1980 to 1983.

Example 2 (Vercambre, 1978)
Studies were conducted in Senegal from 1974 to 1976 on *Raghuva* infestation. In each farm, 50-100 panicles were examined. Twenty farms were evaluated in 1974, 42 each in 1975 and 1976. The incidence ratio was used to determine levels of infestation. Results indicated a decline from 1974 to 1976 with the most severe infestation occurring in northern Senegal. It was also found that maximum panicle damage did not exceed 50-60% of production even when 100% of the panicles were infested.

2. Visual score paired analysis:
This method is a modified form of the incidence ratio method and utilizes the presence of pest attack in a paired analysis for comparing the yielding capacity of undamaged samples. In other words, the undamaged samples within the plant population are treated as the control against damaged samples.

Example 1 (Harris, 1962)
Harris used three methods to study the effect of stem borer attack on maize, sorghum and millet in northern Nigeria. The insecticide treatment trial and the damage intensity/loss ratio were not applied for millet. However, in his visual score method, detailed assessments of borer attack and the yielding capacity of individual stems were made. The assessment of early millet at harvest was done by classifying stems into bored and unbored groups and evaluating their yield capacities. Bored stems yielded less than unbored stems in three cases and more in two (Table 2). In the latter case, borer attack was associated with better growth and hence higher yields. Only in one case in Kano where infesta-

Table 1. Crop infestation of pear millet by *Acicogna ignefusalis* and *Raghuva albipunctella* in farmers' fields in Burkina Faso and Niger, West Africa.

Species			Location		
			Burkina	Faso[1]	(regions)
	North	South	Central	East	West
Stem Borers					
% infested fields	100.0	100.0	100.0	100.0	-
% infested stems	51.0	72.0	66.3	44.6	-
% tunnelled internodes	27.1	35.4	22.3	19.7	-
% *A. ignefusalis*	100.0	81.4	99.7	100.0	
%*E. saccharina*	0.0	14.0	0.3	0.0	-
% *S. calamistis*	0.0	4.6	0.0	0.0	-
Raghuva albipunctella					
% infested fields	80.0	0.0	6.7	0.0	0.0
% infested panicles	17.9	0.0	3.5	0.0	0.0
Mean damage score[2]	3.5	0.0	2.0	0.0	0.0
		Niger[3]	(districts)		
	Niamey	Dosso	Tahoua	Maradi	Zinder
Stem borer (*Acigona ignefusalis*)					
% infested fields	67.0	100.0	94.0	100.0	89.0
% infested stems	35.2	69.1	48.2	58.0	61.5
% tunnelled internodes	17.1	33.4	16.9	25.3	28.6
Raghuva albipunctella					
% infested fields	52.9	12.0	77.4	70.1	60.0
% infested panicles	30.7	4.2	7.5	30.5	16.8
Mean damage score	3.2	1.0	1.5	2.8	2.0

[1] Surveys conducted in 1980 and 1981
[2] Measured on a 1-5 scale when 1 =zero to low damage and 5 = severe damage
[3] Surveys conducted in 1982 and 1983

Table 2. Summary of experiments assessing the effect of stem-borer attack on the yield of early millet [1]

Experiment	Number of stems assessed	Stems bored (%)	Mean yield of grain per stem (lb)	
			Bored stems	Stems not bored
Samaru				
SBE 1957	4202	37.3	0.013	0.012
BP 7 1958	4865	20.7	0.044	0.030
BM 1 1960	8725	13.5	0.065	0.061
W 2a 1960	1906	9.4	0.057	0.073
W 2b 1960	2565	9.1	0.047	0.068
Kano				
K 1 1957	6123	60.6	0.084	0.107

[1] Adapted from Harris (1962)

tion was heavy, was the loss projected at 15%. For late millet, infestation was so severe that virtually no grain could be harvested and loss was estimated at 100%. In another trial, 90% of the stems were attacked and yields were reported low.

Example 2 (ICRISAT, 1983)
In 1982, five pearl millet cultivars (CIVT, Ex-Bornu, Nigeria Composite, Souna III and a local) were sown in large blocks of 20 m × 20 m. At first indication of head exsertion 500 randomly selected panicles (4 reps of 125) were covered with pollination bags to prevent oviposition by *Raghuva*. The bags were maintained for 10 days. A similar number of unbagged panicles were also tagged. At harvest the panicles were scored for *Raghuva* infestation (present or absent) and grain yield was recorded. Grain loss was calculated as follows:

$$Y = \frac{y^1}{n^1} \times (n^1 + n^2)$$

$$\% \, YL = \frac{Y - (y^1 + y^2)}{Y} \times 100$$

Y = where Y calculated attainable grain yield at no infestation
YL = yield loss
n^1 = number of bagged (control) panicles
n^2 = number of unbagged (infested) panicles
y^1 = grain yield from n^1
y^2 = grain yield from n^2

The highest yield loss (14.9%) was recorded on CIVT and the lowest (0.8%) on the local cultivar.

Example 3 (ICRISAT, 1984)
The visual score method was adopted in ICRISAT's farm level studies of yield loss factors using over 600 plots of 2000 m^2 each in farm fields of 4 villages in western Niger in 1981- 1983. These factors included the millet stem borer and the earhead caterpillar. For stem borer, observations were taken at harvest by stem-splitting 50 stems/plot and recording the presence or absence of damage. The yielding capacity of stems were classified in accordance with stem damage.

For *Raghuva,* 250 panicles were randomly selected at harvest in each farm and separated into infested and uninfested lots. Head weight and grain yield were recorded respectively before and after threshing. Analysis of variance and chi-square tests were made.

Results indicated that for *Acigona,* except in one farm, in all test farms there was no effect of stem borer damage on yield. But *Raghuva* scores were much higher in one village and showed a grain loss estimate of 14%. It was low in another where grain loss was also insignificant.

3. Damage intensity loss ratio
This method applies the same measurement parameters as the visual score method but goes one step further by quantifying the degree of infestation (level or amount of damage) and relating these to yield.

Example 1 (Vercambre, 1978)
In the same studies reported earlier, Vercambre (1978) also measured the actual loss arising from the area of panicle destroyed. At the beginning of grain maturity, damaged florets were carefully removed from the panicle and the intensity of attack (damage) was calculated as follows:

$$\frac{\text{panicle area destroyed}}{\text{total panicle surface}}$$

This is a rather difficult method but Vercambre argues that with training and practice, field assistants were able to provide rapid estimates over a large number of farms. Between 50 and 100 panicles per farm were sampled.

By applying the average percentage drop in production calculated on a regional basis, along with the production statistics from the Ministry of Agriculture (Senegal), it was estimated that a loss of 110,000 tonnes of grain (equivalent to 25% of production from the regions of the Sine Saloum and Diourbel of Senegal) occurred in 1974. Breniere (1974) also reported a loss of 74,000 tonnes (15% of total production) in Niger in 1974.

Example 2 (Guevremont, 1983)
n attempt was made to estimate actual loss that occurred in grain weight due to feeding activity of individual larvae of *Raghuva*. This involved the measurement of grain weight in panicle area that was mined and then comparing with grain from non-damaged areas. It was found that loss in grain weight corresponded with grain size (r=0.64), that it increased with grain size, and that it varied between 0.4 and 1.0 g for a mean yield of 34 g per panicle.

4. Quantitative assessment (Insecticide trials)
Insecticide trials are almost always conducted on research stations. These experiments employ paired plot comparisons with one of each pair of plots being protected by insecticide. The results are often exaggerated estimates of actual losses due to insect damage since these trials are carried out under close-spaced, well-fertilized and mono-cropped conditions. Most farmers' crops are wide-spaced, non-fertilized and intercropped. Unfortunately, in Africa, insecticide trials for estimating yield losses are still the simplest approach to measure crop losses and some studies have been reported on millet in recent years.

Example 1 (Guevremont, 1982, 1983)
In experiments conducted in 1981 in Niger, Guevremont evaluated seven insecticides for their efficiency in controlling *Raghuva*. A short maturity cycle cultivar (IVSP 78) was used. The highest yield loss recorded was 6%; calculated from yield differences between the control plots where almost 50% of the panicles had *Raghuva* damage and the most efficient insecticide (Dipterex + SIR 8514) with only 3% panicles infested. In a subsequent study conducted in 1982, using three varieties (HKP, HKP3 and IVSP), yield loss was estimated at only 1-2% for HKP and was unreliable for HKP3 and IVSP.

Example 2 (Gahukar *et al.*, 1986)
The results of several insecticide trials conducted from 1982-1985 by the Integrated Pest Management Project of the Institut du Sahel are not readily available. However, Gahukar *et al.* (1986), in their review have summarized yield loss estimation for *Raghuva* and the results showed considerable variation. In Senegal, in 1981 and 1982 losses varied from 3-82% in Sine Saloum and 15-20% in the region of Louga in 1982. Several correlations were also established between egg or larval incidence, grain damage and yield loss. The authors concluded, however, that damage severity could not be associated with infestation rate and lamented the lack of information on actual losses on farmers' fields.

Example 3 (ICRISAT, 1987)
(a) *Raghuva:* Insecticide trials were conducted in 1984 and 1985 at Chikal (Filinque), Niger using three millet cultivars (HKBtif, CIVT and a local) and Decis (deltamethrin, 0.01% EC). Estimated grain yield loss was highest in HKBtif (41%) and lowest in the local cultivar (8%), while in CIVT it was 17% (Table 3). Crop damage was associated with crop phenology and maturity cycle.
(b) *Acigona;* Two cultivars (Nigeria Composite and a local), and Rogor (dimethoate, 500g a.i/ha) were used to estimate losses due to borer damage at the ICRISAT Sahelian Center, Sadore, Niger. The results showed that low levels of borer infestation resulted in an increase in yield of unprotected plots over the protected control plots (Table 4). Harris (1962) also indicated a similar trend in his experiments.

Table 3. Assessment of crop loss caused by infestation of *Raghuva albipunctella* in three millet cultivars. Chikal, Niger, 1986.

Entry	Treatment	Days to 50% panicle exsertion	Panicles with eggs (%)	Damaged panicles (%)	Damage severity[2]	Yield (kg/ha)	Yield loss (%)
HKBtif	Protected[1] control	46	4	9	1.0	1840	41
	Unprotected	44	54	53	4.2	1090	
CIVT	Protected control	48	4	9	1.0	2310	17
	Unprotected	46	33	22	2.8	1920	
Local	Protected control	59	2	8	1.2	1650	8
	Unprotected	58	11	15	1.8	1520	
Mean		50	15	19	2.0	1720	
SE		3.7	1.9	3.3	0.1	84	

1 Treated with Decis, 0.01% EC
2 Measured on a 1 = 5 scale where 1 = zero to low severity and 5 = high severity.

Table 4. Assessment of crop loss caused by infestation of *Acigona ignefusalis* in two millet cultivars. Sadore, Niger 1985

	Cultivars/Treatment				
	Nigeria Composite		Sadore Local		
Parameters measured	Protected control	Unprotected	Protected control	Unprotected	Mean ± SE
No.larvae/stem (50 DAS)[1]	1.5	3.0	0.0	0.2	1.2 ±0.73
% infested stems (50 DAS)	8.3	10.0	1.7	3.3	5.8 ± 2.10
% internodes tunnelled (50 DAS)	1.4	2.6	0.3	0.6	1.2 ± 0.60
No.larvae/stem (at harvest)	11.5	11.2	6.3	7.5	9.1 ± 1.49
% infested stems (at harvest)	28.0	37.3	17.3	23.0	26.4 ± 2.87
% internodes tunnelled (at harvest)	4.9	8.5	2.6	3.4	4.8 ± 0.52
Grain yield (Kg/Ha)	1856	2076	1414	1432	1720 ± 377
Yield loss (%)		11.9[2]		1.3[2]	

[1] DAS = Days after sowing
[2] Indicates yield advantage of unprotected over protected control.

Conclusion

There are very few reliable estimates of crop losses to insect pests in the developing world and the situation is less encouraging for crops like the millets which provide major caloric inputs for millions of Africans. The generality of the evidence that is provided for crop losses in Africa are often estimates that use techniques that have been developed for developed-country agriculture. For example, the National Academy of Sciences (USA) in 1978 estimated that post-harvest losses in the developing countries averaged between 10 and 20% and much of this loss was caused by insects (Reed, 1984). While these estimates may in part provide enough evidence to justify national investment in pest control research, often times the resultant effect is negative.

Research on pearl millet is only a few years old compared to other cereal crops like rice, maize and wheat. Very little is known of the insect pests of finger millet. Yet these two crops constitute about 50% of the total area cultivated to sorghum and millet in Africa. It is unlikely that reliable data on losses due to insects will be available in the near future. The best we can hope for is that surveys will be undertaken on farmers' fields to provide the basis for future research on these crops. As agricultural production in the developing world continues to change, both in crop preferences and in technological inputs, pests status will change and so will the losses they cause. Detailed studies of their biologies and ecologies will be needed and along with these, crop loss estimates and economic thresholds. But in recent years we have become easy converts to admirable trends such as Integrated Pest Management and have changed our priorities in order to be *a la mode* and the farmers we are supposed to serve have been the victims of our failures. It is essential that we first provide the fundamental components for managing crop pests and in my opinion, the crucial issue here is one of training: to provide the domestic manpower needed to carry out essential research in agricultural production.

References

Breniere J. (1974). Mission d'investigation sur les foreurs du sorgho et du mil au Niger (16 au 27 novembre, 1974). mimeo.

Davies J.C. (1982). Pest losses and control of damage on sorghum in developing countries — the realities and the myths. In: Sorghum in the Eighties: Proceedings International Symposium on Sorghum, 2-7 November 1981, pp 215-223. ICRISAT, Patancheru A.P. India.

FAO (1971). Crop loss assessment methods. FAO Manual on the evaluation and prevention of losses by pests, diseases and weeds. Ed. L. Chiarappa. FAO, Rome, Italy.

Gahukar R.T. (1984). Insect pests of pearl millet in West Africa: A review. *Trop. Pest. Manag.* **30,** 142-147.

Gahukar R.T., Guevremont H., Bhatnagar V.S., Doumbia Y.O., Ndoye M. and Pierrard G. (1986). A review of the pest status of the millet spike worm, *Raghuva albipunctella* De Joannis (Noctuidae: Lepidoptera) and its management in the Sahel. *Insect Sci. Applic.* **7,** 457-463.

Guevremont H. (1982). Etude sur la mineuse de l'epi et autres insectes du mil. Rapport Annuel de recherches pour l'annee 1981. CNRAT, Maradi, Niger.

Guevremont H. (1983). Recherches sur l'entomofaune du mil. Rapport Annuel de recherches pour l'annee 1982. CNRAT, Maradi, Niger.

Harris K.M. (1962). Lepidopterous stemborers of cereals in Nigeria. *Bull. Ent. Res.* **53,** 139-171.

ICRISAT (1981). International Crops Research Institute for the Semi-Arid Tropics. Upper Volta Cooperative Programme Annual Report. 1980. Entomology, pp F1-F36. Ouagadougou, Upper Volta.

ICRISAT (1983). ICRISAT International Cooperation Annual Reports 1982. Vol. 2. Niger and Nigeria. Mimeo.

ICRISAT (1984). International Crops Research Institute for the Semi-Arid Tropics. ICRISAT Sahelian Center Annual Report, 1983. Entomology pp. 31-37. Niamey, Niger.

ICRISAT (1987). International Crops. Research Institute for the Semi-Arid Tropics. Annual Report, 1986 pp.83-86. Patancheru A.P. India.

Ndoye M. and Gahukar R.T. (1986). Insect pests of pearl millet in West Africa. Proceedings International Pearl Millet Workshop. In Press. ICRISAT, Patancheru A.P. India.

Reed W. (1984). Crop losses caused by insect pests in the developing world. Proceedings 10th International Congress of Plant Protection, Brighton, England, 20-25 November 1983 pp. 74-80.

Vercambre B. (1978). *Raghuva* spp. et *Masalia sp. Chenilles des chandelles du mil en Zone Sahelienne. Agron. Trop.* **33,** 62-79.

Assessment of On-Farm Yield Losses in Sorghum Due to Insect Pests

K.V. Seshu Reddy

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is an extremely important staple food in the tropical countries, and especially in Africa. The yields of this cereal crop on peasant farms are low and one of the major factors inducing instability in yields is insect pests. In Africa, the insect pests causing the most significant losses in sorghum from seedling emergence to harvest are: the shootfly (*Atherigona soccata* Rondani); several species of stem borers (*Chilo partellus* (Swinhoe,) *C. orichalcociliellus* Strand, *Eldana saccharina* Walker, *Acigona ignefusalis* Hampson, *Busseola fusca* Fuller, *Sesamia calamistis* Hampson, *S. cretica* Lederer); midge (*Contarinia sorghicola* Coq.); and a range of head bugs (*Calocoris angustatus* Leth., *Dolicoris indicus* Stal., *Creontiades pallidus* Ramb., *Calidea dregii* Germ., *Agonoscelis pubescens* Thnb., *Campylomma* spp., *Eudrystylus* spp., *Mirperus* spp., *Riptortus* spp., *Spilostethus* spp.) (Bohlen 1973, Teetes *et al.*, 1983, Seshu Reddy, 1985).

In Africa, little information on sorghum grain yield losses caused by insects is available. Therefore, assessment of on-farm losses remains a formidable challenge to entomologists. In assessing the potential yield loss by identified pests, a number of factors must be considered. These include: incidence and degree of infestation, stage of the crop when attack occurs; yield potential of crop due to agronomic and other related reasons; crop variety and the inherent capacity of the infested plants to overcome, tolerate or compensate for pest damage. As a crop, sorghum has a low cash value and low yields, and so insecticidal control in most instances is ruled out. However, the crucial role sorghum plays in the diet makes some degree of realistic assessment of losses vital. Furthermore, yield loss assessment in sorghum forms an important tool in Integrated Pest Management (IPM), because it is the standard and guide against which control strategies can be tested (assessed) and improved.

The objective of this paper, therefore, is to discuss the methodologies being adopted to assess on-farm pre-harvest yield losses in sorghum caused by the four major pest species i.e. shootfly, stem borers, midge and head bugs.

Nature of Damage

In assessing potential grain yield losses, the nature of damage caused by the insect pests and the phenological stage of the plant at the time of pest attack must be taken into account. In addition, the biology, ecology, and behaviour of the target pests have to be known.

Shootfly

This is a common pest throughout the semi-arid areas of the world and is widespread in the tropics. Normally damage occurs from one week to about one month after seedling emergence. After hatching, the maggots bore into the shoot of the young plants. As a result of larval feeding the central leaf wilts and later dries up, giving a typical dead heart symptom. The damage can lead to a complete kill of the plant if it occurs early enough, particularly in dry unfavourable growing conditions, or production of numerous tillers which may or may not be themselves attacked. If they are, a typical rosetted plant is produced. Late sowing increases the likelihood of attack.

Stem borers

A range of lepidopterous stem borers are the most important pest species both from a point of regularity of occurrence and the severity of damage caused. The stem borers attack all the growth stages of the sorghum crop and all parts of the plant except roots. Young larvae feed on the leaves when in the whorl which then show the appearance. The late-larval stages bore into the stems of attack increases, the plant may become very ragged in appearance. The latelarval stages bore into the stems and produce dead hearts. There is often extensive tunnelling of the stem. In severe cases of infestation, plant growth is retarded and consequently flowering and grain production are seriously affected.

Midge

The sorghum midge is one of the most damaging insects to grain sorghum in many parts of the world. The female adult midge lays eggs in the florets during anthesis and the resulting larvae feed on the developing ovary, which shrivels and fails to develop (chaffy florets). Often, heads are only partially filled. The presence of a larva within the developing grain can be verified by squeezing, when a red ooze which is the body contents of the larva/pupa appears. The chaffy florets resulting from midge damage can be recognized by the empty pupal cases protruding from the glumes or they may show the emergence holes of the midge parasitoids.

Head bugs

A range of head bugs (both nymphs and adults) infest the panicles as soon as they emerge from the boot leaf. The bugs puncture the developing seeds with their stylet-type mouthparts and suck the contents. The puncture made by the bugs is later recognized as a dark spot on the testa. Consequently, grain attacked in an early stage of development is shrivelled, reducing crop yield and quality. The rate of germination may be depressed.

Crop Loss Assessment Methods

The quantitative losses caused by different insect pest species may be obtained through the following methods (Pradhan, 1964; Leuschner and Sharma, 1983; Walker, 1981 and 1983).

1. Estimation of losses through visual scores.
2. Comparison of yields from different fields having different degrees of infestation.
3. Comparison of the average yields of individual plants free from natural infestation by pests with that of the infested plants in the field.
4. Comparison of yields of sprayed and unsprayed plants.
5. Release of varying number of insects on plants enclosed in cages and correlate damage/yield with the insect density.

All these methods suffer from some disadvantages from the theoretical point of view. From the practical point of view, any of these methods could be suitably perfected and adopted depending upon the crop and insect pest(s) under study in a given area.

1. Estimation of losses through visual scores

Assessment of losses through visual scores is commonly used in surveys and it is an estimation of what is actually lost. Such information may also be obtained directly from the farmers' perception of yield losses caused by insect pests.

In a survey of cereal losses in Kenya and Tanzania (Walker, 1967), the estimated losses in yield of sorghum by stem borer ranged from 18-27%, sorghum shootfly 4-20%, midge 5% (Kenya) and head bugs 6% (Tanzania).

Shootfly: Infestations of up to 90% by sorghum shootfly have been reported in India and Sudan by various workers (Hiremath and Renukarya, 1966; Rao and Gowda, 1967; Schmutterer, 1969).

Stem borers: Harris (1985) estimated the overall losses caused by the stem borers to be in the order of 5 to 10% in many sorghum growing areas, especially where early attack causes loss of stand. However, in a survey conducted in Rusinga Island in Western Kenya, all the farmers interviewed reported 15-40% grain loss as a result of stem borers.

Midge: Midge damage is often associated with head bug and so assessment of yield losses in sorghum becomes difficult. In old Mysore (now Karnataka) state of India, Puttarudraiah (1947) observed about 75% grain loss caused jointly by midge and the earhead bug, *Calocoris angustatus*.

In India, various workers have reported damage by midge to earhead ranging from 48 to 99% (Srivastava, 1985). Heavy losses in grain yield (20-26%) have also been reported by Rao (1966) Thimmaiah *et al.*, (1969) and in Sudan by Schmutterer (1969).

In the USA, recurrent annual losses are estimated at 4% of the grain sorghum crop. In Texas alone, estimates of losses have exceeded 10 million dollars per annum on several occasions (Wiseman et al., 1976). A similar level of overall loss was also estimated in Nigeria in 1958 (Harris, 1961) and recurrent losses of 5 to 10% of the crop are probably typical of most major sorghum growing areas. Local losses in tropical Africa and Asia may exceed 50% and complete loss of some crops is not uncommon (Harris, 1985).

In Mexico, the midge damage was estimated at 50% on commercial sorghum fields and 30% on experimental plots and subsequent yield loss upto 70% (Castro, 1985).

It is therefore very clear that the information obtained during the surveys gives only a very rough indication of the magnitude of crop loss problems.

2. Comparison of yields from different fields having different degrees of pest infestation.

In this method, yield/unit area in fields which have been attacked by different insect pest species at varying levels of infestation is assessed. In addition, the method also quantifies the relationship between levels of infestation and grain loss.

According to Pinstrup-Andersen *et al.*, (1976) yield losses can be estimated on the basis of a production function analysis, in which observed yields (Y) are regressed on the factors (different insect pests, diseases, weeds etc.) expected to influence yields ($X_1, X_2, \ldots X_n$): $Y = f(X_1, X_2, \ldots X_n)$. Each regression coefficient multiplied by the average value of the particular yield limiting factor provides an estimate of the overall impact of this factor on sampled yields. The area affected by each of the factors is estimated directly from the sample data, and production losses are then estimated as average yield losses multiplied by the area affected.

From the practical point of view, this technique is fairly sound although there are often difficulties in working out correlations such as those due to the changing amount of damage during crop phenology. The theoretical flaw, however, is that in spite of two fields being grown under practically identical conditions, they may show different degrees of insect infestation, suggesting that there are some unknown differences in the two fields. Either the infestation has been different or an unknown factor is causing the difference in the yield of the two fields. My experience at the ICIPE's Mbita Point Field Station (MPFS) (on the shores of Lake Victoria) and farmers fields in the neighbourhood, showed that this technique of comparing the actual insect numbers with damage/yield in different fields will not always work out because: (a) In pests like sorghum shootfly, infestation depends on the planting dates; early planted sorghum escapes the infestation, whereas a late planted crop is severely infested. (b) Some varieties of sorghum can show tolerance or recovery resistance to high densities of shootfly attack (Doggett *et. al.*, 1970). (c) In the case of stem borers, the number of species involved, their levels of infestation, types of damage and the age of the plant at the time of infestation are also important. (d) Other key insect pests such as sorghum midge and a complex of head bugs which infest sorghum at flowering and dough stages could also cause substantial yield losses.

3. Comparison of the average yields of individual plants free from natural infestation by pests with that of the infested plants in the field.

In this method, "the paired plant method", level of infestation and yield of individual plants within a field are compared; and then a further comparison is made between yields of healthy plants and plants with varying levels of infestation. The extent of losses can be worked out by the following formula (Judenko, 1972):

Extent of losses $= W - A$ where W is the expected yield and A is the actual yield

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

L = percentage economic loss

$$L = \frac{CP}{100}$$

C = coefficient of harmfulness

P = percentage of plants infested

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

a = mean yield per un-attacked plant

b = mean yield per attacked plant

Using the same information, correlation between the yield and infestation can be determined for individual plants. The advantage of this method over the one in which yields of different fields are compared (method 2) is that it is not affected by variations in soil fertility.

However, the following constraints tend to limit the use of this technique:

(a) The wide range of insect-pests prevailing in the fields.

(b) Presence of varied levels of, the time of attack and extent of damage, by insect pests.

(c) Selective infestation by pests.

(d) Existence of compensatory growth of tillers within attacked plants, and an increase in yield of unattacked plants adjacent to attacked plants.

Therefore, absolute values for yield losses cannot be obtained by this method.

Shootfly: One simple technique to assess the yield losses caused by shootfly is to obtain plant stands in a circle obtained by using a looped rope of known radius of (1.79 m) to obtain a circle of the required area of 10 m^2. Likewise, five circles are made at random, one in each corner, and the fifth in the centre of the field. A dead heart count is taken to 28 davs after emergence (DAE). By obtaining initial plant stand, loss of stand at harvest, total number of plants producing no heads at harvest, direct calculation of loss could be assessed.

Where an indication of the direct loss caused by shootfly on plants at harvest is required, this can be made by tagging, in a large sown sorghum field, 100-500 plants with dead hearts at 28 DAE, and comparing yields from these plants with a similar number which were unattacked but tagged at the same time. This method is useful as it allows for recovery growth by tillering (Davies and Seshu Reddy, 1977).

Stem borers: Loss assessments have been made by Davies and Seshu Reddy (1977) by tagging known numbers of plants with leaf damage and dead hearts produced by stem borers and subsequently noting head production and grain yields. They found that the plants suffering from early borer damage often did not yield any grain. Over 45% of tagged CSH-1 hybrid plants tillered repeatedly in an effort to produce seed, but often produced no heads. Although Walker (1981) reported that the amount of tunnelling in the stem could be directly related to the population of stem borer larvae and to reduction in yield, it is often difficult to relate the degree of stem tunnelling with yield loss. In one experiment in which a hybrid (CSH-1) was tagged and yields from undamaged and damaged plants compared, there was an apparent grain yield loss of almost 20% caused by *C. partellus* (Davies and Seshu Reddy, 1977).

Attempts to correlate length of tunnelling with grain yields have on the whole given contradictory results owing to plant to plant variation — timing of attack is obviously very critical. In general, severe basal tunnelling gives poor heads. On the other hand, complete stem tunnelling results in good yields in some cultivars. However, in some instances, a slight degree of tunnelling in the peduncle just during grain filling can result in a snapping of the head and complete loss of yield. In general, one is forced to make assessments by taking a count of percentage of plants attacked at 9-12 weeks, and by taking yields from attacked and healthy plants at harvest. Samples of 100-500 heads from healthy plants, as confirmed by stem splitting are taken. Sometimes, one is impressed by the number of healthy plants selected which turn out to have borer tunnelling.

By examining healthy and damaged plants and taking the grain yields in the same field, Pradhan and Prasad (1955) correlated the damage by *Chilo partellus* with the yield of sorghum grain in an equation $X_1 = 6.6204\, X_4 - 0.9257\, X_3 - 27.17$ wherein X_1 yield of sorghum grain per plant, X_3 = percentage of length of stem infested, X_4 number of ears per plant. However, the cultivar grown is a very important factor in any such equation.

In order to assess the on-farm losses in sorghum caused by stem borers, plants from fourteen farmers fields were sampled at harvest in the environs of MPFS. It was difficult to find undamaged plants. Among those damaged the infestation levels of borers varied. The damage by the stem borer complex (*Chilo partellus, Busseola fusca, Sesamia calamistis* and *Eldana saccharina*) ranged from 95-100%. The larval and pupal populations of these stem borers per infested plant also varied. Therefore, this technique is not suitable in the fields where a great majority of the plants are damaged and also where insect pests occur in varying population densities during different plant growth stages.

Midge: In general, assessment of midge numbers is very difficult in the field owing to their short-lived nature. It is possible to make direct counts but these serve only as an indication of potential damage. The damage assessments can be obtained by sampling large numbers of heads at the filling stage, taking random spikelets from a known number of heads and squeezing seed between the thumb nails. A red ooze indicates that the developing seed was attacked. Detailed assessment depends on taking 10 sprigs from the top, middle and bottom of random heads in a field at each sample site, bulking them and dissecting 500-1000 sprigs. Timing of sampling is critical and is closely related to flowering.

When midge attacks are severe, crops have a blasted appearance. In such cases, crop loss is assessed by taking a plant population count at harvest and using derived data from samples of damaged and undamaged heads by enveloping paper or fine cloth bags at or before anthesis.

Head bugs: In assessing the losses caused by head bugs, when massive invasions of the crop occur, usual methods of counting damaged heads can be used, again making use of grain weights produced from damaged and apparently undamaged heads. However, a known number of heads can be covered with fine mosquito netting or paper bags as soon as they emerge from the boot leaf. These will serve as controls. At harvest, grain yields from the bagged as well as from naturally infested panicles can be compared and % yield loss worked out.

4. Comparing yields of sprayed and unsprayed plants.
In this technique, yields from the sprayed and unsprayed plants grown under similar conditions are compared, and the difference in yield between the two treatments is the avoidable yield loss. Yield loss studies of this type give information about damage caused by a group of different insect species rather than an individual insect species, unless some type of selective insecticide action is used. However, this technique does not take into account the following facts: (a) Levels of pest infestation and attack at various crop growth stages. (b) Pest control by insecticides might be incomplete. (c) It is difficult to apply insecticides on a very small plot because of interplot effects, and (d) The insecticides may also affect non-target organisms including the crop itself.

However, some attempts have been made by researchers to study the yield losses in sorghum caused by shootfly, stemborers, midge and head bugs by recording the difference in yields between insecticide treated and untreated plots.

Shootfly: Granados *et al.*, (1972) found that in two varieties of sorghum (Thai Hegari and TSS 11-3) when the dead hearts were about 83%, the yield loss was 74.3% and 83%, respectively. Similar observations were also reported by Vedamoorthy *et al.*, (1965). Also, yield has been directly correlated with infestation: for every 1% increase in shootfly infestation, there was a proportionate reduction in grain yields ranging from 16.1 to 56.9 kg/ha in two sorghum cultivars (Rai *et. al.*, 1978).

Stem borers: In India, Ahmed and Young (1969) reported that the grain yields (kg/ha) in treated plots of sorghum for the control of stem borer, *C. partellus* ranged from 1005 to 1624 and from 3083 to 4212 compared with 199 and 336 in the untreated controls. Also, the avoidable losses caused by *C. partellus* in the hybrid sorghum (CSH-1) have been estimated to be about 55 to 83% (Jotwani *et. al.*, 1971).

Studies on the estimation of losses caused by sorghum stem borer complex conducted at MPFS and farmers fields showed that the losses ranged from 28.2% to 45.2%, using different insecticidal applications.

Midge: The avoidable loss of sorghum grain due to midge was also reported by Jotwani *et al.*, (1971), ranging from 15% to 19.8%. However, from the various insecticidal trials conducted throughout India, the avoidable losses due to midge have been calculated to be 45.2% (Leuschner and Sharma, 1983).

Head bugs: In general, information on yield losses caused by head bugs is not readily available. From five insecticidal trials in India, the avoidable losses due to head bugs were calculated to be 43.9% (Leuschner and Sharma, 1983). However, the losses can vary from 5.8 to 83.4% (Rangarajan *et. al.*, 1973, *Subba Rao et. al.*, 1980).

It is well known that insect populations can be affected by applications of different insecticides, concentrations, treatment times or number of applications. The problem of interplot movement of the insect pests may also occur between sprayed plots. Thus there are some obvious disadvantages in using insecticides.

5. Release of a varying number of insects on plants enclosed in cages and correlate damage/yield with the insect density.
This method of crop loss assessment allows the direct comparison of insect density with yield loss. A varying number of target insect pests can be introduced at different plant phenological stages in cages and grain yields compared with those of uninfested plants. This method also allows for the calculation of damage/loss caused by one individual of an insect species.

Using this technique, experiments were conducted by various workers to assess the extent of loss caused by individual insect pest species of sorghum.

Shootfly: At the ICIPE, MPFS, to assess the grain yield losses caused by shootfly, sorghum (cv. Serena - a tillering cultivar) plants grown in cages ($2 \times 4m^2$) in the fields were artificially infested at 2 newly hatched shootfly maggots/plant at 7 and 14 days after emergence (DAE) of seedlings. In order to ensure 100% infestation, 2 shootfly larvae were released. In the case of shootfly larvae, whether there is one or more larvae per plant, the effect is the same, as only one larva is responsible for a dead heart. The grain yields obtained from the infested plants compared with uninfested control showed that in plants infested at 7 DAE, there was a grain yield loss of 29.7% and 27.3% at 14 DAE. The grain yield losses depend on the crop cultivar used and the age of plant at the time of shootfly infestation.

Stem borers: To determine the influence of different larval populations of the stem borer, *C. partellus* on the growth and yield of grain sorghum in South Africa, plants were artificially infested with 0,4,8,12,16,20, and 24 larvae/plant in large polythene bags in a glass house (Van Resburg and Van Hamburg, 1975). They observed that the plants which received 4,8, and 12 larvae/plant showed an increasing loss in yield and a yield loss of upto 68% was recorded.

However, the yield losses caused by *C. partellus* were assessed at the ICIPE, MPFS. In this study, sixty sorghum plants (cv. Serena) were grown in cages ($2 \times 4\,m^2$) covered with a nylon netting immediately after emergence to prevent external infestation. The cages were arranged in a Randomized Complete Block Design (RCBD) with three replications. Sorghum plants of six different ages viz. 10,20,30,40,50 and 60 DAE, were artificially infested into the plant whorls with 5 and 10 neonate larvae of *C. partellus*. At harvest, grain yields of these plants were compared with the yield of uninfested plants.

Results presented in Table 1 show that grain yield of sorghum infested with 5 larvae of *C. partellus*/plant at 10 DAE was significantly ($P<0.05$) lower than the yield loss other treatments. This constituted a 75.4% yield loss over the control. At 40,50 and 60 DAE, yields were not significantly different from the control and these were also not significantly different from each other. These results indicate that at low larval density, late infestations of *C. partellus* on sorghum has little effect on the yield. On the other hand, at higher larval density (10 larvae/plant) yields at different plant age infestation are in decreasing order at 60,50,40,30,20 and 10 DAE (Table 1). However, there were no significant differences in the grain yields of larval infestation between 10 and 20 DAE, between 30, 40 and 50 DAE, between 50 and 60 DAE and between 60 DAE and uninfested control.

These studies show that age of sorghum plant at the time of infestation appears to be crucial. Therefore, yield losses in sorghum caused by *C. partellus* decrease with plant age at the time of infestation. Any attempt to assess losses must therefore include some measure of the average time of attack each year, or at least the probability of getting an early attack.

Midge: Losses by midge can be assessed by introducing varying number of midges into a cage at the most susceptible stage of the earhead i.e. top to half - anthesis. Then the yield from the infested and uninfested heads could be regressed on the varying midge numbers or damage. A head cage developed at the ICRISAT Centre, India, could be used for this purpose. This consists of a wire cage (16cm diameter, 20cm long) which is tied around the sorghum head and covered with a cloth bag. Blue coloured bags give best results (Sharma, 1985).

In India, Jotwani *et al.*, (1977) reported maximum loss due to midge, calculated on the basis of yield from covered sorghum heads as 211 to 408 kg/ha.

In Australia, Passlow *et al.*, (1985) compared the grain yield of panicles exposed to natural midge infestations with yields of equivalent panicles protected during flowering by covering with fine gauze bags. They found that the mean yield losses per panicle per visiting female per day was 0.92 g.

Head bugs: Bug populations could be assessed by quickly enveloping panicles in plastic bags, at various stages of panicle development and cutting off the panicle. A few drops of ethyl acetate dropped into the bag enables the insects to be anaesthetised and counted.

Teetes (1985) gave a very detailed account of the method of damage loss assessment to grain sorghum caused by head bugs. In order to assess losses to grain caused by head bugs, panicles can be infested from the anthesis, milk, soft-dough and hard-dough stages through maturity (36,28,20 and 10 days, respectively). Panicles can also be infested during individual stages of grain development in order to assess damage by bugs during each developmental stage. Panicles at the appropriate stage are selected and randomly infested at one of several infestation levels.

It has also been suggested by Teetes (1985) that adult and/or nymphal (depending on species) bugs could be placed on panicles in cages at the appropriate stage of grain development and could be removed after the designated infestation period. Panicles should be checked every 2 days to maintain constant bug infestation densities. Panicles are harvested at maturity, weighed and then hand-threshed. Data are collected on the prethreshed weight of panicles, gross seed weight per panicle, threshed weight of panicles, and 1000-seed weight. Gross seed weight and prethreshed weight of panicles are used to calculate threshing percentages or per cent thresh (per cent seed weight per panicle). One hundred seeds are selected from each of five panicles per infestation level, stained with an acid fuchsin dye, and examined for seed damage. Seeds bearing stylet sheaths are classified as being damaged.

Data are also collected as the percentage of seeds punctured per panicle, the number of feeding punctures per seed, and the weight of damaged and un-damaged seeds. Panicles from each infestation level should be selected and 100 seeds from each panicle subjected to a germination trial. All data can be analyzed using one-

Table 1. Grain yield and yield losses of sorghum infested with *C. partellus* at different plant ages

Plant age (in Days) at infestation (DAE)	Larval density (No. of larvae/plant) 5 Yield kg/ha	% loss	10 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	36.40^{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	4192^{a}		4192^{a}	

Means in the same column followed by same letter are not significantly different according to Duncan's Multiple Range Test
(DMRT) at 5% level.

way analysis of variance. Comparisons among infestation levels are made using Duncan's New Multiple Range Test (Teetes, 1985).

Teetes (1985) reported that the largest reductions in sorghum grain yield occurred when panicles were infested with various species of head bugs from milk stage to maturity (28 days). No yield reductions occurred when panicles were infested during hard dough, the last 10 days of grain development, at levels upto 16 bugs per panicle. He also found that per cent yield reductions had increased quadratically as the number of bugs increased per panicle.

Conclusion

Assessment of damage and losses on sorghum are in general difficult and time consuming. Sorghum plants are susceptible from the seedling to grain filling stage and therefore it is extremely difficult to make realistic assessments of loss according to specific insect since multiple attacks by a range of pests are the rule. Therefore, in crop loss assessment studies it is very important to record the plant population at the start of the crop cycle, after thinning, and to assess stand loss, number of unproductive and productive plants at harvest.

For the crop loss assessment studies, on national basis, the use of unprotected and insecticide protected plots at a number of locations on subsistence farmers fields, over a number of years, can indicate the extent of yield losses due to a range of pests. However, in order to assess the grain loss caused by a single insect pest species, either to the whole plant(s) or to the panicle alone, the cage method is best. The use of cages would be necessary to remove the effect of pest preference for stronger plants and thus obtain a value of potential yield. The information thus generated could be used to establish economic threshold levels and the insect population/damage and yield loss relationships. These form an essential part of the process of making decisions in pest management.

In Africa, there is an urgent need to study the extent of grain yield losses in sorghum, and in several other food crops. In addition, the economic threshold levels of different insect pests should be determined. This would enable extension workers to be trained to recognize the pest population and crop growth stage at which they should recommend control measures.

References

Ahmed, S.M. and Young, W.R. (1969). Field studies on the chemical control of the stem borer, *Chilo partellus* on hybrid sorghum in India. *Journ. Econ. Ent.* **62:** 478-482.

Bohlen, E. (1973) Crop pests in Tanzania and their control. Verlag Paul Parees Berlin. pp. 142.

Castro, G.D. (1985) Insect problems on sorghum in Mexico. p. 83-87 In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A & M University, College Station, TX, Patancheru, A.P., India: ICRISAT.

Davies, J.C. and Seshu Reddy, K.V. (1972) Insect pests of sorghum and pearl millet. Presented at the All India Workshop on Assessment of crop losses due to Pests and Diseases, September 19-30, 1977, University of Agricultural Sciences, Bangalore, India p. 12.

Doggett, H., Starks, K.J. and Eberhart, S.A. (1970) Breeding for resistance to the sorghum shootfly. *Crop Science* **10:** 528-531.

Granados, G.R., Granados, Y.R. and Jamormman, S. (1972). Effect of sorghum shootfly *Atherigona varia soccata* Rond. infestation levels in a sorghum yield in Thailand. pp 112-118 In: M.G. Jotwani and W.R. Young (eds.) Control of sorghum shootfly. Oxford and IBH Publishing Co., New Delhi.

Harris, K.M. (1961). The sorghum midge, *Contarinia sorghicola* Coq. in Nigeria. *Bull. Ent. Res.* **52:** 129-146.

Harris, K.M. (1985). The sorghum midge: A review of published information 1895-1983. pp 227-232. In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984. Texas A & M University, College Station, TX, USA. Patancheru, A.P., India: ICRISAT.

Hiremath, P.S. and Renukarya, M.K. (1966). Seasonal occurrence, distribution and abundance of the shootfly on hybrid sorghum CSH-1. *Sorghum Newsletter* **9:** 37.

Jotwani, M.G., Chandra, D., Young, W.R., Sukhani, T.R. and Saxena, P.N. (1971). Estimation of avoidable losses caused by the insect complex on sorghum hybrid CSH-1 and percentage increase in yield over untreated control. *Indian J. Ent.* **33 (4):** 375-383.

Jotwani, M.G., Sukhani, T.R., Srivastava, K.P., and Kishore, P. (1977). Field evaluation of insecticides for the control of sorghum midge. *Pesticides* **11(5):** 25-27, 29.

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

Leuschner, K. and Sharma, H.C. (1983). Assessment of losses caused by sorghum panicle pests. Paper presented at the All India Workshop on crop losses due to insect pests, 7-9 January 1983, APAU, Rajendranagar, A.P., India. p 12.

Passlow, T., Franzmann, B.A., and Allsopp, P.G. (1985). Sorghum insect problems in Australia p. 65-72. In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A & M University, College Station, TX, USA Patancheru, A.P., India: ICRISAT.

Pinstrup-Andersen, P., de Londono, N. and Infante, M. (1976). A suggested procedure for estimating yield and production losses in crops **PANS 22:** 359-365.

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

Pradhan, S. and Prasad, K. (1955). Correlation of the degree of damage due to *Chilo zonellus* Swin. and yield of Jowar grain. *Indian J. Ent.* **17:** 136-137.

Puttarudraiah, M. (1947). Field control of the earhead pests of Jola (*Andropogon sorghum*). *Mysore Agric. Journ.* **25(1-2):** 48-53.

Rai, S., Jotwani, M.G. and Jha, D. (1978). Methodology for estimating shootfly damage and grain yield relationship in sorghum. *Indian J. Ent.* **40(2):** 121-125.

Rangarajan, A.V., Mahadevan, N.R. and Jangarajan, A. (1973) Control of stem borer and earhead bug on sorghum, K4. *Sorghum Newsletter* **16:** 96-98.

Rao, D.S. (1966). A note on the pest complex of hybrid Jowar in the Tungabhadra Project area of Mysore State. *Mysore Agric. Journ.* **35(8):** 214-215.

Rao, M. and Gowda, S. (1967). A short note on the bionomics and control of Jowar fly. *Sorghum Newsletter* **10:** 55-57.

Schmutterer, H. (1969). Pests of crops in Northeast and Central Africa with particular reference to the Sudan. Stuttgart, Federal Republic of Germany, Gustav Fischer Verlag, 296 pp.

Seshu Reddy, K. V. (1985). Integrated approach to the control of sorghum stem borers, p 205-215. In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A & M University, College Station, TX, USA, Patancheru, A.P., India: ICRISAT.

Sharma, H.C. (1985). Screening for sorghum midge resistance and resistance mechanisms pp. 275-292. In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July, 1984, Texas A & M University, College Station, TX, USA. Patancheru, A.P., India: ICRISAT.

Srivastava, K.P. (1985). Sorghum insect pests in India p. 45-56. In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A & M University, College Station, TX, USA. Patancheru, A.P., India: ICRISAT.

Subba Rao, D.V., Rao, N. and Narayana, K.L. (1980). Evaluation of insecticides in sprays and dusts for the control of sorghum earhead bug (*Calocoris angustatus*). *Sorghum Newsletter* **23:** 78.

Teetes, G.L. (1985) Head bugs: Methodology for determining economic threshold levels in sorghum p. 301-315. In: Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A & M University, College Station, TX, USA. Patancheru, A.P., India: ICRISAT.

Teetes, G.L., Seshu Reddy, K.V., Leuschner, K. and House, L.R. (1983). Sorghum insect identification hand book. Information Bulletin No: 12. Patancheru, A.P., India: ICRISAT.

Thimmaiah, G., Mutalikadesai, K.S., Panchabhavi, K.S., Kajjari, N.B. and Usman, S., (1969). Study on the occurrence of midge fly (*Contarinia sorghicola*) in Mysore State. *Sorghum Newsletter* **12:** 50.

Van Rensburg, N.J. and Van Hamburg, H. (1975). Grain sorghum pests: An integrated control approach. p. 151-162. In: Proceedings of the first congress of the entomological society of South Africa.

Vedamoorthy, G., Thobbi, V.V., Matai, B.H. and Young, W.R. (1965). Preliminary studies with seed and furrow application of insecticides for the control of the sorghum stem maggot, *A. indica* Malloch (Anthomyiidae). *Indian. J. Agric. Sci.* 35(1): 14-18.

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

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

Walker, P.T. (1983). Crop losses: The need to quantify the effects of pests, diseases and weeds in agricultural production. *Agriculture, Ecosystem and Environment.* **9:** 119-159.

Wiseman, B.R., McMillan, W.M. and Widstrom, N.W. (1976). The Sorghum midge: A bibliography, 1898-1975. USDA Agricultural Research Service ARS - S - 139, 1-8. Washington, D.C. USA: Govt. Printing Office.

Acknowledgements:

The author is grateful to Professor Thomas R. Odhiambo, Director of ICIPE; Prof. Dean L. Haynes and Prof. K.N. Saxena for their keen interest, encouragement and help. Special thanks are due to Mr. P.T. Walker and Dr. M. Brownbridge for their valuable suggestions and critical review of the manuscript.

Assessment of On-Farm Losses in Rice Due to Insect Pests

M. Agyen-Sampong

Introduction

Rice is a highly adaptable plant, that is grown under different ecological conditions in sub-tropical (Egypt) and tropical regions of Africa. The major rice ecologies may be broadly classified as upland, inland swamp, mangrove swamp, irrigated and deep water/floating. These different rice agro- ecosystems harbour a wide diversity of pest species as well as rapid population increases. The relative importance of the different species varies considerably. Thus even within the same ecosystem different species are known to predominate at several locations. Some pests are also strictly restricted to particular stages in the phenology of the rice plant.

The rice plant at the vegetative stage of growth (seedling and maximum tillering stages) is attacked by a large number of insect pest species among which are the stalk-eyed flies, *Diopsis thoracica* West. (*D. macrophthalma*); armyworm, *Spodoptera exempta* Walker; gall midge, *Orseolia oryzjvora* Harris & Gagne; bloodworm, *Chironomus* sp; termites; grasshoppers; caseworm, *Nymphula* stagnalis Zell and ladybird beetle (*Epilachna similis* Muls). During the reproductive stage, almost all of these disappear and lepidopterous stemborers and rice bugs become pests of major importance.

Reliable and detailed information on rice crop damage due to insect pests in tropical Africa are rare. The estimates available are usually deductions based on few experiments and field observations comparing crops protected from insect damage with unprotected checks. Information on crop losses is usually incomplete and varied consisting of estimates of losses occurring in especially bad years or in only affected locations. References such as, "serious pests" and "heavy losses" are common in the literature. However, Crammer (1967) estimated that 33 per cent of potential rice production is lost to pests in Africa out of which 14.4% was attributed to insect pests.

In the Côte d'Ivoire, losses caused by insect damage in rice fields average 1 ton of paddy per hectare or about 25% (Breniere, 1969). In Djibelor, Senegal, the application of Lindane and Diazinon at 3 kg a.i/ha also gave about 25% increase in yield (Veracambre, 1977).

Agyen-Sampong (1977) recorded yield loss of about 30% in irrigated rice due to lack of stem-borer protection in Ghana. Crop protection on farmers' irrigated fields in Senegal gave yield increase of 3.25 and 5.67 ton/ha (WARDA, 1979). In Nigeria, losses due to insect pests on rice are estimated at between 25 and 30%. Grain yield increase of 34.8% was obtained on deep-flooded rice in Mali, while increases ranging from 10 to 20% were reported for mangrove swamp in Sierra Leone (WARDA, 1980a).

In Egypt where over 500,000 ha rice crop is irrigated, crop loss caused by *Chilo agamemnon* is over 10 per cent (El- Azizi, 1978).

Nature of Crop Loss

Damage done to the rice crop by insect pests often results in the reduction of either the quantity and/or quality of rice. This indicates that there is a relationship between insect pest population density infesting the crop/damage and yield loss. Neither insect pest populations nor crop losses are static — they tend to vary from season to season and location to location.

However, even when infestation/damage to rice appears high, the real losses of yield may be small and not necessitate control measures. Farmers and extension officers often are not able to distinguish between damage and economic injury due mainly to lack of training. The intensity and effect of damage depends on the stage of the crop. Young rice seedlings more often succumb easily to damage by pests. However, during period of active growth of the plant, maximum tillering period may be able to successfully withstand pest attack by rapidly compensating and so show little or no reduction in yield. Limited research and education on rice pest management in Africa, make it difficult for farmers and extension officers to appreciate the fact that some levels of pest damage or the effect of high population of some pest species has no measurable effect on yield or quality of the crop. Five years field trials relating yield to African white rice borer *Maliarpha separatella* attack in Central Côte d'Ivoire (Pollet, 1979) indicate stemborer infestation of 50 to 70% results to maximum of about 13% crop loss. During 1979 armyworm outbreak in Sierra Leone, extensive (70%) defoliation by the armyworm of 4-5 week old seedlings caused no significant crop loss while about the same level of defoliation of the younger seedlings led to complete crop loss (WARDA 1980b). Again, high loss occurs when crop is attacked later during crop growth. For example, rice stemborer, *Chilo* spp. infestation during flowering leads to "white heads" formation. Thus no crop could be harvested from affected panicles.

Crop Loss Assessment

The importance of crop loss assessment has been to bring in focus the necessity of use of good cultural practices and other pest management practices to achieve better control for high yield. However, different authors have assigned different reasons for assessing crop losses which have succinctly been summarised as follows:

1. To define the economic status of a given pest species in order to plan research priorities and allocation of resources.
2. To determine pest infestation intensity at which control measures need to be applied.
3. To estimate the effectiveness of control measures.
4. To establish economic thresholds and economic injury levels.

5.To assess the use of public funds to study pests and;
6. To give a basis for directing future research and agriculture planning (Kumar, 1984).

Rice entomologists readily identify pest damage to rice plants, but rarely know the symptoms which cause yield loss, especially how much damage causes yield loss and to what degree. Even more difficult is understanding the relationship between pest density and yield loss.

The fundamental principle of integrated pest control is that the pest populations are maintained at levels below those causing economic injury by suitable control measures. The economic injury level is the lowest population density which will cause sufficient crop damage to justify the cost of artificial control measures. Before economic level is reached the density at which control measure is needed to prevent an increasing pest population is referred to as economic threshold. The level involves understanding of the relationship between population (and/or plant damage) and yield loss. It also involves cost/benefit analysis and the treatment required to prevent that yield loss.

Estimation of Crop Loss in Rice Field

Basically, two major steps are involved in the assessment of yield losses, namely, assessing insect pest infestation by appropriate and reliable sampling techniques and relating population density levels or damage to yield loss.

Reliable sampling methods and procedures are used to quantify the insect populations or intensity and yield loss. Direct or indirect sampling method can be used for insect pests.

1. Actual counts of insects per unit area for example, total numbers of, say, armyworms, case worm per square metre or individual plots.
2. Relative counts based on number of insects per unit time of collection or observation, or per sweep of, say, grasshoppers, stalk eyed flies, light trap for adult stemborers, or number per sticky board.
3. Indirect counts where the products of their activity are noted. These include indices such as "white heads", "dead heart" of stemborers, termites on upland rice and "onion shoots" of gall midge. These are assessed by visual counting, counts per unit effort.

Many sampling methods developed depend on the specific insect pests and applied to the climate and the conditions of the location in which they are assessed. Some rice crop sampling techniques which are applicable to various insect pest population/damage to rice have been developed which may relate to yield loss (Agyen-Sampong, 1982; Akinsola and Agyen-Sampong 1984; Dyck, 1978; Gomez and Bernardo, 1974; Onate 1965; WARDA 1978, 1979). For further comprehensive account of specific sampling methods and techniques relevant to ecological studies, consult Southwood (1978), Cochran (1973) and Nishida and Torii (1970).

Natural pest infestation: In rice fields, insect pest attack on the plant is often expressed in terms of damage or damage symptoms. Randomised plots of pest infestation are laid out or plots, fields or individual hills are selected at random. The pest infestation is estimated and yields are taken. These can then be related to pre-determined infestation levels of other fields of recorded previous seasons.

Under natural infestation "paired-plant" method may be used. Individual affected and unaffected hills/stems are paired or taken in groups and subsequent performances are studied and yield taken. Adjacent pairs of unaffected hills should also be marked to quantify any compensation made by the unaffected stem adjacent to a less competitive neighbour.

In Madagascar modified paired plant method was developed (Breniere et al. 1962 and Breniere and Rodriguez 1963) to estimate loss cause by *Maliarpha separatella*. Two hundred stems were examined at random, healthy panicles (n), partly empty panicles (n′) and dry empty panicles (n″) were separated. The grain weight of n and n′ were taken as p and p′ respectively. The total yield/ha (R) was also noted. The yield loss is calculated as:

$$(n \frac{[p\,(n'\,n'')] - p'}{p + p'} - R$$

It has been noted (FAO, 1971) that this method gives loss in terms of real yield, not a sample yield, but over estimates loss as it often occurs with loss estimation under natural infestation. Losses caused by other factors such as other pests, soil, climate or loss before heading may be included. Walker (1981) suggested the use of stratification to obtain meaningful relationship between these factors.

In West Africa, where *M. separatella* infestation scarcely causes "white head", above formula may not be applicable.

Manipulation of infestation with chemicals: The use of chemicals to vary degree of pest population/damage and relate to yield is a common crop loss evaluation method by rice scientists in Africa. In these replicated crop loss experiments basically compare protected and unprotected plots. The protected plots may receive maximum application of an appropriate insecticide from seedling to harvest, whereas the non-protected plots are allowed to be damaged by naturally occurring population of the same insect pest. Control measures for other pests such as nematodes, phytopathogens, weeds and vertebrate pests e.g. birds are applied to both protected and non-protected plots.

By careful selection of insecticides, rate and timing of application, yield losses can be obtained for rice seedling pests; termites, armyworms, *Heteronychus oryzae,* leaf feeders, such as *Epilachna similis:* and stemborers - *Chilo zacconius* and *C. diffusilineus, Sesamia* spp. and *M. separatella. M. separatella,* unlike the other stem borers, heavy infestation occurs before losses become of economic importance. In Madagascar stem infestation of more than 90 per cent cause losses of one ton per ha (Breniere and Rodriguez 1963) while in West Africa, 400 to 800 kg/ha when stem infestation is 40-60 per cent (Agyen-Sampong 1982, and Akinsola and Agyen-Sampong 1984).

Data obtained from paired treatment experiments can often be analysed by using the "t-test" statistics for test of significance (Church, 1971). The loss in yield attributed to the insect or group of insect pests can be computed by applying the formula below:

$$\frac{\bar{X}_1 - \bar{X}_2}{\bar{X}} \times 100 \text{ where } \bar{X}_1 \text{ mean yield of protected plots}$$

$\bar{X}_2$ mean yield of non-protected plots

The results from paired-treated experiments give a measure only of the estimated loss caused by a particular pest in a particular season and location, as reflected by the intensity of a single pest on crop yield. Such experiments do not indicate the increment of loss per unit increment of pest intensity; such information shows a more reliable picture of crop loss. However, to obtain this information more complex field experiments are required which may include: (a) The establishment of various intensity levels for each of the pests under study - insecticides applied at different rates and timing can produce such effect. (b) Reliable methods for measurement of pest intensities. (c) Determination of crop yield at each level of pest intensity and; (d) The statistical evaluation of crop loss data obtained (Le Clerq, 1971).

Thus, correlation and regression statistical procedures could be used to evaluate relationship of two variables, such as pest damage and yield from the detailed paired-treated experiments. The degree of association is measured by the value of correlation coefficient (r) which may be positive or negative correlation. The higher the number of pairs of observations on which a correlation coefficient is calculated the more reliable the relationship.

Regression function gives out more detailed information of economic significance than correlation coefficient. A regression relationship between two sets of correlated variables can be represented in equation or graphically either by a straight line or by a curve. Thus relationship between, say, pest reduction and pest intensity can be translated into pest damage, since for each unit of pest intensity, the resultant amount of yield loss can be estimated.

The average regression line for an area can be calculated if a series of crop-loss paired-treatment experiments are done at different locations for several seasons. In subsequent years, estimates of pest intensity only need to be done in a number of fields; and by referring to the calculated regression line the area yield loss for the particular area can be estimated (Le Clerq, 1971).

In Madagascar, on extensive irrigated fields, intensity levels of *Maliarpha*/loss relationship was established. A correlation in insecticide trials between percentage loss calculated by the above formula developed in Madagascar, and the numbers of larvae per 100 stems was estimated (Breniere and Rodriguez, 1963). On farmers fields in the northern Sierra Leone mangrove swamps rice for three successive cropping seasons *Maliarpha* stem infestation/yield regression relationship were established. To obtain different levels of infestation within a field, different plots were given different insecticidal applications at different times.

Various curves, linear and non-linear, were fitted to the sets of data from the different sites. The operative factors in the field which influence crop loss assessment. These factors include, the growth vigour and resistance of the plant; length of time the larvae fed within the stem, the part of the tiller attacked by the larvae and the cultural practices of the farmer (WARDA, 1977, 1978, 1979).

Data should be interpreted with caution. Some insecticides e.g. Furadan may stimulate rice growth to give more yield while others may reduce yield. Again the insecticides could affect other pests which influence yield such as nematodes.

Experiments should be conducted at multilocational sites for at least three years in order to overcome some of these limitations.

Caging: confine insects or keep insects: In a randomised experiment insect pests of various densities could be caged in rice fields. A series of infestation levels are established. Uninfested controls are needed to indicate the effect of the cages on the plants.

The effects of the pest infestation are measured at each level and the yields are noted at maturity and rélationship between pest intensity and yield loss is established. The results could be evaluated by correlation and regression relationship.

Agyen-Sampong and Fannah (1980) used cages to estimate the relationship between rice bug intensity and "dirty panicle" syndrome in Sierra Leone, using regression function.

Although this is a widely acceptable method, the cage might affect yield and the behaviour of the insect pests that are caged. Cages may drastically change the microclimate around the plants and produce results that may not apply to the open field.

Resistant varieties: Yield is a varietal characteristic and therefore different varieties will yield differently under the same level of infestation. However, if susceptible and resistant varieties can be found which have similar yields when not infested, exposure to natural infestations will result in different infestation rates and different yield.

Ukwungwu and Odebiyi (1984) used paired – treatment method — protected and unprotected — on resistant and susceptible rice varieties to estimate yield losses caused by *M. separatella, C. zacconius* and *Sesamia* spp. in Nigeria.

In conclusion, experimentation of on-farm losses in rice due to insect pests in Africa has received little attention.

Reliable evaluation of crop loss assessment could be complex and difficult; considerable innovations and information are needed to complete our knowledge on rice crop losses due to insect pests, but expertise and funding are limited to conduct adequate comprehensive research. It is envisaged that through international support by way of funding and specialised training, for example, by ICIPE; and in collaboration with national research institutes for improvement in crop loss assessment could be accomplished.

References

Agyen-Sampong M. (1977). Insect pests of rice in Ghana and their control. In: Proc. WARDA Seminar Plant Protection for the Rice Crop WARDA. March, 1977.

Agyen-Sampong M. (1982). Sampling methods for rice insects. spp. 372-383. In: Concept, Techniques and Application of Integrated Pest Management in Rice in West Africa. Edited by E.A. Akinsola *et. al.*

Agyen-Sampong M. and J.S. Fannah (1980). Dirty panicles and rice yield reduction caused by bugs. *Inter'l Rice Res. Newsl.* **5**: 11-12.

Akinsola E.A. and M. Agyen-Sampong (1984). The ecology, bionomics and control of rice stemborers in West Africa. *Insect Sci. Applic.* **5**(2): 69-77.

Breniere J. (1969). Importance des problems entomologiques dans le developpment de la riziculture de l'Afrique de L'ouest. *L'Agron. Trop.* **24**: 906-927.

Breniere J. and H. Rodriguez (1963). Le borer du riz a Madagascar: efficacite des insecticides: Sensibilite Varietale: experimentation 1961. *Agron. trop.* **18**: 427-459.

Breniere J., Rodriguez H. and Ranaivosoa (1962). Un ennemi du riz a Madagascar, *Maliarpha separatella*, or borer *Agron. trop.* **17**: 223-302.

Church B.M. (1971). The place of sample survey in crop loss estimation. In: L Chiarappa (Ed.). Crop loss assessment methods. FAO manual of evaluation of losses by pests, diseases and weeds (not sequentially paginated).

Cochran W.G. (1963). Sampling techniques, 2nd Edition. John Wiley and Sons. Inc., New York 413 pp.

Cramer H.H. (1967). Plant protection and world crop production. Pflschutz - Nach. Bayer **20**: 1-54.

Dyck V.A. (1978). Country Statement — Egypt. In: Rice in Africa pp. 319-321.

FAO (1971). Crop loss assessment methods. FAO manual on the evaluation and prevention of losses by pests, diseases and weeds. Ed. L. Chiarappa. Alden Press, Oxford.

Gomez K.A. and Bernardo R.C. (1974). Estimation of stemborers damage in rice fields. *J. Econ. Entomol.* **67**:(4). 509-513.

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

Le Clerq E.L. (1971). Field experiments for assessment of crop losses. In: L. Chiarappa (Ed.). Crop loss assessment methods. FAO manual of the evaluation of losses by pests, diseases and weeds (not sequentially paginated).

Nishida T. and T. Torri (1970). A handbook of field methods for research on rice stemborers and their natural enemies. International Biological Programme Handbook No.14. London. 132 pp.

Onate B.T. (1965). Estimation of stemborer damage in rice fields. *Phil. Statis* **14**: 201-221.

Pollet A. (1979). Le forer blanc du riz irrigue en RCI *Maliarpha separatella*. Les relations plante-insecte. Congres sur la lutte contre les insectes en milieu tropical. Marseille, 13-16 Mars 1979.

Southwood T.R.E. (1978). Ecological methods with particular reference to the study of insect populations. Halsted Press, New York. 524 pp.

Ukwungwu M.N. and J.A. Odebiyi (1984). Yield Losses in Resistant and Susceptible Varieties of Rice in Nigeria due to *Chilo zacconius* and other Stem Borers. *Tropical Pest Management* **30(3)**: 291-295.

Vercambre B. (1977). Development of a chemical control method against pests of irrigated rice in Senegal. In: Proc. WARDA Seminar Plant Protection for the Rice Crop. WARDA, March, 1977.

Walker P.T. (1981). Methods for studying the Pest/Yield relationship and for Appraising Losses Due to Insects and Mites pp 73-78. In: FAO Crop loss assessment methods — Supplement 3 Ed. L. Chiarappa, Commonwealth Agricultural Bureaux. Slough.

WARDA (1977). Regional Mangrove Swamp Rice Research Station. Annual Report for 1976.

WARDA (1978). Regional Mangrove Swamp Rice Research Station. Annual Report for 1977.

WARDA (1979). Regional Mangrove Swamp Rice Research Station. Annual Report for 1978.

WARDA (1980a). Research Department Annual Report. WARDA, Monrovia, Liberia.

WARDA (1980b). Regional Mangrove Swamp Rice Research Station. Annual Report for 1979.

Assessment of On-Farm Losses in Cereals in Africa Due to Soil Insects

T.G. Wood and R.H. Cowie

Introduction

Cereals are grown throughout Africa and generally constitute the major staple food. They are attacked by a wide range of pests, the most spectacular losses being due to epidemic, migratory pests such as locusts and African armyworm. However, they also suffer chronic attack by other pests, resulting in consistent annual losses. Soil pests, defined here as those pests in which the damaging stage of the life-cycle lives in the soil, constitute an important group of these chronic pests.

The most important cereals in Africa are maize (14.6 $\times 10^6$ ha), sorghum (14.1 $\times 10^6$ ha) and millets (16.7 $\times 10^6$ ha), with rice and wheat increasing in importance.

Some of the more important soil pests are listed in Table 1. Termites are the most significant, followed by the larvae of various beetles, particularly Scarabaeidae. Various other insects are of lesser or only local importance. Other major groups of soil pests include millipedes and nematodes. The latter present a special case, but millipedes are included here since they damage plants in a similar way to some insects.

Table 1. Examples of damage to cereals in Africa by soil insects

Crop and pest	Country	Author
MAIZE		
Termites (Isoptera)		
Macrotermes	Nigeria	Harris (1969), Wood *et al.* (1980)
	Sudan	Wood (unpublished)
	Ethiopia	Crowe and Shitaye (1972), Sands (1976), Wood (1986)
	Zambia	Wilson (1963)
	Malawi	Mathews and Whellan (1974)
	Zimbabwe	Mitchell (1972), Rose (1962)
Odontotermes	Nigeria	Harris (1969) Wood *et al.* (1980)
	Zimbabwe	Rose (1962)
Pseudacanthotermes	Nigeria	Harris (1969) Wood *et al.*, (1980)
	Ethiopia	Wood (1986)
Allodontermes	Nigeria	Wood *et al.*, (1980)
	Tanzania	Bigger (1966)
Ancistrotermes	Nigeria	Harris (1969), Wood *et al.*, (1980)
	Zimbabwe	Mitchell (1972)
	Tanzania	Bigger (1966)
Microtermes	Nigeria	Harris (1969), Wood *et al.*, (1980)
	Tanzania	Bigger (1966)
	Zimbabwe	Rose (1962)
Hodotermes	Zimbabwe	Rose (1962)
Amitermes	Nigeria	Harris (1969), Wood *et al.* (1980)
Microcerotermes	Nigeria	Wood *et al.*, (1980)
Beetles (Coleoptera)		
Gonocephalum	Zambia	Wilson (1963, 1972)
Emyon	Zimbabwe	Rose (1962)
Zophosis		
Buphonella		
Dercodus		
Psammodes		
Eulepeda		
Scarabaeidae	Zimbabwe	ZAR (1979)
Caterpillars (Lepidoptera)		
Pachyzanchla	Egypt	Hammad *et al.* (1969)
Mole crickets (Orthoptera)		
Grylloptalpa	Egypt	Isa (1973)

Crop and pest	Country	Author
SORGHUM		
Termites (*Macrotermes*)	Ethiopia	Wood (1986)
Beetles (Scarabaeidae)	Sudan	Pollard (1956)
	Zimbabwe	ZAR (1979)
Millipedes (*Peridontophyge*)	Mauritania	War on Want (Personal Communication)
MILLETS		
Millipedes (*Peridontophyge*)	Mauritania	War on Want (Personal Communication)
Termites (*Macrotermes*)	Ethiopia	Wood (1986)
RICE (Paddy)		
Diptera (*Chironomus*)	Egypt	Abdul-Nasr *et al.*, (1971)
RICE (Upland)		
Termites (*Macrotermes, Microtermes, Trinervitermes*)	Nigeria	Harris (1969), IITA (1971) Malaka (1973)
WHEAT		
Termites (*Microtermes*)	Tanzania	Sands (1977)
	Zambia	Wilson (1972)
BARLEY		
Termites (*Macrotermes*)	Ethiopia	Wood (1986)
TEFF		
Termites (*Macrotermes*)	Ethiopia	Crowe and Shitaye (1972), Wood (1986)

Literature on soil pests in these crops in Africa is scanty. However, in India there is much published information on soil pests, and as agriculture in Africa becomes more intensive, many of the problems currently experienced in India can be expected to develop similar significance in Africa. The two most important groups of soil pests in India are termites and scarabaeid beetles (Veeresh and Rajagopal, 1983; Veeresh, 1977, 1980; Verma and Kashyap, 1980). Yield losses from termites on wheat and barley can exceed 45% (Verma *et al.*, 1978, 1979) and over 20% on maize and finger millet (Sudhaker and Veeresh, 1985). As in Africa, sorghum and pearl millet suffer very little damage from termites. However, sorghum and finger millet appear to be damaged by a wider variety of pests than in Africa, including ants (*Pheidole* and *Monomorium*), crickets, ground beetles (*Gonocephalum*), wireworms, root aphids (*Tetraneura*), and weevil larvae (*Myllocercus*) (Hiremath *et al.*, 1986; Veeresh, 1985). *Myllocercus* also damages pearl millet (Singh and Singh, 1977). Roots of paddy rice are attacked by root weevils (*Echinococcus*) (Srivastava *et al.*, 1976), crickets (*Brachytrupes*) and mole crickets (*Gryllotalpa*) (Chatterjee, 1973), and roots of upland rice by aphids (Panda and Satpathy, 1976).

Assessment of Damage and Yield Loss

Soil insects are cryptic, difficult to observe and qualitative and quantitative assessment of their populations and activities requires special sampling techniques. Discussion of these techniques is outside the scope of this paper, but reviews can be found in Kevan (1955), Murphy (1962) and Lee and Wood (1971).

In Africa cereals are exposed to soil pests from sowing to harvest. Some pests, such as *Gonocephalum* (Coleoptera, Tenebrionidae) damage seeds, thereby preventing germination; others, such as *Macrotermes* (Isoptera) and millipedes cut seedlings at the base of the stem resulting in loss of stand. However, most damage by soil pests, such as the termites *Microtermes* and *Ancistrotermes* and various insect larvae is to the root system. Damage results in lowered translocation of water and nutrients, increased susceptibility to pathogens, wilting leading to reduced vigour or mortality, or lodging of mature plants with subsequent damage to grain on the ground from various invertebrates, vertebrates and saprophytes. Thus, damage can occur from sowing to maturity and assessment of yield losses needs to take into account all growth stages of the plant. This is illustrated diagramatically in Figure 1.

Loss of seed and/or seedlings results in loss of stand. Potential yield losses vary depending on the capability of the remaining plants for compensatory growth and higher yields due to reduced plant completion. During the vegetative growth phase attack on roots weakens or kills plants, and, again there is the possibility of compensatory yields from adjacent, undamaged plants. Once the ear heads are formed and mature, compensatory growth is not possible and lodged plants can be damaged on the ground or suffer total loss if not harvested.

Some techniques for assessing yield loss due to insect pest damage to cereals were reviewed by Judenko (1973). These and other techniques in increasing order of complexity include:

1. Assessment of percentage of plants infested or attacked.
2. Assessment of intensity of damage
3. Comparison of yield of attacked and unattacked plants ("paired plant" method).
4. Pesticide trials comparison of treated and untreated plots.
5. Assessment of yield of caged plants with and without experimentally induced infestations.
6. Artificial simulation of damage.

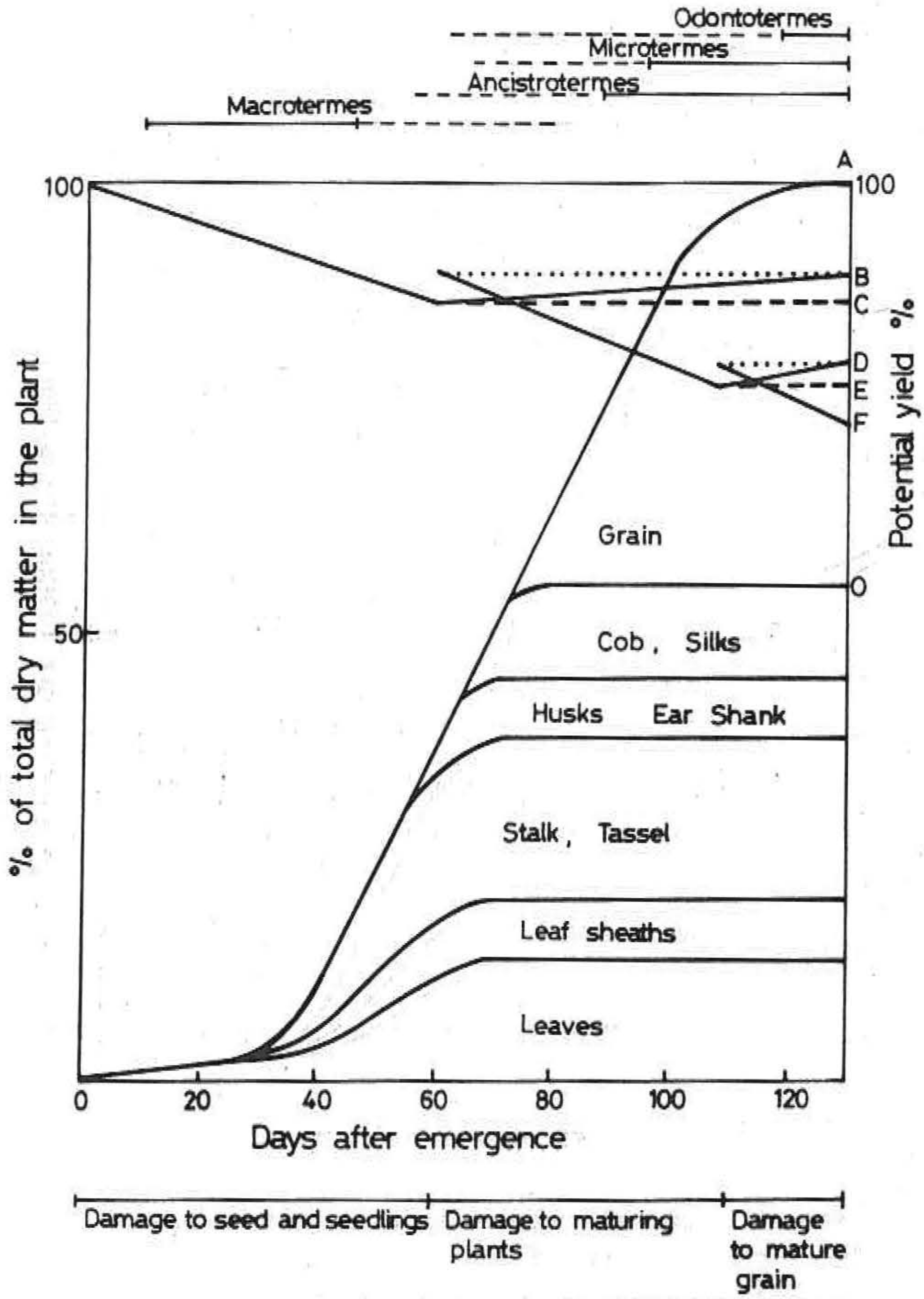


Figure 1. Diagrammatic representation of growth stages of maize and yield loss due to damage to seeds and seedlings by *Macrotermes* (A-B), maturing root systems by *Ancistrotermes* and *Microtermes* (B-D) and mature grain by *Odontotermes* (D-F). Continuous lines represent actual yield loss accounting for compensatory growth of undamaged plants. Coarse dotted lines represent yield losses in absence of compensatory growth (i.e. A-C for *Macrotermes*, B-E for *Ancistrotermes* and *Microtermes* and D-F for *Odontotermes)*. Additional damage to lodged grain is not represented.

On-farm assessment of seedling damage, wilting and plant mortality due to soil pests can be assessed by methods 1 to 4 and 6. Method 5, which would involve establishing controlled, artificial infestations of root systems is not practical in the field, although it is possible with plants confined to pots or in previously sterilised soil. On-farm assessment of reduction in yield due to lowered translocation of water and nutrients is difficult because of the problems of assessing damage to the root system without destructive sampling. For soil pests methods 1 and 4 have been the most commonly used. The big disadvantage of method 1 is that the percentage of plants infested often bears little relationship to yield loss, as the latter depends on the timing and severity of the attack. Method 4 has been widely used, and where a single soil pest is largely responsible for damage, can give useful practical results. However, it does not differentiate between damage caused by the individual species of a spectrum of soil pests, nor the varied responses of different soil pests to insecticides. There is also the possibility that soil insecticides may inhibit plant growth and that systemic insecticides in addition to controlling soil pests will increase yield by reducing damage from foliar pests. Method 3, although more time consuming than methods 1 and 4, is probably the most accurate if damage by the pest under study can be differentiated from damage from other pests. In practice, a combination of methods may have to be used and adapted to the prevailing circumstances of crop and pest complex.

The problems and methodologies will be illustrated with reference to the complex of termite pests attacking maize in Africa.

Termite Damage to Maize and Assessment of Yield Losses

Several species of termites damage maize from the seedling stage to maturity (Table 1, Fig. 1). The most important of these are *Microtermes,* which attack maturing and mature plants.

Macrotermes damage to seedlings.

In Africa various species of *Macrotermes* build large epigeal nests (mounds) often housing many thousands or even 1-2 million individuals (Collins, 1981; Darlington, 1984). They construct shallow subterranean foraging galleries radiating from the nest for distances of up to 50 m (Darlington, 1982). The main galleries give rise to a network of smaller galleries from which foraging parties can exploit potential food resources over extensive areas of land. Their usual food is dead wood, dead grass and dung. They forage directly on underground sources of food, or, under the cover of a specially constructed layer of soil, on sources of food on the surface. Seedling maize is either cut just below the soil surface or just above the soil surface with access from soil-covered galleries impinging on the base of the plant. Usually, the seedlings are completely severed, resulting in lowered plant populations.

In most African countries these losses appear to be sporadic and localised. However, in Zambia (Wilson, 1963), Zimbabwe (Rose, 1962; Mitchell, 1972) and Ethiopia (Crowe and Shitaye, 1972; Sands, 1976; Wood, 1986) these losses appear to be more widespread and occasionally catastrophic. All these reports express losses as percentage of plants attacked (Method 1). Losses of up to 60% have been reported from Ethiopia (Wood, 1986).

Using Method 1, yield loss *(L)* can be expressed as:

$$L = (Y_1 \times T) - Y_2$$

Where T = total number of germinated plants, Y_1 average yield of unattacked plants, Y_2 actual total yield. However, this simple method can give distorted estimates of yield loss because of various factors which include compensatory yield of unattacked plants, attack by other pests or diseases and selective attack (e.g. on weak plants) by the pests. At the seedling stage the most important of these is compensatory growth of unattacked plants. This is illustrated diagramatically in Fig. 2, where compensatory growth from unattacked plants is postulated to be a maximum at a plant density of 75% of the recommended sowing rate. Using this model yield losses can be calculated by measuring yields from unattacked plants where there is no possibility of compensatory growth and from unattacked plants where compensatory growth is possible due to adjacent spaces created by dead plants (i.e. Methods 3). If:

T = total number of germinated plants

X = number of surviving plants with no possibility of compensatory growth giving a yield per plant of Y_1

Z = number of surviving plants with the possibility of compensatory growth giving a yield per plant of Y_2

then:

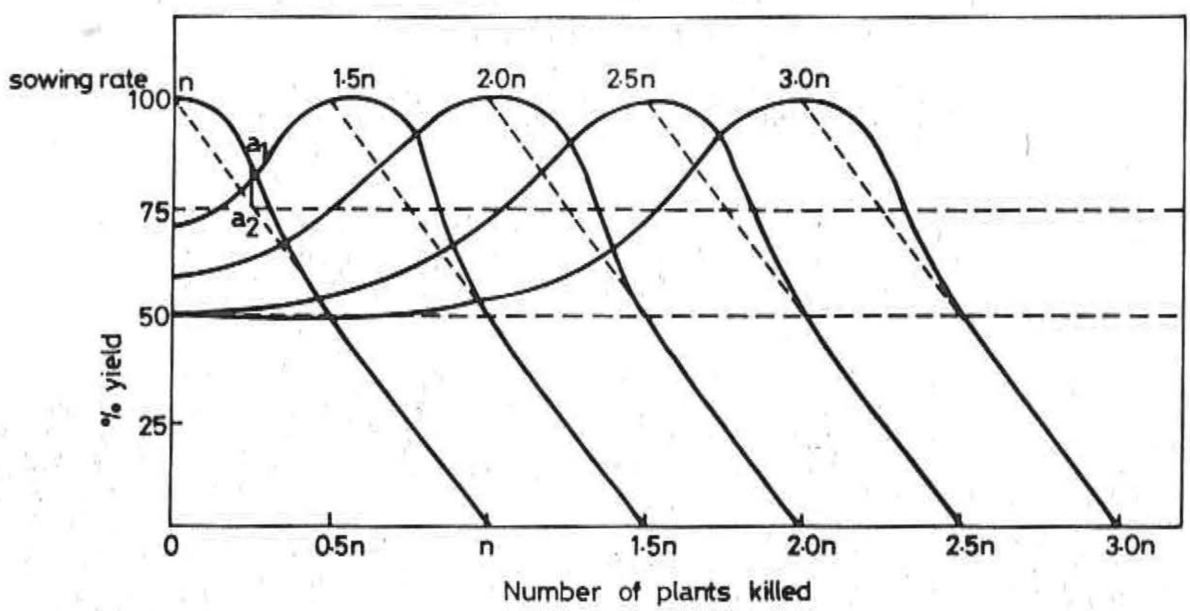


Figure 2. Diagrammatic represention of yield losses in maize at various sowing rates due to seedling mortality caused by *Macrotermes,* millipedes etc. n = optimum number of plants per unit area to give maximum yield; 0.75 n plants gives maximum compensatory growth; yield depression by excess competition is a maximum of 50% at a plant density of 2.5 n. Dotted line represents yield in the absence of plant competition and compensatory growth.

Number of plants killed = $T - (X + Z)$
Potential yield (P) = TY_1
Actual yield (Y) $XY_1 + XY_2$
Yield loss = $P - Y$

Using Fig. 2, at the recommended sowing rate (N) and 25% (0.25N) plants attacked the actual yield would be approximately 88% of the potential yield (a_1, Fig. 2) as opposed to 75% (a2, Fig. 2) calculated by Method 1.

Many farmers in areas of high *Macrotermes* damage resort to higher than recommended sowing rates to compensate for expected loss of plants. However, if sowing rate is high and *Macrotermes* attack is low then yields will be depressed by excessive competition between plants (Fig.2).

Macrotermes occasionally cut the base of well- established plants (Fig. 1) but this is insignificant compared with seedling damage, although there is less potential for compensatory yield when more mature plants are killed.

Ancistrotermes and Microtermes damage to maturing and mature plants

These termites have entirely subterranean nests consisting of a diffuse network of galleries and chambers. In contrast to the readily observable damage by *Macrotermes*, damage by *Ancistrotermes* and *Microtermes* (and occasionally *Odontotermes* and *Allodontermes)* has no immediate observable effect on the plant. These termites enter and consume the larger roots and prop roots and continue their excavations into the stem, which can be excavated and packed with soil to heights varying from 1-2 cm to over 1 m in intensive attacks (Wood *et al.*, 1980). The only evidence of these subterranean attacks are broken prop roots or 'lodging' i.e when the plant falls over due to its weakened root system or weakened tem. Observations by Bigger (1966) in Tanzania, (Wood *et al.*, 1980) in Nigeria and Gebremedhin (personal communications) in Ethiopia indicate that little damage occurs before 9-10 weeks but attacks can rapidly intensify and become extensive as the plants mature. Yield losses due to lowered translocation of water and nutrients depend on the timing of the attack in relation to formation of the grain (Fig.1). Lodged plants suffer further yield losses from damage to grain on the ground by termites, ants, rodents and saprophytic fungi and bacteria. The incidence of lodging can be increased by excessive wind and rain.

The use of Method 1 (percentage of plants attacked) leads to distorted estimates of yield loss. Adoption of Method 3 (comparative yield of attacked and unattacked plants) does not take account of the timing or severity of the attack nor the secondary attack on lodged plants. Wood *et al.*, (1980) adopted a method which combined Method 3 and Method 2 (assessment of intensity of attack) to measure yield losses due to *Microtermes* in Northern Nigeria. Some of these data from 32 plots studied over 4 years are shown in Table 2 and discussed below.

At harvest, plants were divided into five classes as follows: SU - standing, unattacked
SAI - standing, roots only attacked
SA2 - standing, roots and stem penetrated
SA3 - standing but leaning (without touching the ground) due to root and stem penetration
L - Lodged due to root or root and stem penetration

The damage per plot varied from 2.4 to 44.9% for all combined SA categories, 0.4 - 32.7% for L, and 4.7 - 56.0% for both categories combined. Yield losses on SA plants were much lower than on L plants and on only four plots were losses on SA plants in excess of 1.0%. This was because severe attack on the root system only occurred after the grain had fully matured. The only significant losses were on lodged plants on plots 19 and 20 where continuous cultivation had resulted in the build-up of large populations of *Microtermes* which damaged lodged grain. Significantly there was no correlation between percentage of plants damaged (SA or L) and yield loss.

The operations described above are time consuming and laborious. For soil pests the most commonly used method of estimating yield losses is by the use of insecticides applied to the soil in order to compare yields on treated and untreated plots (Method 4). The disadvantages of this method have been outlined above. However, where a single pest is dominant the method gives

Table 2. Damage and loss in yield of maize in Northern Nigeria due to *Macrotermes* (adapted from Wood *et al.* 1980) For explanation of SU, SAI etc., see text.

Plot and year	Number of plants	%plants attacked				Dry weight grain per plant (g)					Change in yield (± d.w. grain)					% loss compared
	per plot[1]	SA1	SA2	SA3	L	SU	SA1	SA2	SA3	L	SA1	SA2	SA3	L	Net	with SU
1975																
\	320	32.6	10.2	0.8	10.2	104.8	108.9	107.8	85.3	94.6	+1.3	+0.3	−0.1	−1.0	+0.5	–
)	324	34.6	8.8	1.6	10.4	104.0	109.5	86.9	88.0	90.2	+1.8	−1.4	−0.2	−1.4	−1.2	3.0
9	308	10.7	10.6	2.1	32.7	96.0	93.5	88.0	77.0	77.0	−0.3	−0.9	−0.4	−6.5	−8.1	8.1
:0	290	10.3	6.5	2.2	29.2	102.0	88.0	93.5	82.5	77.0	−1.4	−0.5	−0.4	−7.2	−9.5	9.5
1976																
\	319	2.9	2.0	2.4	22.4	101.3	109.9	111.6	92.6	94.2	+0.2	+0.2	−0.2	−1.6	−1.4	1.8
9	310	1.8	2.3	1.7	13.6	89.0	89.0	82.0	88.0	60.5	0.1	−0.2	0.0	−4.4	−4.6	4.6
0	306	2.2	2.4	1.4	15.3	78.5	72.0	78.5	71.5	49.5	−0.2	0.0	−0.1	−5.7	−6.0	6.0

[1] 100 plots = 1 ha

useful practical results. Trials in Gemu Gofa, Ethiopia, where *Ancistrotermes* is the dominant soil pest, showed that timing of the 10 attack was a critical factor in determining yield losses (Table 3). At Boreda there was no difference in the incidence of lodging on treated and untreated plots, and lodged plants had heavier grain weights than standing plants. However, untreated plots yielded approximately one third that of treated plots due to an almost three-fold increase in the number of plants attacked. The attack started early in the season and at 80 days approximately 50% of plants sampled had damaged root systems, some almost completely destroyed, resulting in lowered translocation of water and nutrients and lowered grain yields on both standing and lodged plants. However, at Chano Mile the root system was attacked much later and although 98% of plants on untreated plots had their root systems damaged (in contrast to 25% on treated plots) there was no significant difference in yield on treated and untreated plots.

Table 3. Damage and yield loss in maize due to *Ancistrotermes* in Gemu Gofa, Ethiopia (adapted from Gebremedhin, personal communications)

Locality	% plants with roots attacked	% plants lodged	Yield from kg ha^{-1}	standing plants	lodged plants
Boreda:					
treated[1]	30	23	700	55	45
untreated	88*	34 n.s.	234*	29	71
Chano Mile:					
treated[1]	25	29	2547	74	26
untreated	98**	44**	2306 n.s	60	40

[1]treated: seed dressing of aldrin, 25 g a.i. per 10 kg seed.
Difference between treated and untreated significant at 5.0% (*), 1.0% (**), not significant (n.s.).

The results of these trials in Nigeria and Ethiopia were obtained by harvesting at maturity and by hand picking cobs from lodged plants. Peasant farmers in Africa are subject to seasonal constraints in supply of labour. In the localities studied in Nigeria, farmers habitually harvested cobs from lodged plants and therefore the trials accurately reflected farmers losses. However, at Boreda (a farmers co-operative) in Ethiopia, cobs on lodged plants were not harvested due to lack of labour, and after harvesting standing plants the fields were given over to cattle grazing. Farmers recognised these losses and were responding by returning to local, lower-yielding varieties.

Odontotermes damage to standing grain

Wood *et al.*, (1980) described damage by *Odontotermes smeathmani* (Fuller) to mature, standing maize in Northern Nigeria. These subterranean termites start their attack by covering the base of the stem with a thin layer of soil under which they consume dead leaf sheaths. Eventually the entire stem and cobs covered in a layer of soil and the cobs destroyed. This type of damage is rare and appears to be confined to drier regions (less than 860 mm annual rainfall) where maize growing is a marginal enterprise. In this case, assessment of the percentage of attacked cobs (Method 1) is an accurate reflection of yield loss.

Discussion

Soil insect pests often cause more damage to cereals in the early stages of growth by damaging the roots and/or cutting the stems of seedlings. If the damage is not too severe, compensatory growth of the remaining plants may result in yield losses being much less than would be expected from a simple assessment of the number of plants damaged. Estimates of yield losses need to account for compensatory growth, although the ability of plants to compensate decreases as the crop matures. Damage to the root systems of maturing plants results in reduced yield of grain if the disruption to the translocation of water and nutrients occurs before the ear heads are fully formed. Severe attack on the root system (e.g. by termites or beetle larvae) of maturing or mature plants can result in lodging with subsequent damage to grain on the ground by a variety of pests and saprophytes. Estimation of yield losses often requires a combination of methodologies which include assessment of the percentage of plants attacked and comparison of yield of attacked and unattacked plants with the latter subdivided into plants capable and incapable of compensatory growth. Particularly where a single pest is dominant, these methods can be usefully complemented by insecticide trials comparing yields on treated and untreated plots.

Assessment of yield loss is not an end in itself. It is a basic working tool for the economic rationalisation of various pest management strategies which, in their turn, need to take account of farmers' socio-economic constraints. In the example given of *Macrotermes* damage to maize, the farmers' options are to sow at the recommended rate and use insecticides to protect the crop, or to withhold the use of insecticides and sow at a higher rate in the expectation that a range of damage levels will give him a sub-maximal yield. The same principle applies to the choice of high yielding varieties susceptible to lodging by *Microtermes* or *Ancistrotermes*, or lower yielding varieties less susceptible to lodging. Without knowledge of yield losses the farmers' options are limited and based largely on experienced guesswork.

References

Abdul-Nasr S., Isa A., Kira T. and El Tantaway A.M. (1971). Effect of the blood worms (*Chironomus* sp. and the rice fly (*Ephydra macellaria* Egger) on rice seedlings in U.A.R. (Diptera: Chironomidae and Ephydridae). *Bull. Soc. Ent. d'Egypte* **54:** 203-211.

Bigger M. (1966). The biology and control of termites damaging field crops in Tanganyika. *Bull. ent. Res.* **56:** 417-444.

Chatterjee P.B. (1973). Two harmful insects of rice in North Bengal. *Indian Farming* **22:** 35

Collins N.M. (1981). Populations, age structure and survivorship of colonies of *Macrotermes bellicosus* (Isoptera: Macrotermitinae). *J. Anim. Ecol.* **50:** 293-311.

Crowe T.J. and Shitaye G.M. (1972). *Crop Pest Handbook. A guide to the more important pests of field and plantation crops in Ethiopia.* Institute of Agricultural Research, Addis Ababa.

Darlington, J.P.E.C. (1982). The underground passages and storage pits used in foraging by a nest of the termite *Macrotermes michaelseni* in Kajiado, Kenya. *J. Zool. London.* **198:** 237-247.

Darlington, J.P.E.C. (1984). A method for sampling the populations of large termite nests. *Ann. Appl. Biol.* **104:** 427-436.

Hammad, S.M., El Minshawy, A. and Saad, A.H. (1969). Studies on *Pachyzancla biarcicalis* Walk. (Lepidoptera: Pyralidae). Bull. Soc. Ent. de l'Egypte **52:** 313-317.

Harris, W.V. (1969). *Termites as pests of crops and trees.* Commonwealth Institute of Entomology, London.

Hiremath, I.G., Lingappa, S., Viraktamath, C.A. and Mushtak Ali, T.M. (1986). Occurrence of the ground beetle, *Gonocephalum hofmannseggi (*Coleoptera: Tenebrionidae) on finger millet (*Eleusine coracana* (L.) Gaertn.). *J. Soil. Biol. Ecol.* **6:** 62-66.

IITA (International Institute of Tropical Agriculture) (1971) *Annual Report.* IITA, Ibadan, Nigeria.

Isa, A.L. (1973). On the effect of certain soil insecticides on corn stand and growth. *Agric. Res. Rev.* **51:** 7-14.

Judenko, E. (1973). Analytical method for assessing yield losses caused by pests on cereal crops with and without pesticides. *Tropical Pest Bulletin* **2:** 1-31.

Kevan, D.K. McE. (1955). *Soil Zoology.* Butterworth, London.

Lee, K.E. and Wood, T.G. (1971). *Termites and soils.* Academic Press, London.

Malaka, S.L.O. (1973). Observations on termites in Nigeria. *The Nigerian Field* **38:** 24-40.

Mathews, G.A. and Whellan, J.A., (1974). *Malawi Crop Protection Handbook.* Malawi Ministry of Agriculture and Natural Resources, Department of Education Training, Extension Aids Branch.

Mitchell, B.C. (1972). Termite survey of Rhodesia. *Rhodesia Agric. J.* **69:** 39.

Murphy, P.W. (1962). *Progress in Soil Zoology.* Butterworth, London.

Panda, N. and Satpathy J.M. (1976). Aphid damage to upland paddy. *Entomologists' Newsletter* **6:** 4.

Pollard, D.G. (1956). The control of chafer grubs *Schizonycha* sp. in the Sudan. *Bull. Ent. Res.* **47:** 347-360.

Rose, D.J.W. (1962). Pests of maize and other cereal crops in the Rhodesias. *Rhodesia Agric. J. Bull.* **2163:** 1-23.

Sands, W.A. (1976): *A visit to Ethiopia to examine termite problems in Wollega Province 17-26 May 1976.* Report CVR/76/1, Centre for Overseas Pest Research, London.

Sands, W.A. (1977). The role of termites in tropical agriculture. *Outlook on Agric.* **9:** 136-143.

Singh, K.M. and Singh, R.N. (1977). The upsurge of *Myllocerus undecimpustulatus maculosus* Desb. on pearl- millet under dryland conditions at Delhi. *Indian J. Ent.* **39:** 300.

Srivastava, A.S., Nigam, P.M., Katiyar S.S.L. and Awasthi, B.K. (1976). Chemical control of paddy root weevil, *Echinococcus oryzae* Mshll. (Coleoptera; Curculionidae). *Labdev J. Sci. Tech.* **B 13:** 79-81.

Sudhakar, K. and Veeresh, G.K. (1985). Crop loss estimation due to termites (*Odontotermes obesus* and *Microtermes obesi*) on dryland crops. *J. Soil Biol.* Ecol. **5:** 58-64.

Veeresh, G.K. (1977). Studies on the root grubs of Karnataka, with special reference to bionomics and control of *Holotricha serrata* F. (Coleoptera: Malolonthinae). *Monograph series no. 2, University of Agricultural Sciences, Bangalore, India.*

Veeresh, G.K. (1980). Influence of agriculture on the outbreak of white grubs in India. In *Soil Biology as related to land use practices* (Daniel L., Ed.). USA, EPA, Washington D.C., 301-310.

Veeresh G.K. (1985). Importance of soil insect pests in relation to sorghum production. *Proceedings of the International Sorghum Entomology Workshop, Texas A & M University* (eds. Leuscher K. and Teetes G.L.). ICRISAT, India. 105-113.

Veeresh, G.K. and Rajagopal, D. (1983). *Applied Soil Biology and Ecology.* Sharada Publications, Bangalore, India.

Verma, A.N. and Kashyap, R.K. (1980). Termites — their damage and control in field crops. *Memoirs of the Entomological Society of India* N. **8:** 1-53.

Verma, A.N., Bhanot, J.P. and Khurana, A.D. (1978). Effect of termite damage in earing stage of wheat crop on reduction in grain yield. *Indian J. Ecology* **5:** 108-109.

Verma, A.N., Kashyap, R.K., Bhanot, J.P. and Khurana, A.D. (1979). Effect of seed treatment and soil application of aldrin and BHC on termination, termite damage and yield of barley. *Indian J. Ent.* **41:** 164-169.

Wilson, K.J. (1963). Underground pests of maize in Northern Rhodesia. *Rhodesia Agric. J.* **60:** 111-114.

Wilson, K.J. (1972). A review of soil dwelling insects that have become important pests of agriculture in Rhodesia. *Rhodesia Agric. J.* **69:** 17-21.

Wood, T.G. (1986). *Report on a visit to Ethiopia to advise on termite damage to crops.* Report R 1347 (R). Tropical Development and Research Institute, London.

Wood, T.G., Johnson, R.A. and Ohiagu, C.E. (1980). Termite damage and crop loss studies in Nigeria — a review of termite (Isoptera) damage to maize and estimation of damage, loss in yield and termite (*Microtermes*) adundance at Mokwa. *Trop. Pest Manage.* **26:** 241-253.

ZAR (Zimbabwe Agricultural Research) (1979). *Annual Report 1976-77 of the Plant Protection Research Institute, Zimbabwe 112 pp.*

Cereal Crop Losses Caused by Locusts in Eastern, Central and Southern Africa

A.C.Z. Musuna

Introduction

Special reference is made to the International Red Locust Control Organisation for Central and Southern Africa (IRLCO-CSA) region where the writer's experience was gained.

In this region, growing of cereal crops accounts for most of agricultural production as indicated in Table 1. The major cereal crops which include maize, sorghum and millets are all liable to attack by different locusts a constraint which can severely limit their productivity in terms of harvest.

The need to establish a foundation for routine crop loss data illustrating the economic importance of locusts was recognised at the 4th International Locust Conference held in Cairo in 1936 (Uvarov and Bowman, 1938). It was established then that any attempt to increase the productivity of cereal crops in tropical Africa cannot afford to ignore assessment of the potential impact of these insect pests. The appropriate methods of cereal crop loss assessment were reviewed by Walker (1983). However, because of the peculiar difficulties involved, it is well-known that reliable and precise statistical information on the damage effect of locust outbreak and the expenditure incurred in their control is very limited.

The aim of this paper is to present a brief reference to the locusts that threaten cereal crop cultivation in the region and to review a few of the recorded instances of losses caused by these insects.

Table 1. Areas and yields of the main cereal crops grown in eastern, central and southern Africa that are liable to attack by locusts

A. Areas under crop (Modified after Odhiambo, 1984)

Crop	'000's hectares	% of total area
Maize	7830	33
Sorghum	2684	11
Millet	1414	6
Wheat	751	4
Total	11679	64

B. Annual yields ('000's Metric tonnes) (Adapted from FAO Yearbook, 1986)

Country Crop	Botswana	Kenya	Malawi	Mozambique	Swaziland	Tanzania	Uganda	Zambia	Zimbabwe
Maize	7	1934	1395	337	110	1348	448	831	1394
Sorghum	5	154	146	183	-	463	447	12	62
Millet	1	74	-	-	-	331	576	13	106
Wheat	-	192	-	-	-	79	15	15	148
Rice	-	37	33	57	3	393	23	-	-

Locusts Affecting Cereals in East, Central and Southern Africa

The locust species that can cause plagues in the region are: the red locust (*Nomadacris septemfasciata* Serville), the African migratory locust (*Locusta migratoria migratorioides* R & F), the brown locust (*Locusta pardalina* Walker) and the desert locust (*Schistocerca gregaria* Forskal).

Life-cycles

The red locust life-cycle starts at the beginning of the rainy season, mainly October to December. The female lays about 3 egg pods in moist soil, which contain about 100 eggs each. The incubation period lasts about 30 days after which first- instar hoppers hatch. The hoppers develop during January to March through 6 instars before becoming adults. During this period groups of hoppers may form bands which march in the dense tall grass. From April to September adult locusts form swarms which can fly and invade widespread areas. The red locust produces one generation a year.

The life-cycles of the African migratory, brown and desert locusts develop similarly through egg, hopper, and fledgling prior to the adult stage. The number of eggs laid and the duration of successive life stages are indicated in Table 2.

Table 2. Summary of life-cycles of the various species of locusts in eastern, central and southern Africa

	Red locust	African migratory locust	Brown locust	Desert locust
Egg pods laid	3	1-5	4-5	2-4
Eggs per egg pod	100	30-100	45	60-160
Incubation period	30	30	15	10-70
Hopper instars	6	5	5	5-6
Days to hopper development	50-60	24-35	25-30	22-70
Generations annualy	1	4-5	3	3

Origin of locust swarms

There are areas in eastern, central and southern Africa where permanent red locust populations breed and from where plagues can originate (Symmons, 1964). These outbreak areas are shown in Fig. 1. It is from some of these areas that the last plague in 1929-45 started and spread to most of Africa south of the Equator.

The outbreak areas of African migratory locusts are in the flood plains of the Middle Niger in Mali. During the last plague in 1931-34 major swarms of African migratory locusts originated from there.

Brown locusts do not have definitive outbreak areas, but they can breed heavily in the Karoo semidesert of South Africa when conditions become suitable, and can

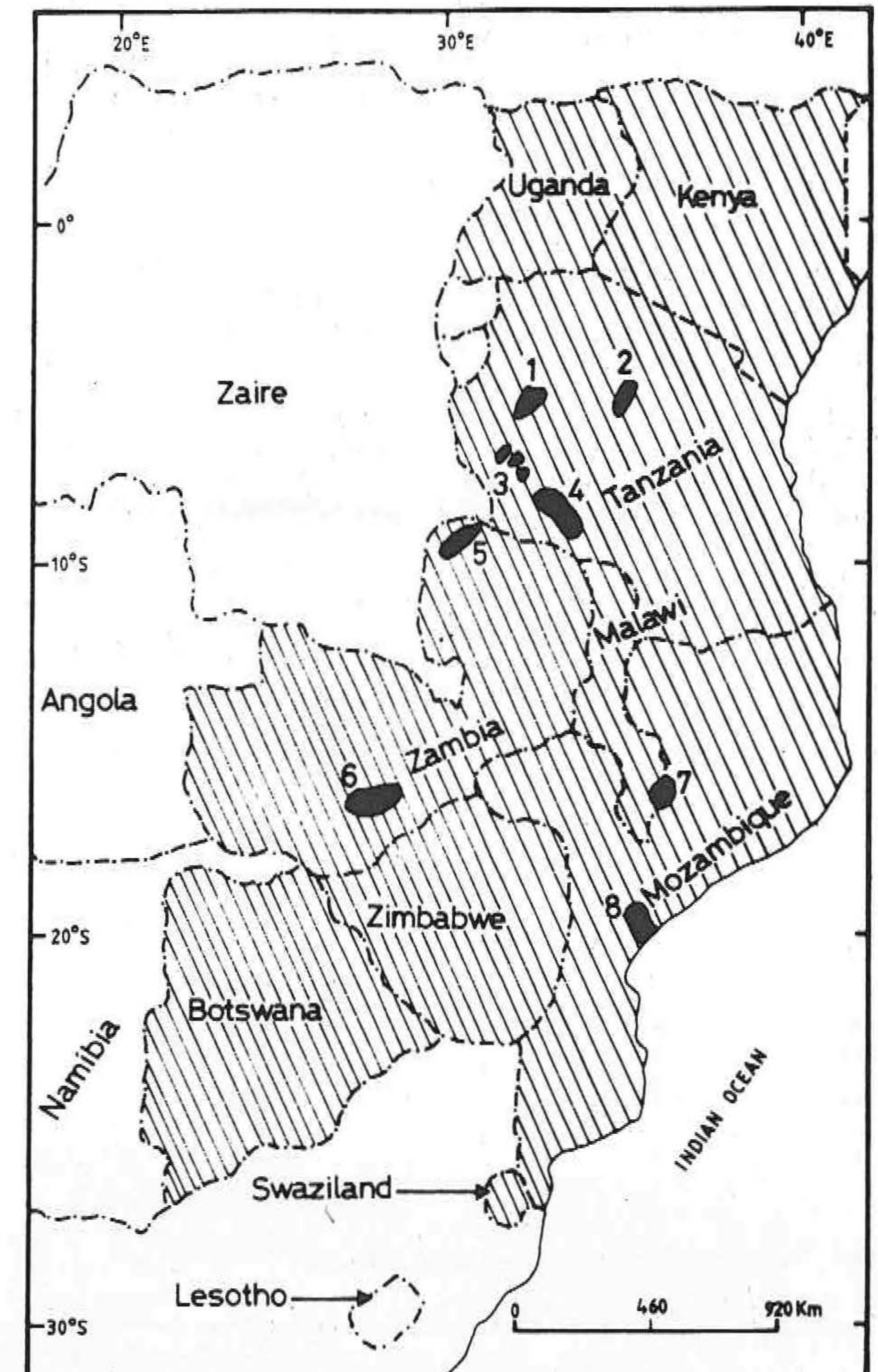


Figure 1. The recognised red locust outbreak areas in IRLCO CSA region

invade neighbouring countries. For example, in the first half of 1986 a severe invasion of brown locusts occurred into Botswana from South Africa (Moobola, 1987a). At that time huge bands and swarms of these locusts spread over practically all the districts in the southern half of the country.

The invasion areas of desert locusts in Africa lie mainly north of the equator but there are no well-defined outbreak areas. However, swarms of desert locusts can migrate to Kenya, Uganda and Tanzania.

Economic Importance of Locusts

Both hoppers and adults of red, brown and African migratory locusts normally feed on wild grasses but if these are not available they can eat cereal crops. Desert locusts eat a wider range.of wild vegetation but frequently they also attack cereal crops.

The effect of cereal crop damage caused by locusts varies according to the growth stage and type of the crop; growing plants are often entirely defoliated and ripening grain is eaten away. According to Bullen (1966) the reasons why locusts are able to do so much damage to crops are a function of their feeding habits, their abundance and swarming behaviour. Locusts feed mainly during the day. A locust eats its own weight which is equivalent to 2g. of vegetation per day. Therefore, an average locust swarm containing about 50 million locusts can consume 100 tons per day. If breeding conditions have been ideal, intensive and extensive population build-up can occur leading to numerous hopper bands and swarms. Swarm displacement is mainly by daylight, determined by wind speed and direction. Where a moving swarm will land is unpredictable, but it can travel more than 50 kilometres per day. Thus cereal crops within outbreak and invasion areas are highly vulnerable to attack by the locusts.

The liability of crops and countries to damage by locust infestation was rated by Crop Vulnerability Indices which were compiled routinely by the Anti-Locust Research Centre (Anon, 1966).

Costs incurred

To appreciate the magnitude of possible losses of cereal crop production in the region and the monetary costs of anti- locust campaigns, numerous examples can be cited from regions of the continent, but only a few are quoted in the present paper. Figures are also given that relate to the upsurge of red and brown locusts in the region during 1985-87.

1. During the last major locust plague South Africa spent an amount estimated to be 933,000 UK pounds over a period of two seasons 1933-34 and 1934-35 in combating red locusts to protect crops (Anon, 1982). The losses sustained during that period were recorded as 20,000 UK pounds worth of damage to maize, sugar cane and pasture.

2. During the 1925-35 brown locust outbreak period in South Africa, losses of maize, wheat and grazing were calculated to be 138,000 UK pounds (Du Plessis, 1937).

3. In Madagascar African migratory locusts caused losses in rice and sugar cane production estimated to be 200,000 UK pounds annually during 1949-69 (Tetefort, 1969).

4. There is a large number of references concerning crop loss due to desert locust infestations and expenditure incurred in controlling them in several continents (Anon, 1982).

5. Over the period 1970-84 very low locust infestations were recorded in the IRLCO-CSA region (Materu, 1985). It is assumed therefore, that insignificant crop damage was caused by these pests. However, during 1985-87 a heavy upsurge of red and brown locusts occurred in the region (Moobola, 1987a & b). Unfortunately there are no precise estimates of cereal crop damage that was caused by both pests during the period. However, the financial expenditures incurred over that period to control the locusts can be illustrated partly by the cost of insecticides used (Table 3), although a satisfactory deduction of the damages prevented as a result cannot be drawn therefrom.

Table 3. The cost of insecticide used in the IRLCO-CSA region for control of red locusts, African migratory locusts and brown locusts during 1986 and 1987

Country	'000's U.S. Dollars
Botswana	430
Malawi	11
Tanzania	148
Zambia	10
Total	599

Conclusion

The last locust plague on the African continent occurred more than four decades ago and it resulted in heavy losses of cereals among other crops. The period since then was characterized by comparatively low locust activity interspaced by periodic upsurges. The organisations responsible for locust work were able to suppress the infestations in time. Consequently, routine assessment of potential crop yield loss was not done. Unfortunately, according to red locust plague dynamics (Symmons, 1964) the resurgence of these pests in east, central and southern Africa during 1985-87 probably predicts the beginning of yet another plague. It is necessary therefore, to strengthen surveys and other research efforts on crop damage due to locusts in order to improve planning of control strategy to prevent further losses of crops.

References

Anon, (1966). The Locust Handbook. Anti-Locust Research Centre. London.

Anon, (1982). The Locust and Grasshopper Agricultural Manual. COPR. London, England 690 pp.

Anon, (1986) FAO Yearbook, Rome.

Bullen, F.T. (1966). Locusts and grasshoppers as pests of crops and pasture: a preliminary economic approach. *J. Appl. Ecol.*, **3:** 147-168.

Du Plessis, C. (1937) Economic importance of the locust problem in the Union of South Africa and South West Africa. In Proc. 4th Int. Locust, Conf., Cairo, Egypt. 5pp.

Materu, M.E.A. (1985). Control of the red locust (*Nomadacris sepstemfasciata* Serville) in Africa in the seventies. *Zimbabwe Agric. J.* **82:** 6.

Moobola, S.M. (1987a). Annual Report IRLCO-CSA for 1986. Ndola, Zambia.

Moobola, S.M. (1987b). Annual Report IRLCO-CSA for 1987. Ndola, Zambia.

Odhiambo, T.R. (1984). International aspects of crop protection: the needs of tropical developing countries. *Insect Sci. Applic.*, **5:** 59-67.

Symmons, P.M. (1964). The dynamics of the most recent plague of the red locust, *Nomadacris septemfasciata* (Serville) with special reference to the importance of climate and weather (Thesis).

Tetefort, J. (1969). Les sauterelles migratrices et les recherches acridiennes a' Madagascar. Bull. Madagascar, Nos 280-281: 31 pp.

Uvarov, B.P. and Bowman, B.M. (1938). The economic importance of locusts and grasshopper problem throughout the world. In Proc. 5th Int. Locust Conf., Brussels, pp. 190-236.

Walker, P.T. (1983). The assessment of crop losses in cereals. *Insect Sci. Applic.* **4:** 97-104.

ACKNOWLEDGEMENTS

This paper is presented with the kind permission of the Director of the International Red Locust Control Organisation for Central and Southern Africa. The author is indebted to Mr. E.K. Byaruhanga for his constructive criticisms and suggestions during the preparation of the manuscript and to Mr. F.N. Mugisha for taking the photographs. Thanks are also due to Mrs. M.M. Sitali for typing the manuscript.

Cereal Losses Caused by Armyworm in Eastern and Southern Africa Current Information and Research Proposals

D.J.W. Rose, M.J. Iles and A. Ward

Introduction

Armyworm, *Spodoptera exempta* (Wlk.) feed on cereals and grassland in Africa and south western Arabia (Haggis, 1984). They are also occasionally reported as the indirect cause of death to cattle which feed on infested pastures (Bryson, 1982; Newsholm *et al.*, 1983). Their notoriety is reflected in popular names which describe characteristics of outbreaks — Mystery worms because of their sudden appearance and disappearance; Hailworms in recognition of their occurrence after major storms; and the African armyworm for its most dreaded characteristic, moving in large numbers out of infested cereals or grasslands where the food supply has been exhausted to destroy adjacent areas. The publicity given to outbreaks of armyworm by newspapers and radio has meant that, like locusts, armyworm are known in urban areas as well as in the farming community. Consequently armyworm have developed a political importance which affects the assessment of on-farm situations and subsequent control decisions.

Current Information on Losses

A. Scientific Research

(a) The Insect

The extent and severity of outbreaks and the yield losses due to armyworm have never been systematically recorded, although some indications are given in the initial reports to DLCO-EA and extension services. Work done by Brown and Odiyo (1968) supports the subjective view that the worst outbreaks do cause serious losses, they showed that one larva can consume 250 mg (dry weight) of maize foliage during the sixth instar and that it is during the fourth and subsequent instars that 90% of consumption takes place. Odiyo (1979) calculated that at a density of 28 sixth instar larvae per square metre, the larvae in a square kilometre would eat as much as 124 head of cattle. Watts *et al.*, 1982 estimated that only 4 larvae per square metre of a similar rangeland pest justified control measures. Armyworm frequently occur in densities greater than 100 per square metre.

(b) Crops

Brown and Mohamed (1972) considered the problem of crop response to armyworm damage and found that "Especially under favourable environmental conditions regeneration after defoliation of both maize and sorghum in the earliest stages of growth treated (3–4 leaves open) recovery can be virtually complete". They found that losses did not become severe until the apical meristem of the plant was above ground level, which was at the nine-leaf stage. These conclusions were based on experiments in which damage was simulated.

In 1986 (Ward and Green unpublished report) information was collected from a major outbreak on wheat. This showed that losses were greatest on plants attacked less than 30 days after sowing. Mean yield losses per farm were estimated as varying from 25–50 per cent on damaged fields and over three quarters of the 24,000 ha area was infested. Other workers have found similar losses due to defoliation by insects or hail on various cereals (Cruz and Turpin 1983; Harrison 1984; Kieckhefer and Kantack 1980; Levine *et al.*, 1984; Mulder and Showers 1986; Vorst 1980).

Crop loss trials by G.K.C. Nyirenda (pers. comm.) set in farmers fields infested by armyworm gave maize yield losses of 75 per cent and 76 per cent for severely damaged plots, and 30 per cent and 45 per cent for partly damaged plots, when fertilizer was not applied, and slightly less loss if fertilizer was applied.

The effect upon cereals (particularly maize) of defoliation is related to:

a. The age of the cereal when defoliated. For example, cereals which are past the tillering stage (in the case of those capable of tillering) and maize beyond the silking stage are unable to make a good recovery.

b. The severity of defoliation.

c. The availability of inputs to support recovery, the most important of these is water; and growing conditions generally.

d. Time. Although cereals can support considerable defoliation at certain stages of growth, defoliated crops may not be ready for harvest until some time after undamaged crops and therefore may not reach maturity if there is a short growing season.

B. Economic Analysis

An initial review of available information which might be used for economic analysis indicated that this was confined to data on cereal production and light trap catches of moths. In the case of Tanzania an attempt was made to examine the relationship between cereal production and armyworm attack, using moth catch as an indicator. It became apparent, however (Iles, 1986), that available data were either incomplete or insufficiently reliable to permit a satisfactory analysis of this relationship. While trap data, although sometimes incomplete, would have indicated the relative importance of different years for armyworm, production data bore little relationship to actual production in several regions. The data collected at the regional and district levels comprised at best a general summary of the local situation in respect of armyworm. Although important evidence has been recorded on the effect of armyworm attack at the farm level, this was of a largely anecdotal nature and does not lend itself to the systematic and in-depth analysis required.

In order to examine the situation at the farm level, a pilot survey was undertaken in 1986 (Iles) during which a questionnaire was developed and tested, in a number of regions, with farmers who have experienced armyworm attack. The questionnaire was designed to obtain farmer level information on armyworm outbreaks, the farmers' response, the costs of any responses, the losses resulting from damage, the effects of other factors and the assistance provided by government to help farmers control outbreaks and limit their effect on crops and livestock.

Data Base For Survey Area Selection

Factors which influence the type of secondary data required for selection of areas in which to survey are:

(a) The importance of subsistence farmers and their economic vulnerability to the effects of armyworm damage to their crops and livestock;

(b) Regional importance of maize and millet the major susceptible crops;

(c) The variability in stage of crop development (and consequent susceptibility to armyworm attack) between the different agro-ecological zones;

(d) Pattern of previous armyworm outbreaks.

Sample Selection

In order to make a selection, data were required from two sources: regional statistics, where available, and from research and extension staff. Using these data, areas were selected according to their ability to represent the variation that exists within the region for the following criteria: armyworm outbreaks; importance of cereal production, focussing on maize and millet, and maize phenology.

The criteria for village selection were that they should have experienced armyworm attack and should not be atypical for the district in terms of type of agriculture and agroclimate. Villages adjoining local administration headquarters were avoided whenever possible as being atypically close to control support services.

Survey Data

The data provided important information on the nature of outbreaks, farmers' responses and the level of government support. Preliminary analysis in respect of the effect of armyworm on yield and the quantification of losses, has emphasised a major difficulty in separating stress factors. There are a large number of stress factors (other pests, particularly insects and birds; weeds and post-attack growing season). The situation is made more complicated because of other factors, such as changing technology, which are stimulating yields. Thus, forces are operating on yields in different directions. Consequently, it is difficult to accurately apportion loss to armyworm.

Considerations for Further Research

There is considerable scope for further work on crop loss due to armyworm attack in Africa. The migratory habit and sporadic occurrence of this pest make straightforward experiments using protected and unprotected plots unfeasible and artificial infestations have proved unsuccessful. The most practical course is to collect data from natural outbreaks and follow the crop through recovery to harvest.

Action thresholds for insecticide application on cereals are needed, their development would involve recording the age and density of larvae, characterizing the crop at outbreak sites and monitoring the crop during subsequent visits. Data on other factors influencing yield would also be recorded. From these data, the effect of different densities of larvae on cereals of known age and stage of development would be assessed and action thresholds determined.

Farmer Surveys

The complexity of factors interacting with armyworm to reduce cereal yields suggests that further survey work will be required after existing data has been analysed.

(1) The scope of the survey may be modified to concentrate on the history of co-operating farmers during the recent past in both armyworm and non-armyworm years. The information gathered would compare production over the period covered, listing the different stress factors operating during each respective season. In order to collect this information satisfactorily, co-operating farmers would be visited two or three times over the course of the season. The survey would be conducted with a large sample but confined to a limited number of sites according to differences based on their importance for armyworm attack, notably critical (because they may be the source of a series of successive outbreaks) and primary outbreaks.

This approach would add to the understanding of the nature of armyworm outbreaks, important for determining recommendations for control and would make an important contribution to armyworm loss assessment. It would still leave gaps in terms of interactions of different factors causing loss because of difficulties in quantifying them. Also, the problem of adequately characterising the nature of the outbreak would remain.

Crop Loss Assessment Case Studies

Stress factors can only be satisfactorily disaggregated at the farm level by observing the armyworm damaged crop over the course of a season and comparing it with adjacent undamaged crops. By so monitoring crops subjected to attack, the nature of the outbreak and subsequent crop response can be accurately measured. It would also offer simultaneously the possibility of observing the effects of pest control on crops and untreated plots. The main disadvantage with this approach is that since it would entail a relatively high research input it could not be contemplated on many farms because of the costs of logistical support requirements.

A combination of the two approaches

It is proposed that a combination of the two approaches should utilise a common group of farmers, with those involved in the case study comprising a sub-sample of the survey. This would provide the advantage of both approaches i.e., accuracy and suitability for extrapolation, without the disadvantages. The survey findings could be applied to the population as a whole. The case studies would be used to explain the situations recorded in the survey. The area identified for survey would be monitored with co-operation required from farmers whose crops were undergoing armyworm attack. Cooperating farmers would be included in the wider survey which would rely on conventional survey methods.

Conclusion

Data on yield loss in cereals are sparse and much of what is available is unreliable. Further research is necessary to identify action thresholds for control and to carry out economic assessments of the effect of the pest at farmer and national level. A methodology combining conventional farm surveys together with the detailed observation of affected/unaffected and treated/untreated crops drawn from the survey sample should be tested for its ability to determine losses caused by armyworm.

Acknowledgements

Thanks are due to the Ministries of Agriculture in Tanzania, Ethiopia, Kenya and in particular to those staff concerned with armyworm surveillance and control, and to staff of the Desert Locust Control Organisation — Eastern Africa Armyworm Project for advice and assistance.

Bibliography

Brown, E.S. and Mohamed, K.A. (1972). The relation between simulated armyworm damage and croploss in maize and sorghum. *E. Afr. agric. For. J.* **38,** 3:237–257.

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. Afri. agric. For. J.* **33:**245–256.

Bryson, R.W. (1982). Kikuyu poisoning and the armyworm. *J. Afr. Vet. Assoc.* **53,** 3:161–165.

Cruz, I. and Turpin, F.T. (1983). Yield impact of larval infestations of the fall armyworm to midwhorl growth stage of corn. *J. econ. ent.* **76:**1052–1054.

Haggis, M.J. (1984). Distribution, frequency of attack and seasonal incidence of the African armyworm *Spodoptera exempta* (Walk.) (Lepidoptera:Noctuidae) with particular reference to Africa and south western Arabia. TDRI, L69, iv + 116 pp.

Harrison, F.P. (1984). The development of an economic injury level for low populations of fall armyworm (Lepidoptera: Noctuidae) in grain corn. *Flor. Ent.,* **67:**335–339.

Iles, M.J. (1986). An economic assessment of the African armyworm with special reference to Tanzania: research proposals. (Internal report to the Government of Tanzania) TDRI, London.

Kieckhefer, R.W. and Kantack, B.H. (1980). Losses in yield in spring wheat in South Dakota caused by cereal aphids. *J. econ. ent.* **73:**582-585.

Levine, E., Clement, S.L. and McCartney, D.A. (1984). Effect of seedling injury by the stalk borer (Lepidoptera:Noctuidae) on regrowth and yield of corn. *J. econ. ent.* **77:**167–170.

Mulder, P.G. and Showers, W.B. (1986). Defoliation by the armyworm (Lepidoptera:Noctuidae) on field corn in Iowa. *J. econ. ent.* **79:**369–373.

Newsholm, S.T., Kellermanm, T.S., Westhuizen, G.C.A. and Soley, J.T. (1983). Intoxification of cattle on Kikuyu grass following *Spodoptera exempta* invasion. *Ond. J. Vet. Res.* **50:**157–167.

Odiyo, P. (1979). Forecasting infestation of a migrant pest: The African armyworm *Spodoptera exempta* (Walk) Phil. Trans. R. Soc. Lond. B 287, 403–413.

Vorst, J.J. (1969). *Influence of defoliation and stand reduction on Zea mays* L. Thesis, University of Nebraska. pp.95.

Watts, J.G., Huddleston, E.W. and Owens, J.C. (1982). Rangeland entomology. *Ann. Rev. Ent.* **27:**283–311.

Current Status of the Larger Grain Borer *Prostephanus truncatus* (Horn) in Africa

Peter Golob

Introduction

Prostephanus truncatus (Horn), the Larger Grain Borer (LGB) was reported for the first time in Africa in 1981 by Dunstan and Magazini. An indigenous storage pest of Central America, it was assumed to have been introduced with grain imports into Tanzania during the 1970s (Golob and Hodges, 1982).

In 1982, in response to a request by the Government of Tanzania, the United Kingdom financed a comprehensive survey to determine the extent of the beetle and the damage it was causing in the Tabora region of western Tanzania, the area where most of the affected farmers resided. LGB-infested maize in stores of farmers in 56 villages throughout the region was examined and spot estimates of damage and losses determined. Samples infested with LGB had sustained a mean of 8.9% weight loss after only 3-6.5 months storage (Hodges *et al.*, 1983), a level approximately five times greater than would have been expected had this beetle been absent.

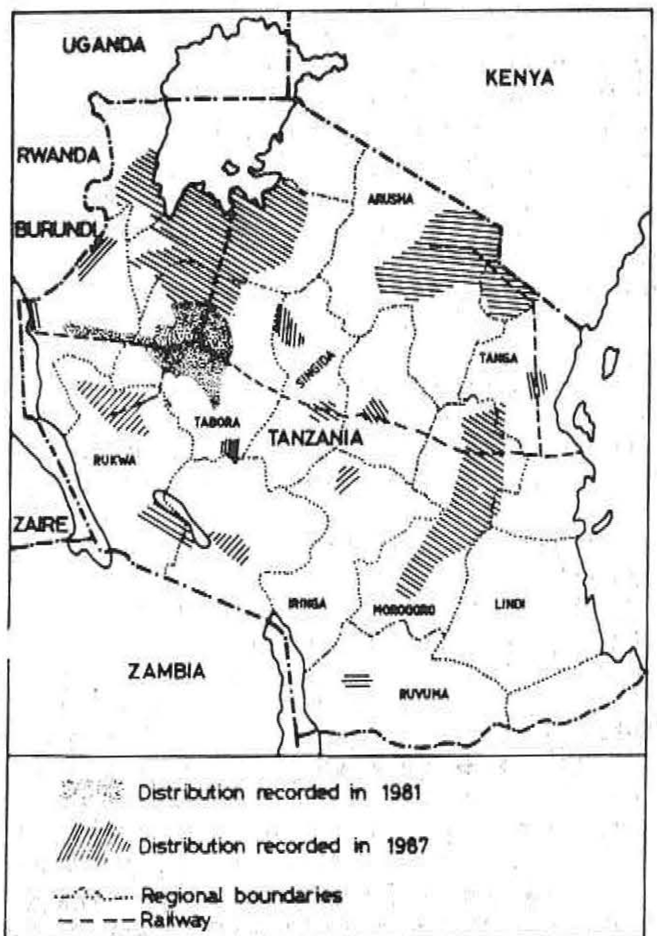


Figure 1. Map of Tanzania showing distribution of *Prostephanus truncatus* (Horn), the Larger Grain Borer

At the time of the survey LGB was found throughout all the inhabited areas of Tabora region except for a small area in the north-east, where sorghum rather than maize is the main food staple. The beetle was also found in markets in trading towns of Shinyanga and Mwanza, to the north of Tabora and in Kilosa, near Morogoro further to the east (Golob and Hodges, 1982). The recorded distribution of LGB in 1982 is illustrated in Figure 1. From subsequent surveys it was concluded that the beetle must have been present in other areas of the country at that time, particularly in Kilimanjaro region in the north-east.

In 1984, as a result of the unprecedented losses that were occurring in farm stored maize the Government of Tanzania, together with the U.K. Overseas Development Administration (ODA) initially and subsequently with FAO, established an extensive control programme to reduce the level of economic loss that was bearable, both nationally and by the individual farmer.

Current Distribution of the Beetle

Tanzania

By the middle of 1987 LGB had become distributed throughout Tanzania, only two regions in the south, Mtwara and Lindi have remained free of the pest since the first outbreak was reported (Figure 1).

Most of the inhabited areas of western Tanzania are infested as are large sections of Kilimanjaro region and northern Arusha region, south of Mt. Meru. The other region of extensive infestation is Morogoro. Although these areas have been infested for many years, judging by the extent of the beetle, it is not possible to conclude whether they were the result of a single or multiple importations of insects.

Only limited outbreaks have been reported in the large maize producing areas of southern Tanzania. Nine villages near Songea in Ruvuma region, five villages in Mbeya region and five villages in Iringá region became infested. Intensive eradication campaigns have been undertaken in these three areas and in parts of Arusha region as well (see below).

Other African Countries

LGB was first reported from Kenya in 1983 by Kega and Warui. South of Mt. Kilimanjaro the Pare tribe inhabit the hilly region which traverses the border. Relatively free movement of trade across the border has resulted in the Taveta area of Kenya becoming infested. Fortunately, the infestation was detected before the insect became very widely established in the country and the introduction of a vigorous quarantine and control programme has resulted in the pest being confined to that original area. Recently, however, the beetle was reported from the north of Mt. Kilimanjaro, near

Oloitokitok (Shamala, M., personal communication) which is adjacent to Taveta. The presence of the Tsavo West National Park has provided a natural barrier against the spread of the pest.

Smuggling maize from the Kibondo district of Kigoma region in Tanzania has resulted in large areas of Burundi becoming infested. LGB has been found on farms in many parts of the country, particularly in the north and east (Figure 2). The beetle has also been reported on dried cassava in Bujumbura markets imported by boat from Zaire across Lake Tanganyika (Baes, H., personal communication).

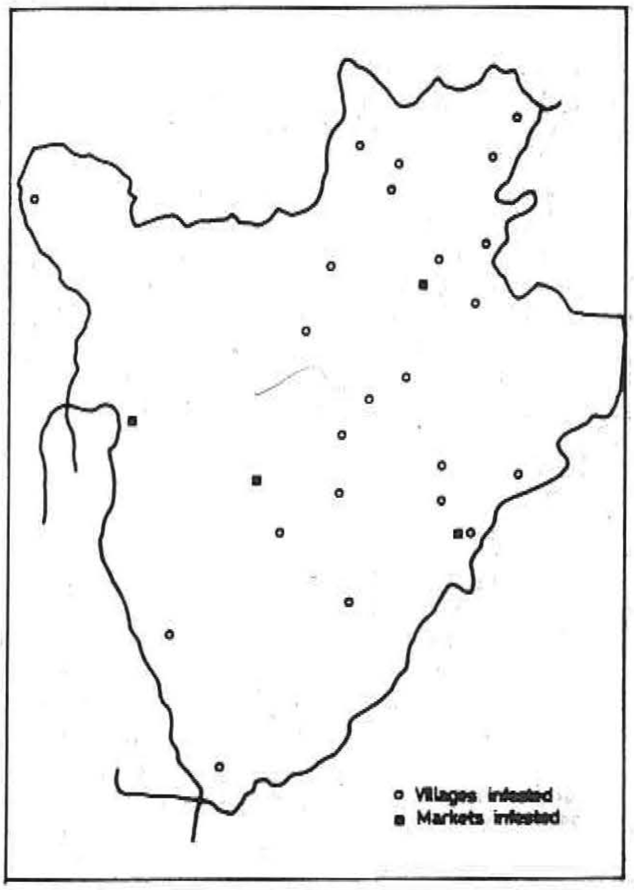


Figure 2. Map of Burundi showing distribution of *Prostephanus truncatus* (Horn), the Larger Grain Borer

LGB was first reported from west Africa in Togo in 1984 (Krall, 1984). In 1986 it was recorded in neighbouring Benin to the east (Krall, S., personal communication).

Damage and Losses

Visible Damage

The LGB has been observed to reproduce and develop only in maize, dried cassava and dried sweet potatoes. Adults are able to infest mature maize cobs before they are harvested. In the laboratory the beetle has been found to reproduce in soft wheat (Shires, 1977) but this ability has not been reported under practical, field conditions. The beetle is however, able to damage a wide variety of materials on farms including cereal and pulse grains, leather and soap articles and the fabric of mud-plastered buildings. Unlike many other Bostrichidae, LGB is unable to develop and reproduce in dead wood (Laborious, A., personal communication) though it can extensively damage wooden objects including structural poles of houses.

Loss Assessment

An assessment of maize storage losses sustained by 108 farmers in three villages in Tabora region was undertaken during the 1985/86 season in an attempt to measure the effect of the recommendations. In Nkokoto village, Urambo district the mean weight loss of samples of maize collected from 33 farmers who had stored for 7 months was 2.3% whilst samples collected from 24 farmers who stored for 9 months had lost a mean of 5.6%, the range being 0-34.4%. However, only a small quantity of grain remaining at the end of the storage season was affected at these levels. When food removals for home consumption or for sale throughout the year were taken into account the real food loss during the season was less than 2%. Similar results were obtained from the other two villages.

Compared to the mean of 8.9% loss when spot estimates were obtained in 1984, these losses were very low. Partly, the success in combatting LGB and the resultant low losses were a direct result of the FAO campaign. Farmers, acutely aware of the measures needed to control LGB shelled and treated the cobs immediately the beetle was seen. Thus LGB did not have an opportunity to become established. However, a second reason for the low estimate was because during this particular season there were few LGB in evidence; farmers in general throughout the region did not report high levels of infestation. Insect numbers only became apparent towards the end of the storage season, by which time there was only a small proportion of the original produce left in store to be infested.

It is very unlikely that reliable estimates of storage losses, as a result of uncontrolled LGB infestation, could be obtained in Tanzania. Farmers react to the presence of the beetle so quickly that infested produce would not be allowed to remain untreated. Losses will continue to be low, a reflection of the success of the extension project (see below).

In Burundi cereal storage losses are minimal because maize production is low and farmers only store for a maximum period of four months, insufficient time for LGB to produce large populations. The low ambient temperatures experienced for much of the year also restrict insect development. In much of Burundi the mean daytime maximum for most of the year is below 22°C whereas the optimum temperature for LGB development is 30-32°C (Shires, 1979). Thus farmers have no incentive to eliminate or control LGB with the very significant consequence that Burundi could act as a continual source of reinfestation.

On-farm weight loss of dried cassava as a result of LGB attack has not been studied. However, in a simulated field study in Tabora Hodges *et al.*, (1985) found weight losses after 12 weeks storage to be 23.3% and 14.8% for roots fermented before drying and unfermented roots respectively. These losses increased to 73.6% and 52.3% after 17 weeks. Dried cassava can be damaged more readily than maize and as there is no method for protecting cassava with insecticides, farmers have been recommended to leave the tubers in the ground until required for consumption.

Control

LGB is most readily controlled by synthetic pyrethroid insecticides. Compounds such as permethrin, deltamethrin, phenothrin and fenvalerate induce mortality in adults and restrict development of succeeding generations much more effectively than organophosphorus compounds (OP) (Golob *et al.*, 1985). This response to pyrethrins is similar to that exhibited by *Rhyzopertha dominica* (F), the Lesser Grain Borer, a closely related, cosmopolitan, Bostrichidae pest of cereals, but is unlike that of all the other common farm storage pests found in Africa. Beetles such as *Sitophilus* species and *Tribolium* species and moths such as *Sitotroga cerealella* (Olivier) are much more readily controlled by pirimiphos-methyl, fenitrothion and other OPs than by pyrethroids (e.g. Bangston *et al.*, 1975).

Trials carried out in Tabora between 1983 and 1986 have all clearly demonstrated the effectiveness of both permethrin and deltamethrin in controlling LGB as illustrated in Table 1.

One of the recommendations for farmers is that they shell their maize before storage. Not only does this practice facilitate the application of insecticide dusts but it diminishes the potential damage as a result of LGB attack. Laboratory work (Howard, 1983) and field trials and observations (Golob *et al.*, 1985) have clearly demonstrated that LGB develops more successfully on maize stored as cobs than when stored as loose grain. However, storing grain predisposes towards infestation by *Sitophilus* species which does not normally pose problems when maize is stored on the cob. In order to negate the problems of *Sitophilus* species, an insecticide dust containing both permethrin and pirimiphos-methyl has been made available to farmers.

The original insecticide dust used by farmers contained 0.5% permethrin as the active ingredient which, applied at the recommended rate of 50 g per 90 kg of maize, provided a nominal dosage of 2.8 mg/kg. The dust currently available contains 0.3% permethrin and 1.6% pirimiphos-methyl and when applied at 100 g per 90 kg of grain produces 3.3 mg/kg permethrin and 17.7mg/kg pirimphos-methyl. Although these dosages provide initial nominal residues which are in excess of the levels recommended by the FAO/WHO Joint Meeting on Pesticide Residues which are, for raw cereals, 2 mg/kg for permethrin and 10 mg/kg for pirimiphos-methyl, so much active ingredient is lost during applications and subsequent decay during storage, that these levels do not present a hazard at the time of consumption.

The effectiveness of insecticides on the fecundity of LGB and *Sitophilus*, measured by the numbers of adults emerging from treated grain after different storage periods, is illustrated in Table 2.

Deltamethrin not only controls LGB but, unlike permethrin, it also controls other storage pests including *Sitophilus zeamais* Motsch (Evans, 1985). Thus this compound can be used as a general storage insecticide and in Togo it is available as a 0.05% dilute dust for use by farmers. It has not been used in Tanzania because it cannot be readily formulated locally.

In Kenya spray applications of pirimiphos-methyl have been used comprehensively for control. These applications were undertaken in an area where the outbreak of LGB was restricted to a few hundred farmers. In Tanzania, in similar areas of localized infestations, spraying has also been undertaken in conjunction with insecticide dust application in attempts to entirely eliminate the pest from those areas. It is too early to critically judge the success of these eradication programmes.

Table 1. Percentage number of damaged grains in samples of maize grain treated with different insecticide dusts after 6 and 8-10 months storage in Tabora, Tanzania

Treatment	Dosage	1983 (months) 6	1983 (months) 10	1984 (months) 6	1984 (months) 8	1985 (months) 6	1985 (months) 10
Control	-	29	100	89	95	19	70
Permethrin	2.5	0	4	2	3	0	6
Permethrin +	2.5+						
Pirimphos-methyl	10	4	82	2	9	0	0
Deltamethrin	0.5	2	4	0	1	0	
Malathion	12	16	98				
Methacrifos	10	9	90				
Pirimiphos-methyl	10	4	82				
Chlorpyrifos-methyl	10	1	33				

Each datum represents the mean of four replicates.
Samples were 300 g from each replicate of 7.5 kg of grain.

Table 2. The number of adult insect progeny emerging from shelled maize grain treated with insecticide dusts in Tabora, Tanzania

Treatment	Dosage ppm	1983 6	8	10	1984 6	8	1986 6	8	10
		Months of storage after treatment							
Control	10 (300)	10 (400+)	8 (205)	20 (35)	30 (115)	2 (0)	5 (8)	- (500+)	
Permethrin	2.5	0 (0)	5 (10)	0 (150)	0 (0)	0 (5)	0 (0)	0 (2)	0 (50)
Permethrin + Primiphosmethyl	2.5 + 10				2	0	0	0	0
Pirimiphosmethyl	10	10	70 (6)	110 (65)	(140)				
Chlorpyrifosmethyl	10	0 (0)	10 (5)	190 (150)					
Methacrifos	10	18 (20)	10 (280)	40 (270)					
Malathion	10	50 (10)	90 (110)	45 (240)					

Each datum represents the mean of four replicates, each of 300 g.
Data in parentheses are numbers of *Sitophilus sp.; other data are numbers of LGB.*

The Extension and Control Campaign in Tanzania

As a result of the intensity of the infestation of LGB in Tanzania a concerted national campaign is being undertaken to eliminate the beetle. The extent of the distribution and damage has resulted in Tanzania undertaking action on a much larger, broader scale than any of the other affected countries.

During the first quarter of 1984 ODA funded a four-man team to undertake a countrywide survey of the LGB problem and then to draw up a proposal for a long-term control campaign for the country. This proposal was subsequently incorporated into the project co-ordinated by FAO, which commenced in 1984 and which is still active.

The FAO project is a multidonor funded programmme which supported five closely integrated projects. Two extension and control field campaigns, one conducted in eight regions of western Tanzania and the other in three regions of the northeast, were financed by the Australian and Swedish governments respectively. A nationwide training programme was funded by the Canadian government, FAO, and then the Dutch government funded a programme co-ordinator together with vehicles and other inputs to maintain project activities. A fifth project, also funded by FAO, investigated the need to improve traditional storage structures and maize shelling methods.

The Field Control Campaigns

Aims and Objectives

The aims of the campaigns were to reduce storage losses on farms and to contain the beetle within LGB-infested areas. More specifically, the objectives sought to:

- train agricultural field staff in good agricultural practices particularly related to farm storage;
- ensure that all farmers became aware of the importance of the pest and of the measures they could take to combat it;
- ensure that farmers were able to obtain the necessary insecticide when it was required.

Project Staffing and Training

Staff in the regional and district offices of the Ministry of Agriculture and Livestock Development (MALD) were assigned to the programme to attend to the day-to-day activities of the extension campaign. The main tasks of these Post-Harvest Officers (PHO) were:

- to ensure the insecticide was distributed to each village and that revenues obtained from its sale were collected and returned to the Ministry;
- to train Field Extension Officers (FEO) in the appropriate methods for on-farm control;
- to organize village meetings, in collaboration with the FEO's, to inform and instruct farmers;
- to assist in evaluating the success of the control campaign. In western Tanzania, the regions were amalgamated into three zones to facilitate co-ordination of the project's operations and a Zone Supervisor was appointed to oversee the activities of the PHOs within his/her zone. All PHOs were provided with a motorcycle to enable them to visit all their villages, and the supervisors were each provided with a Land-Rover.

All PHOs attended a two-week training course during which they were taught basic farm storage technology and also teaching and extension techniques. Zone Supervisors were sent overseas for training.

Regular storage seminars were held by PHOs for their FEOs at each district headquarters so that developments could be quickly disseminated to FEOs and then to farmers.

A series of seminars using drama and facilitated discussion as the main teaching techniques were conducted to boost the confidence and morale of the FEOs as well as to teach improved extension techniques. These seminars were recorded on video and edited versions will be used in the future as teaching tools.

In each zone a mobile pest control team was established, responsible to the Zone Supervisor, whose main tasks were to disinfest commodities in village and co-operative stores by fumigation and insecticide spraying. Team leaders were extensively trained in the appropriate technologies on a six- week course and they themselves trained their team members.

To assist with the dissemination of information many types of audio-visual aids were used in the campaign. Because LGB became a problem of major political significance a great many articles were devoted to it in the national press. Regular features were broadcast over the radio. FAO subsidized the production of a large number of different posters and of an information booklet which was distributed to FEDs, schools and other institutions.

Distribution of Insecticide

Since the end of 1982 Tanzania has imported 405t of 0.5% permethrin dust for farm use. The dust was only distributed to those regions where LGB was present and although each region was assigned insecticide according to its needs, on average each region had to distribute 5-10t each year to its farmers.

The lack of any formal means of distribution of insecticide created many problems for MALD, the lack of transport being the most acute. FAO and ODA provided several lorries which were used by MALD to transport dust from railheads to each district headquarters and then to district divisions, wards and, in many instances, to individual villages. Often the FEOs were given the responsibility of purchasing and supplying their particular villages with dust. Although this system worked well in many areas it did significantly increase the workload of the FEO and also burdened him/her with the added responsibility of collecting revenue from the farmers. In many instances, when FEOs failed to account for the income from the sale of the dust, then losses were made good by deductions from salaries.

When the co-operative unions were established in 1985 many of the tasks concerned with procuring produce and supplying inputs became their responsibility, including the supply and distribution of farm storage insecticide. It is hoped that this switch from MALD will eliminate most of the distribution problems once the infrastructure of the unions begins to operate efficiently as their staff gain experience.

Much of the permethrin was obtained in 25kg sacks. Although convenient for transportation, packets of this size presented many problems when the dust had to be sold to individual farmers. Farmers in western Tanzania store approximately five sacks of maize (500 kg) each year and they required only 250 g of permethrin dust to treat the grain. At each village it was necessary to break down each large sack of insecticide to meet the needs of the individual. Most villages did not possess accurate scales and to measure the dust they used instead a volumetric measure provided by a clean can, originally containing margarine. The can held approximately 800 g of dust, well in excess of what was required. Consequently, many problems occurred with the sale of the dust:

- farmers did not buy any because the smallest quantity that could be purchased was too expensive;
- they did not buy any because they had no container in which to store the excess;
- they did not buy any because there were no written instructions concerning the way the dust had to be applied;
- if they did buy the dust the lack of instructions resulted in widespread over- and under-dosing;
- many farmers did not know what to do with the excess; some overdosed, others stored it for future use often in unsuitable containers and others discarded the excess, thus wasting funds. This misuse would also tend to increase the rate of development of insect resistance.

These problems were mostly overcome when FAO provided one million small plastic sacks in which the dust could be repackaged prior to sale to the farmer. More than 150 t were repacked into 50 g sachets throughout Tanzania, at each district centre. Regional and district MALD officers employed casual labour to undertake the repackaging which was supervised by the PHOs. The final consignment of 150 t of permethrin dust was provided by the EEC in prepacked, fully labelled 50 g sachets.

By the end of 1986 all of this dust had been used and was being replaced by a locally formulated 'cocktail' containing pirimiphos-methyl and permethrin. Unfortunately, in order to reduce costs the cocktail is now being packed in 25 kg bags once again so that the onus of providing farmers with the correct, most appropriate quantity for treating their maize, 100 g for one bag of maize, will fall to co-operatives who may well be unwilling or unable to repack the dust.

The Containment and Eradication Programmes

Where isolated outbreaks of the beetle have been reported, MALD have attempted to eradicate the beetle from the area. In 1986 the Plant Protection Ordinance was amended to include a section relating specifically to LGB. The new Ordinance gave MALD extra powers to enable it to control the movement of produce around the country, to carry out *ad hoc* inspections in order to contain the beetle and permitted the introduction of comprehensive eradication programmes.

Eradication programmes have begun in several areas near Iringa, Songea, Mbeya and Keratu towns. Each programme began with an intensive control campaign (see below) and the effects on the LGB populations were closely monitored during the remaining and subsequent storage seasons. Whenever the beetles are observed, action to control them is carried out again. Tn date the campaigns have lasted for two seasons and only in two areas have the treatments had to be repeated. It is, however, too early to predict how successful these eradication programmes will be, particularly as it will require at least two complete seasons without the beetle being present before the area can be declared free of the pest.

Monitoring
Monitoring is undertaken by visual inspection and by the use of pheromone traps.

Male *P. truncatus* produce an aggregation pheromone which has been partially described in recent years (Hodges et al., 1984). The pheromone is impregnated in a plastic vial which is imbedded in a piece of corrugated cardboard. This trap, which is treated with a 1% solution of permethrin, is placed in a heap of cobs, amongst grain or in any other place likely to harbour beetles. Traps are left *in situ* for two weeks and then examined for insects.

Pheromone traps have been found to be a very effective way to detect low populations of the beetle. If stored in a refrigerator, the vials retain their activity for a year or more.

Continuous monitoring is carried out by the FEOs who are under strict instructions to report new sightings of the beetle by farmers. Such reports can reach MALD headquarters in Dar es Salaam within 24 hours by radio transmitters allowing a speedy response by the Ministry.

Treatment
MALD has several trained mobile pest control teams located throughout the country which could be despatched to any area at short notice. In an area where there are 5-10 villages infested, up to three teams may be required.

In collaboration with the local administrative and political organizations the people in the affected area are mobilized to participate in the programme. The area is quanrantined. All farmers in the quarantined villages are required to shell their maize and treat it with insecticide. Labourers are recruited locally and trained to use a pneumatic knapsack sprayer. Under the supervision and with the assistance of the pest control teams the labourers carry out a comprehensive spraying programme in the villages. All houses and stores are treated, including communal stores, schools and dispensaries. Fumigation is also undertaken if necessary.

This intensive campaign continues until the entire area has been treated. Whilst the spray programme continues the surrounding villages are monitored for the presence of the beetle and where LGB is found the village is immediately included in the programme of disinfestation.

Restriction of the Movement of Produce
The programme to contain the beetle depends almost entirely on preventing infested produce being moved to uninfested areas. Most official transportation of produce is by road and checkpoints have been established in several areas in order to monitor the condition of the commodities. A system of certification is being introduced which allows produce out of an infested area, after treatment, only when accompanied by an authority issued by the PHO. Lack of a certificate would result in the commodity being returned to its origin or to it being treated on the spot.

Movement of produce by rail is also an important method by which LGB has been distributed around Tanzania in the past. Figure 1 shows LGB is restricted in several areas to the line- of-rail villages. However, controlling the movement of privately-owned produce by rail has proved to be extremely difficult, though the introduction of a certification system is beginning to exert some influence.

The government restrictions have only recently been imposed and are not having a significant effect at the moment. Only when rigorous imposition of the Ordinance is effected will it be possible to minimise the movement of infested produce.

Evaluation of the Campaign
The campaign in western Tanzania has been evaluated in two ways; firstly by assessing reduction in losses and secondly, by assessing farmers' responses to the recommendations. As discussed above, although the losses

Table 3. Farmer response to the control recommendations in western Tanzania at the end of the 1985/86 storage season.

Region	Tabora	Shinyanga	Mwanza	Kagera*	Kigoma	Rukwa	Total
No. of farmers interviewed	954	735	700	350	245	280	32.55
% who saw LGB	82.0	77.4	70.0	75.7	63.2	35.0	72.3
% who purchased permethrin dust and used it for LGB control	50.4	75.7	67.2	33.1	38.8	36.7	55.9
% who purchased permethrin dust after seeing LGB	61.5	97.9	96.1	43.8	61.3	100.0	77.3
% who treated grain rather than cobs	87.4	91.0	69.4	79.3	88.4	90.3	83.6
% who thought permethrin was effective (cob and grain treatments)	80.7	82.9	87.5	59.5	98.9	96.1	82.5
% who stored grain rather than cobs	66.1	73.8	49.9	22.9	52.7	49.6	57.3

* At the time of the survey Kagera region had only been incorporated into the project area for 4-5 months; the farmers received permethrin late in the season so that their responses to the recommendations was relatively poor.

found in the three villages surveyed were low, this was not a particularly meaningful way of evaluating the campaign.

At the end of 1985 farmers' responses were determined by questionnaire. The PHOs in 10 districts each interviewed 35 farmers in each of 10 villages. Allowing for survey wastage, responses from more than 3,200 farmers were obtained.

A summary of the results is illustrated in Table 3. Fifty-six per cent of the total purchased and used permethrin for LGB control; this represented 79% of those who actually saw LGB in their maize. Of the farmers who used permethrin 83% said that it was effective against LGB. Of the remaining 17% most had misused the chemical by either underdosing or by applying it to cobs. Fifty-seven per cent of farmers stored maize grain rather than cobs and, although there are no data concerning the types of stores used before the introduction of LGB, this must represent a very substantial increase in the proportion storing shelled grain.

A more comprehensive survey was undertaken in 1986 and when the results are collated they will be published, together with additional data obtained from the survey carried out in 1985.

Conclusion

There is no doubt that if left unprotected, stored maize and dried cassava will sustain very heavy damage if infested by LGB. There are now simple precautions that the farmer can take to alleviate this damage. However, these precautions represent a dramatic change to traditional practices so that the main problem now concerning control of the beetle is one of extension.

In Tanzania, by far the most seriously affected of the African countries currently harbouring the beetle, FAO has initiated a comprehensive programme of extension, control and containment which will remain successful so long as the necessary resources and enthusiasm continue to be provided. This programme could be used as a model for other countries in the region if they so desire.

There are currently five countries in Africa known to be harbouring the beetle. It is essential that all possible measures be taken to prevent the beetle from spreading to other countries on the continent. To achieve this the phytosanitary conditions existing in these five countries must be improved to a level at which guarantees can be given that produce exported through official channels is free from LGB. An upgrading in the produce inspection services of countries concerned is necessary and feasible. Furthermore, attempts must be made to prohibit illegal movement of produce across borders. This can only be achieved from the full co-operation of the people living on the borders and they must be made aware of their responsibilities by massive publicity campaigns. Unless this movement across borders can be stopped, it is inevitable that LGB will soon be found in many more countries in Africa.

References

Bengston, M., Connell, M., Davies, R.A.H., Desmarchelier, J.M., Phillips, M.P., Snelson, J.T. and Sticka, R. (1980). Fenitrothion plus (1R)-phenothrin, and pirimiphos-methyl plus carbaryl, as grain protectant combinations for wheat. *Pestic. Sci.* **11:** 471-482.

Dunstan, W.R. and Magazini, I. (1981). Outbreaks and new records. Tanzania. The larger grain borer on stored products. *FAO Plant Prot. Bull.*, **29:** 80-81.

Evans, N.J. (1985). The effectiveness of various insecticides on some resistant beetle pests of stored products from Uganda. *J. stored Prod. Res.* **212:** 105-109.

Golob, P., Changjaroen, P., Ali, M.A. and Cox, J. (1985). Susceptibility of *Prostephanus truncatus* to insecticides. *J. stored Prod. Res.*, **21:** 141-150.

Golob, P. and Hodges, R.J. (1982). Study of an outbreak of *Prostephanus truncatus* (Horn) in Tanzania. Report G. 164. Trop. Prod. Inst., London.

Hodges, R.J., Dunstan, W.R., Magazini, I. and Golob, P. (1983). An outbreak of *Prostephanus truncatus* (Horn) (Coleoptera, Bostrichidae) in East Africa. *Prot. Ecol.*, 5: 183- 194.

Hodges, R.J., Cork, A. and Hall, D.R. (1984). Aggregation pheromones for monitoring the greater grain borer, *Prostephanus truncatus*. *British Crop Protection Conference — Pests and Diseases*, Brighton, November 1984, pp. 255-260.

Hodges, R.J., Meik, J. and Denton, H. (1985). Infestation of dried cassava (*Manihot esculenta* Crantz) by *Prostephanus truncatus* (Horn) (Coleoptera, Bostrichidae). *J. stored Prod. Res.*, **21:** 73-77.

Howard, D.C. (1984). The population biology of the greater grain borer *Prostephanus truncatus* (Horn). Ph.D. thesis. Univ. of Reading, U.K.

Kega, V.K. and Warui, C.W. (1983). *Prostephanus truncatus* in Coast Province, Kenya. *Trop. stored Prod. Inf.* **46:** 2.

Krall, S. (1984). A new threat to farm-level maize storage in West Africa: *Prostephanus truncatus* (Horn) Coleoptera, Bostrichidae). *Trop. stored Prod. Inf.*, **50:** 26-31.

Shires, S.W. (1977). Ability of *Prostephanus truncatus* (Horn) (Coleoptera, Bostrichidae) to damage and breed on several food commodities. *J. stored Prod. Res.*, **13:** 205-208.

Shires, S.W. (1979). Influence of temperature and humidity on survival, developmental period and adult sex ratio in *Prostephanus truncatus* (Horn) (Coleoptera, Bostrichidae). *J. stored Prod. Res.*, **15:** 5-10.

FAO's Experiences with Crop Loss Assessment

G.G. M. Schulten

Introduction

Justification for the collection of data on pre- and post-harvest losses, as given in the literature, can be summarized as follows:

- to provide essential information to set priorities and assign resources for research, training and extension in plant protection and post-harvest loss reduction;
- to allow for rational decision-making at farmer and at national level on the most effective and economical way to control pests, diseases and weeds and to reduce post-harvest losses;
- to monitor the effectiveness of introduced strategies and methods to reduce pre- and post-harvest losses.

Loss data also play an important role in creating an awareness of the need for pest control and for the improvement of the post-harvest system. Notwithstanding the obvious need to assess pre- and post-harvest losses, statistically reliable data are scarce, in particular for Africa.

From 1967 FAO gave high priority to pre-harvest-loss assessment activities and also from 1977, to post-harvest loss assessment in cereals. Both activities showed a similar development. Initially most emphasis was laid on the collection of statistically reliable data at country or regional level, and, to effect this, methodologies were developed or refined, seminars and workshops were held and manuals for loss assessment were prepared. It came to be realized, however, that considerable funds, transport and manpower are required to obtain quantification of losses with acceptable fiducial limits. It also became more and more understood that in the case of multiple infestations of different biological agents — insects, diseases, weeds or combinations — the pest-intensity loss relationship becomes so complicated that its determination is very questionable and lacks practical relevance. So in both activities the attention was gradually shifted from 1980 onwards from loss assessment for problem identification to loss assessment as a tool in crop or post-harvest loss-reduction programmes.

Loss Data and Justification for Action

Data on losses are often used to justify plant protection activities or to solicit financial support to develop or strengthen such activities. However a plain statement of say 30 per cent pre-harvest loss in a crop can be misleading. It easily leads to the wrong conclusion that, by preventing this loss, a 30 per cent gain in production can be achieved. In practice, this is seldom the case. Mostly the pre-harvest losses are caused by a number of biological agents each contributing a certain percentage to the total loss figure. Losses caused by particular pests, diseases or weeds may be too low to be reduced economically but when these losses are totalled a considerable pre-harvest loss may be found. The same applies to post-harvest losses. The losses in the individual components of the post-harvest system from in-field drying, through harvesting, threshing, shelling, drying and storage to processing may be relatively small and uneconomic to reduce, but when combined they result in a total post-harvest loss of 10-20%.

Loss data are often required to justify fund allocation for plant protection. However, the actual losses are not the only criteria. Potential losses due to the introduction of new pests, diseases and weeds should also be anticipated, and such prevention requires considerable funds for setting up and maintaining plant quarantine services. The control of migratory pests is justified because the potential loss they can inflict is well known.

Pests, diseases and weeds may also prevent the growing of certain crops, thus reducing crop production potential. For example, farmers in certain parts of Mauritania stopped growing millet in 1985 because of heavy damage by meloid beetles.

If farmers cannot store certain crop varieties because of high insect damage, they will prefer varieties which are less susceptible. These varieties may however yield less. Lack of harvesting or threshing equipment may prevent farmers from planting a large average or from growing improved varieties. So improvements in the post-harvest system are not only justified because of actual loss reduction, but also because postharvest improvements can enable the farmer to produce more. In addition there are other justifications for post-harvest projects not leading directly to an increase in food, for example the need for mechanized threshing or shelling to remove labour constraints; the introduction of small mills to reduce the workload for women; the development of adequate drying and storage systems to prevent aflatoxin contamination; the construction of small warehouses and training of personnel to improve marketing, etc.

In the literature many data on losses are found. The reliability of these data should never be taken for granted; especially if quoted only, without giving information on how the data were collected and interpreted. Two examples may serve:

- The author of this article once wrote a paper — Storage Losses of Maize in Malawi (Schulten, 1975). It was observed that there were large differences between maize varieties in susceptibility to storage pests. Hybrids were found the most susceptible and in the case of the hybrid SR 52 a storage loss of 10 per cent was determined, but this hybrid was grown on a limited scale. Improved varieties were less susceptible and the storage loss was calculated at 5%. Most maize cultivated was, however, traditional varieties with very low storage losses. Based on this, the total storage loss was estimated at 1-3% of the total crop produced. The storage loss, however, which was quoted in NAS 1978, referring to the above-mentioned paper, was 8%.

- In 1972/1973 in Malawi, 4 experiments were conducted in small plots to determine the economic importance of the rice stem borer *Diopsis macropthalma* Dalman (*Diopsis longicornis* Macquart) (Feijen, 1978). In one plot a loss of 23 per cent in yield was found. From the collected data, however, it was concluded that under normal conditions the influence of *Diopsis* attack is positive or neutral because early attack often promotes early tillering and so damage is compensated and yields may even increase. *Diopsis* infestation only becomes negative if poor growing conditions are combined with a late (and heavy) attack. Walker, 1987 lists data on losses due to various pests and, referring to Feijen's paper, gives a 23 per cent loss for *Diopsis*. This was actually in one case a correct statement but taken out of context it may easily lead to the conclusion that any type of control is justified because of the high loss.

Pre-Harvest Loss Assessment

In October 1967 the Director-General of FAO convened a "Symposium on Crop Losses" to emphasize the need for the development and use of experimental methods to estimate crop losses quantitatively (FAO, 1967). The objective of these investigations is to determine the relationship between a given degree of observed intensity of a pest in the field and the yield of the crop likely to result. This is achieved by relating known levels of pest intensity or damage with actual yields associated with these levels, i.e. intensity (or damage) — loss relationships. The combination of these relationships with survey data on pest intensity or extent of damage leads to loss data at country or regional level. Data have to be collected over several years to obtain a picture on the magnitude of the losses since pest incidence varies from year to year. Details on methodologies to be followed in loss assessment can be found in FAO, 1967; Chiarappa 1979, 1981; Walker, 1983; Teng, 1987. On the recommendation of the 1967 Workshop, the "Manual on Crop Loss Assessment Methods", with 2 supplements, was prepared (Chiarappa, 1979, 1981). Besides background papers on loss assessment in general, 136 methods are summarized to determine losses caused by particular arthropod and vertebrate pests, diseases, weeds and nematodes. However, only a part of the methods refer to pests in tropical and subtropical crops.

Experiments and surveys for loss assessment can be very expensive. There is an understandable and justified reluctance, in particular in developing countries, to spend scarce resources otherwise than directly for problem solving. Therefore to identify problems on a regional or country-wide basis FAO prefers to make use of indirect data (Van der Graaff, 1981). These consist in particular of:

- the expert opinions of knowledgeable persons and of their experiences obtained in crop improvement projects, farming systems research, etc.;
- distribution and intensity surveys of pests, diseases and weeds;
- data on losses which were found in pesticide trials, on-farm demonstrations, etc.

Where possible the collected information should be verified by loss assessment studies in small plots in farmers' fields. Once information is gained on the magnitude of losses caused by a particular pest, disease or weed, priorities for loss reduction can be set and activities undertaken.

The described approach is logical for the development and introduction of pest control measures. However, it should not be overlooked that farmers are already conducting pest control, in particular by applying pesticides. The economic justification for these applications is often based on loss data which were once collected in the past and have acquired the status of overall validity because of lack of information on what is really happening at farm level.

Litsinger (1984) analysed trials in farmers' fields over a period of eight years in the Philippines. Significant yield differences between parcels receiving the maximum level of insect control (9-11 applications per 10-12 week season) and unsprayed parcels were found in only 50 per cent of cases. Similar data was given by Sumangil (1984) and Kenmore (1987).

Pesticides are used in Africa at farm level on an increasing scale in food crops such as maize and rice and in cash crops like coffee, cocoa and cotton. Very little work is being undertaken to assess the economic benefits of different control options when conducted at farm level. For example a study to assess the effectiveness of insecticide use at farm level against stalkborers dates back as far as thirty years ago (Swaine, 1957). Therefore the first priority for loss assessment in Africa appears to be a verification of the cost effectiveness of pesticide treatments at farmer level. Farming systems research is the approach way to collect the relevant data and full use should be made of the experiences of loss assessment activities conducted, and methods developed, in the past. The question may be raised as to whether suitable methodologies exist. The answer is yes and no. Considering the ever-increasing number of publications on loss assessment, the answer should be yes. However, most of the developed methods can only be used by researchers and offer extensionists and farmers little assistance in taking decisions as to whether to treat the crop or not. In this context the experiences obtained by the FAO Inter-Country Programme for Integrated Pest Control in Rice in South and South East Asia are very appropriate (Kenmore, 1987). The Programme stresses the need for better crop loss assessment methods for the farmer to use. An empirical approach is recommended accurate pest intensity: loss relationships applicable to different environments are still undetermined, if not impossible. The collection and development of suitable methods for use at farm level is seen as the challenge for crop loss assessment.

Post-Harvest Loss Assessment

Interest in post-harvest started three or four decades ago. Initially the main emphasis was put on the prevention of losses in export crops. From the mid-eighties onwards it was, however, more and more realized that considerable losses also could take place at small-farm levels.

Around 1970 new developments took place. It became generally acknowledged that there were no reliable data on losses, there was no standard loss assessment method and the concept of the "post-harvest system" became widely accepted. Before starting a loss prevention programme it was considered necessary to assess the losses taking place in all components of the system, from maturity of the grain, at harvesting, drying, threshing, winnowing, transport, storage and primary processing. A first manual for loss assessment methodology was prepared (Harris and Lindblad, 1974).

The Harris and Lindblad Manual has been tried out in many projects and improved methods have been developed. A better insight has been obtained into the possibilities and limitations of loss assessment and on the costs involved. FAO evaluated the results of loss assessment studies conducted in its projects and organized a workshop to discuss the experiences obtained (Schulten, 1982; FAO, 1983).

Three types of loss assessment surveys could be identified:

- general or preliminary survey of specific problem points and on-site appraisals. This type of survey is normally conducted during problem formulation and leads to a first understanding of the post production system and identification of the causes of loss.
- Non-randomized survey in which a complete scientific sampling design is not followed. The expected result of such a survey is an estimate with a certain reliability of the losses taking place in the post production component studied. Most surveys executed should be classified as non-randomized because, for differing reasons, complete randomization could not be reached.
- Randomized survey aiming at obtaining quantitative data on losses with stated fiducial limits. Only very few surveys can be qualified as such.

In addition, losses are assessed in comparative trials such as testing of equipment for post-harvest operations (harvesting in relation to maturity, threshing, storage methods, etc.).

In the mid-seventies much emphasis was put on the need to collect statistically reliable data on losses for national planning (allocation of resources), the justification of projects and for project evaluation. Experience thus acquired indicates that a statistically reliable loss assessment in the various components of the post-harvest system of cereal grains is possible, but it is costly and time consuming.

Guidelines for the conducting of such randomized surveys can be found in Harris and Lindblad (1978), Boxall (1986) and, in particular for the rice post-harvest system, in FAO, (1987). It is essential that the primary (villages) secondary (farms) and tertiary (fields, stores) sampling units are correctly identified. The sampling frames, which are used for agricultural surveys in most cases can also serve for loss assessment surveys. Area, cluster and line sampling techniques can also be effectively used. To obtain truly randomized samples of unshelled (unthreshed) produce from farmer's stores poses a particular problem. The only solution appears to be the complete emptying of the store and to select the sampling unit (for example a maize cob) with a table of random numbers. It will be obvious that in most situations this cannot be done. To determine weight losses in the final sample which are caused by insects, in particular those which develop inside grains, three methods are proposed by the Harris and Lindblad Manual viz:

(a) Standard volume/weight method (bulk density method)
(b) Count and weigh method
(c) The converted percentage-damage method

Later on a new method was developed, the thousand grain mass method (Proctor and Rowley, 1983). All four methods have their advantages and disadvantages. None is completely satisfactory.

The disadvantage of the bulk density method lies in the necessity for a base line weight (i.e. knowledge of the bulk density value at the time the grain entered the store) at the beginning of the assessment for each unit (store) to be sampled. Positive loss values may be found when losses are low due to the normal variation in weights between replicates. The bulk density method becomes inadequate especially for small grains or grains in which the bulk is variable.

The thousand grain mass is to a large extent independent of internal infestation and in that respect overcomes one of the disadvantages of the count and weigh method. Difficulties arise if the proportion of broken grains changes significantly between successive samplings.

The converted percentage damage method only gives an estimate, based on the percentage of damaged grains, of the loss. The Count and Weigh method at present seems the easiest to conduct since no moisture control readings are necessary. By dissecting a representative sample of grains, hidden infestation can be taken into consideration as well (cf. De Lima, 1979).

The accuracy of various methods used to determine weight losses caused by insects is discussed by Reed (1986).

Depending on the grain variety and method used, the 95 per cent confidence limits of a mean loss are in the order of one or a few per cent but can increase considerably if the sample is not homogeneous. To this error, which is caused by the within-sample variation, should be added the original sampling error. As mentioned earlier a real randomized sampling of grain is extremely difficult and so the inherent error in storage loss data is often considerable.

Many data on post-harvest losses are given in NAS, 1978. The validity of much of the data is, however, questionable because loss assessment methodologies were not well developed when most of the data were collected.

Losses determined with the recommended methodologies described above are reported by Tyler and Boxall, 1984 and can be found in various unpublished FAO reports. The data show that losses are very location and crop specific and therefore only some general trends will be given.

Storage losses at farm level, are expressed as weight loss of the initial quantity stored, are in the order of 1.5% for insect losses, 0.5-2.5% for mould and 0.5-1% for rodent losses, all data being for storage periods up to 9 months.

Often farmers consider these losses too low to take effective action. Loss reduction is tried by admixing an insecticide with the often unshelled or unthreshed produce and under these conditions is only of limited effectiveness.

Only in the case of infestation by the Larger Grain Borer, *Prostephanus truncatus* (Horn), which causes losses 3-5 times higher than those caused by indigenous pests, are farmers prepared to shell their maize and treat it effectively with a suitable insecticide.

While storage losses at farm level are often relatively low, much higher losses may occur when the mature crop is left too long in the field due to, for example, labour constraints. Serious loss may take place in rice during harvesting due to shattering of grains. Threshing/shelling and processing losses can be unnecessarily high because of the use of unsuitable or obsolete equipment.

At the beginning of the Prevention of Food Losses Programme, loss assessment in all components of the post-harvest system was considered necessary and methodologies were developed.

When more information became available on the causes of post harvest losses and on where in the post-harvest system losses were likely to be found which could effectively be reduced, loss assessment surveys were limited to a general survey of some specific components of the post-harvest system to obtain an impression of the magnitude of the losses and to identify possibilities of actually reducing the losses economically and in a way which is attractive to the farmer.

The developed loss assessment methodologies are now largely used to assess the effectiveness of improvements in the post- harvest system.

For a rapid assessment of losses caused by insects, the count and weigh and percentage-damage methods appear to be the most appropriate.

Quality loss assessment and improvement has remained largely limited to the rice post-harvest system. Grain quality standards used in the countries concerned are a practical tool to assess these losses and to monitor activities to reduce them.

Concluding Remarks

The efforts to assess pre- and post-harvest losses have resulted in methodologies which should be used to assess the magnitude of the losses and to monitor progress in loss reduction. Large-scale loss assessment studies at country or regional level are considered not cost-effective and of limited reliability, because of many interacting factors. With regard to pre-harvest losses there is a need to develop practical and simple loss assessment methods for use by extensionists and farmers.

References

Boxall, R.A. (1986). A critical review of the methodology for assessing farm level grain losses after harvest. Tropical Development and Research Institute. Report G/9 pp. 139.

Chiarappa L. (1970, 1981). FAO manual of crop loss assessment methods + supplements. FAO + CAB, Farnham Royal, Slough, U.K. Looseleaf.

De Lima C.P.F. (1979). The assessment of losses due to insects and rodents in maize stored for subsistence in Kenya. *Trop. stored Prod. Inf.* **38:** 16-21.

FAO, (1967). Papers presented at the FAO Symposium on Crop Losses. Rome, 2-6 October 1967. 330 pp.

FAO (1983). Prevention of Food Losses Programme. Experiences with loss assessment in Post harvest loss reduction programmes. 21 pp.

FAO (1987). Prevention of Food Losses Programme. Draft Manual for loss assessment in rice post-harvest systems (prepared by R.W.V. Anthony and J.R. Arboleda) 49 pp.

Feijen, H.R. (1978). Economic importance of rice stem borer, *Diopsis macrophthalma* in Malawi. *Exp. Agric.* **15:** 177-186.

Harris, K. and C.S. Lindblad (1978). Post-harves grain loss assessment methods. *Cereal Chem.*, 193 pp. St. Paul, Minnesota, USA.

Kenmore, P.E. (1987). Crop loss assessment in a practical integrated pest control programme for tropical Asian rice. In: Teng. P. (Editor 1987). Crop loss assessment and pest management. p. 225-241. APS. St. Paul Minnesota, USA.

Litsinger, J.A. (1984). Assessment of need-based insecticide application for rice. Paper presented at MA-IRRI Technology Transfer Workshop, March 15, 13 pp.

NAS (1978). Post-harvest food losses in developing countries. 206 pp. National Academy of Sciences Washington D.C. USA.

Proctor, D.L. and Rowley, J.G. (1983). The thousand grain mass (TGM): a basis for better assessment of weight losses in stored grain. *Trop. Stored Prod. Inf.* **45:** 19-23.

Reed, C. (1986). Characteristics and limitations of methods to estimate losses in stored grain. Postharvest Grain Systems R & D. Special Report No.16. 23 pp. Food and Grain Institute Manhattan, Kansas 66506, USA.

Schulten, G.G.M (1975). Losses in stored maize in Malawi and work undertaken to prevent them. Bull. EPPO **5(2):** 113-120.

Schulten, G.G.M. (1982). Consultancy report on loss assessment. Prevention of Food Losses Programme. 54. pp.

Sumangil, J.P. (1984). IPM for cost reduction in the Masagna-99 rice production programme. Paper presented at the Agritech 84 Conference, 9 September, Manilla, Philippines. 6 pp.

Swaine, G., (1957). Maize and sorghum stalk borer *Busseola fusca,* in peasant agriculture in Tanganyika. *Bull. Entomol.* Res., **48:** 711-722.

Teng, P. (Editor) (1987). Crop loss assessment and pest management 270 pp. APS Press. St. Paul, Minnesota USA.

Tyler, P.S. and Boxall, R.A. 1984. Postharvest loss reduction programmes. A decade of activities; what consequences. *Trop. Stored Prod. Inf.* 4-13.

Van der Graaff, N. (1981). Increasing reliability of crop loss information: the use of indirect data. In: Crop loss assessment methods (Edited by Chiarappa) supplement **3:** 65-69. FAO and CAB, Farnham Royal, Slough, UK.

Walker, P.T. (1983). Crop losses: The need to quantify the effects of pests, diseases and weeds on agricultural production. Agriculture, Ecosystems and Environment **89:** 119-158.

Walker, P.T. 1987. Losses in yield due to pests in tropical crops and their value in policy decision-making. *Insect Sci. Applic.* (in press).

Storage Losses in Traditional Maize Granaries in Togo

C.U. Pantenius

Introduction

In many tropical and subtropical countries an inadequate food supply for the population is still one of the most urgent problems. Rapid population growth combined with low productivity in the agricultural sector and an inequitable distribution of resources are among the principal factors contributing to this situation.

The strategy most often applied in the past to cover the rising demand for food was essentially based on three approaches:

- reduction of the rate of population growth through family planning and birth control,
- increase in food production through planting of high-yield strains and use of chemical crop treatment products, and
- extension of planting acreage.

It is only recently that increasing attention is being given to improved measures for protection of agricultural products after the harvest.

In developing countries, approximately 90% of cereals produced are intended for human consumption and improved post-harvest protection measures could increase food supply by 30-40%. A bulletin of the National Academy of Sciences estimates post- harvest losses in developing countries at 2-40% for rice, 1-100% for maize, 2-52% for wheat and 1-68% for pulses. The wide range of loss estimations given for each variety indicates how difficult it is to make precise measurements of post-harvest losses. For this reason, many authors criticise the lack of an adequate methodology for obtaining loss data. The problem of finding an appropriate methodology can no doubt be attributed to the tremendous variety of post-harvest situations. It is nearly impossible to establish a simple and generally applicable method of loss assessment. Nonetheless, there is a need for an appropriate methodology for realistically determining the extent of postharvest losses due to microorganisms, insects and rodents, which would permit development of socio-economically appropriate countermeasures for protecting stored products. For this reason, in a twoyear study in Togo from 1983-1985, three methods of post-harvest loss assessment discussed by FAO were tested in subsistence farmers' maize granaries for their precision and applicability. Testing procedures were closely based on recommendations developed by Harris and Lindblad (1978), Proctor and Rowley (1983).

Material and Methods

Topography of southern Togo (Figure 1)

The coast consists of a sandy strip of land of an average width of 5 km, which borders extensive lagoons fed with the water of the Sio, Haho and Mono rivers. On the other side of the lagoons is a raised plain covered with a layer of laterite clay, extending 30-50 km inland. To the north continues a high plateau of lithogenic soil. The Togo mountain range rising to an average of 400 metres above sea level extends from the southwest to the north-east.

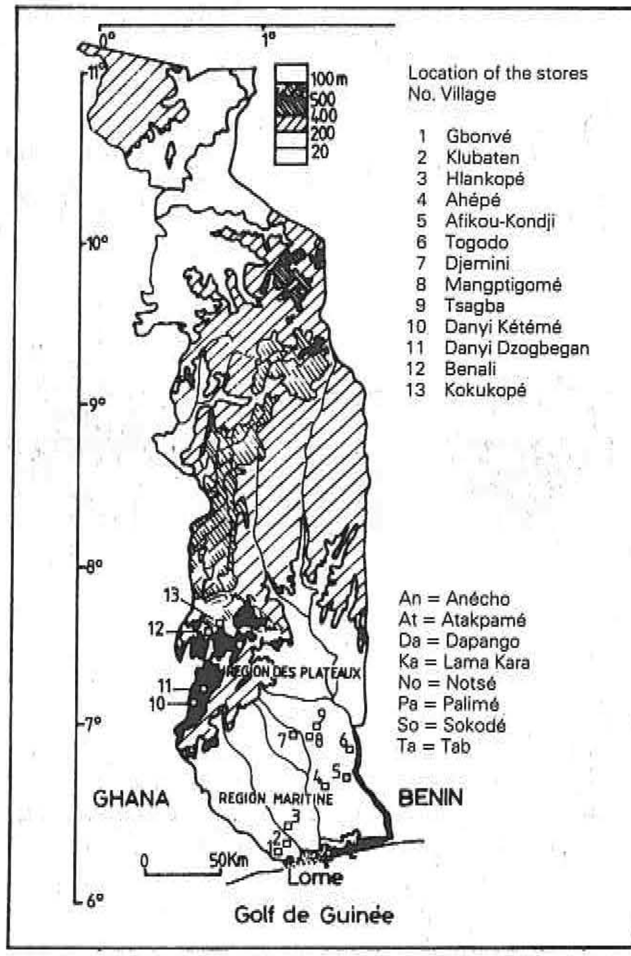


Fig. 1: Map of Togo and sites of sampling

Climate

Most of Togo falls within the climatic zone characteristic of the tropical rain forest. Nonetheless, rainfall is lower here than in neighbouring countries. On the coast and in adjacent regions, two rainy seasons occur per year. The first one lasts from March to July, the second from September to October. In the interior, only one rainy season occurs. Due to the two rainy seasons in the south, two maize harvests per year are possible. Lowest average yearly rainfall is measured on the coast (900 mm/year), and the highest level of rainfall (1,500- 1,700 mm/year) is to be found on the plateaus of Danyi and Akposso in the Togo mountains.

Maize production

Maize can be grown in Togo from the coast to the level of Sokodé and occupies approximately 65% of agricultural acreage. Principal maize-growing areas are in the

Région Maritime around Vogan and Tabligbo. North of Atakpamé, maize production is progressively replaced by sorghum and millet. In maize- producing centres high-yield strains such as NH1 are becoming more and more important. Nonetheless, local varieties continue to predominate. All strains form white kernels with soft mealy endosperm. Local strains have limited yield potential, but due to their higher resistance to drought conditions compared to hybrids, they are considered more reliable. Furthermore, due to a high level of husk impermeability, local strains have good storage qualities. Vegetation period of both strains is ca. 85- 90 days.

Storage conditions

In maize cultivating regions of Togo, three storage methods for the harvest of the first rainy season predominate, of which the "Ebli-va" is the most extensively used (Figure 2).

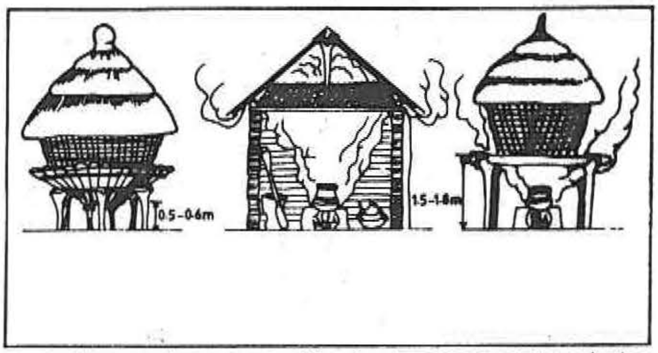


Fig. 2: The most important traditional maize-storage-systems in the southern region of Togo

Ebli-va:

In the Ebli-va granary, the maize ears in their husks are piled on a funnel-shaped wood construction placed on a central pillar 50-60 cm high. The farmers establish an outer ring of maize ears by arranging the largest ears in a circle alternately positioning tip or base towards the exterior. Smaller and medium-sized ears are then poured loosely in to the centre of this circle. By progressively adding such layers of maize one on top of another, a cylinder of an average 2 m in diameter an 1-2 m high is formed.

Kédlin:

In areas with higher rainfall, where the maize cannot dry sufficiently before being harvested, one observes modifications of this type of storage. In these areas, maize is piled up in the same manner on a level platform ca. 1.8 m high, so that it is possible to set up a traditional cooking spot under the platform. The heat generated by the cooking fire, regularly lit only during the first 3-4 weeks of storage, brings about rapid drying of the maize. This type of granary is mostly to be found in the mountainous regions aroud Akposso.

In-house smoked storage:

In the southern mountainous regions, on the Danyi Plateau, which has similar climatic conditions to Akposso, maize is stored within the dwelling in the space between ceiling and roof above a constantly used cooking spot. Due to the closed construction and the heat reception, the stored ears very rapidly reduce their moisture content to 8-10%.

The second harvest, generally smaller, is not always stored in one of the commonly used types of granaries. The maize can be stored in baskets, or even piled in a corner of the dwelling.

Establishment of maize sample

Selection of sample granaries was based on all characteristic goegraphic, and thus also climatic and storage-technical aspects. Further more, traditional maize strains as well as hybrids were taken into consideration.

Traditional maize granaries were considered to be only those in which the ears were stored in their husks and no modern physical or chemical techniques of storage protection were used. In total, 10 granaries were chosen for the investigation of the primary storage season and 3 for the secondary season.

For each granary investigated, 100 ears were removed at four- week intervals beginning on the day it was filled, and brought to the laboratory for analysis. As a sample based on all reachable parts of the granary would have led to over- representation of the large externally placed ears, the 100 ears were taken only from the top according to the following scheme.

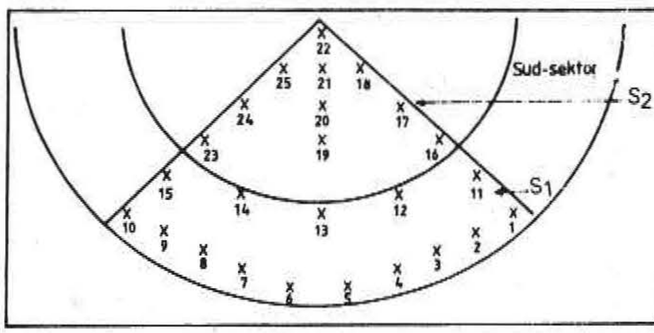


Fig. 3: Sampling points of maize ears in the granary

Analytical methods

For assessment of dry weight losses, the following methods were used: count and weigh method, standard volume/weight method and the 1000-grain-mass method.

The procedure used in the count and weigh method and the standard volume/weight method was based on the approaches described by Harris and Lindblad (1978) in their manual "Post- harvest grain loss assessment methods". The thousand-grain mass method was applied according to the recommendations developed by Proctor and Rowley (1983).

Results

First of all, I would like to present the results according to the count and weigh method. As can be seen from Figures 4 and 5, 80-90% of observed losses are due to insects. We note that the harvest of the second rainy sea-

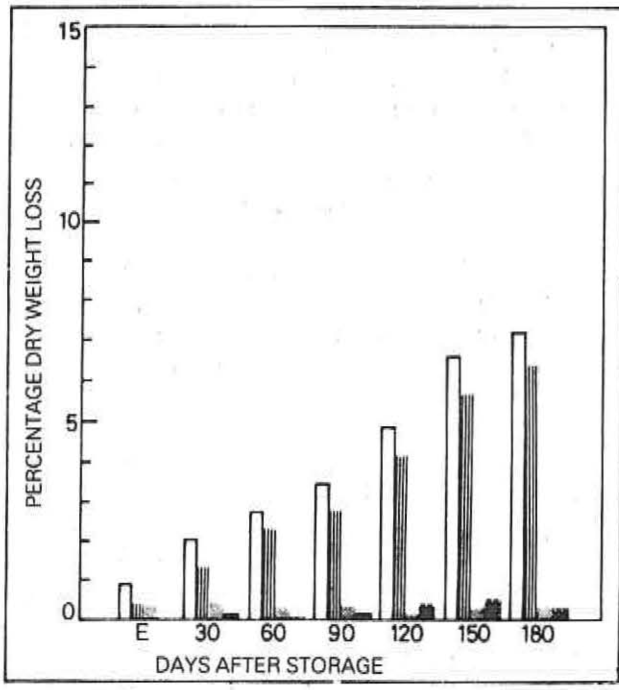


Fig. 4: Evolution of dry weight losses during the first storage season after parasite attack

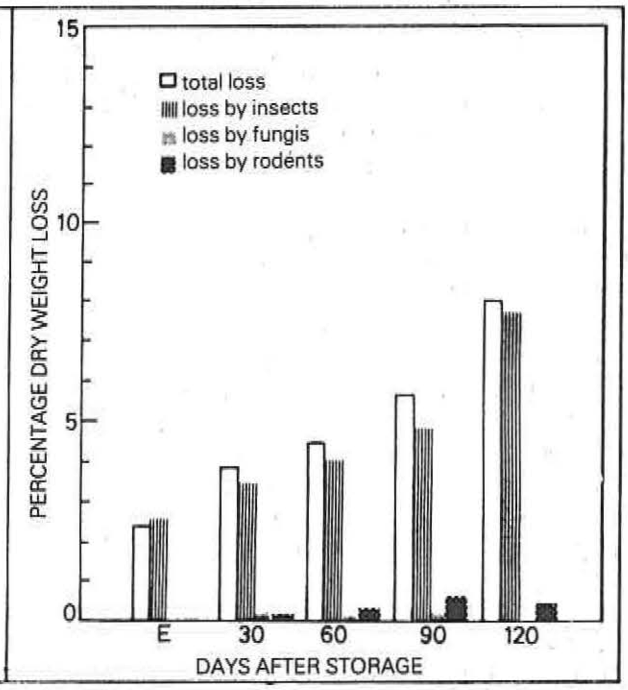


Fig. 5: Evolution of dry weight losses during the first storage season after parasite attack

son, because of high infestation while still in the field, suffered significantly higher weight losses than the harvest of the first rainy season during the first months of storage.

Losses due to insects in the first harvest, at 0.4% versus 2.6% for the second harvest on the day of storage; can be described as very low. However, in some cases, the rate of loss of the primary storage season increased disproportionately, with the result that the differences between the primary and the secondary storage season in later months were no longer apparent. In the course of the 120-day secondary storage season, the losses due to insects mounted to 7.7%. If we subtract the initial 2.6% loss, this elaves 5.1% that can be described as real storage losses. This means that aproportion of 3: .% of observed losses had already occurred before storage. During the 180-day primary storage season, the relative weight losses rose to 6.4%. By far the highest proportion (93.8%) of these losses occurred with 6.0% during the period of storage.

An increase of microorganisms during the storage seasons could not be significantly demonstrated. All observed losses due to microorganisms could be explained by field infestation. It may seem apparent that microorganisms are less important as a source of loss; however, they must be taken into consideration as a source of damage.

In view of the nutritional consequences of fungal attack, other criteria need to be applied especially in consideration of the fact that maize infested by microorganisms such as *Aspergillus* spp. is, strictly speaking, no longer fit for consumption and must be considered as total loss.

Losses due to rodents rarely rose above an average of 1%. But in view of the heterogeneous nature of the data, this general observation does not reflect individual cases where rodents caused a great deal of damage.

Since the importance of microorganisms and rodents as loss factors was significantly less than that of insects, the following discussion will treat only loss due to insects.

As can be seen from Fig.6, hybrid strains are less well

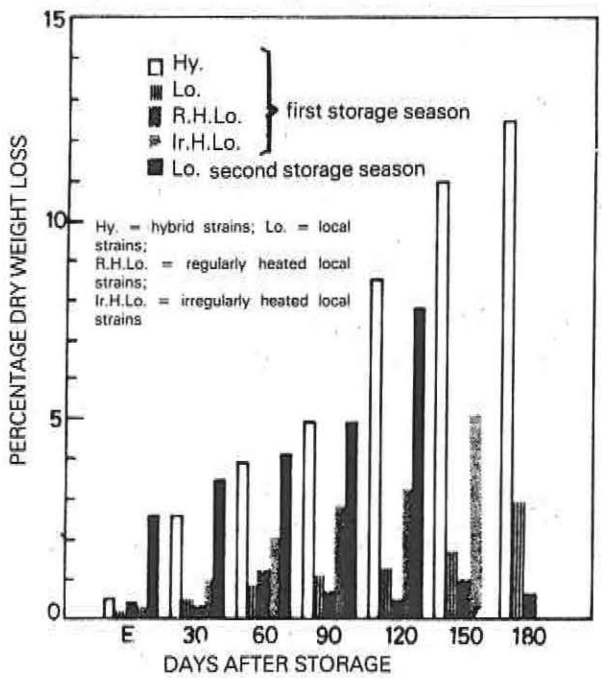


Fig. 6. Evolution of dry weight losses during the first and second storage season in view of different strains and treatments.

adapted to traditional methods of storage. The better adaptation of local varieties compared to hybrids could be proved on a level of p < ter 180 days of storage, the losses in hybrid granaries amounted to 12.5%. Local varieties stored under comparable conditions, at the end of the same period of observation suffered only 2.9% losses.

In the regularly smoked granaries, with 0.2% losses during the storage season, no substantial loss increase could be observed. Loss data during storage barely rose above 1% on the average and could on the whole be attributed to infestation before storage. The positive protective effect of regular smoking was proved against all other variants with a significance level of p = 0.01%.

With only occasional smoking, no protective effect could be detected. Even in the case of hybrid strains, no preventive effect was noticed. In "Kedelin" granaries, 150 days after storage, a dry-weight loss of 5.1% was observed, 4.8% having occurred during storage.

Comparison of measurement methods

Comparison of data resulting from the different methods - count and weigh method, standard volume/weight method and 1000-grain mass method - showed that measurements according to the count and weigh method lay between those of the standard volume/weight method (with relatively lower results) and the 1000- grain mass method, with by far the highest loss data (Fig.7). No significant differences between the results of the count and weigh method and the standard volume/weight method could be discovered.

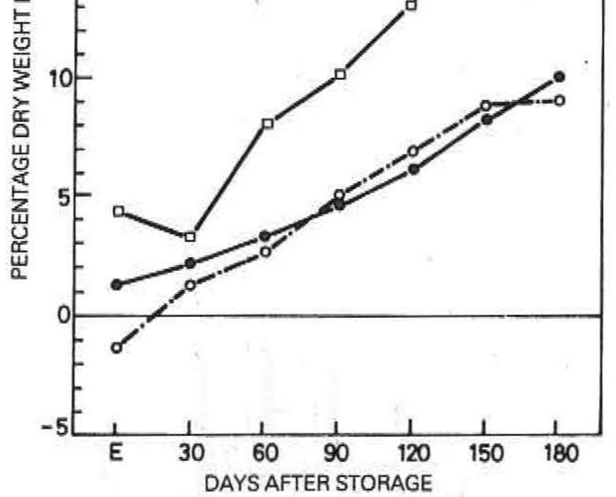


Fig. 7: Evolution of dry weight loss according to the applied loss assessment methods

From the thirtieth day atter storage onward, both of these methods produced practically identical results for losses due to insects and microorganisms. On the other hand, the results of the 1000-grain mass method showed a fundamental difference compared to those of the other procedures. This method caused a significant overestimation of losses. In addition to the hard- to-identify margin of error in the quantification of broken kernels, the heterogeneous nature of the sample no doubt also contributed to imprecise results.

Loss Development after *P. truncatus* Infestation

In the spring of 1984, *P.t.* was discovered in Togo for the first time. This was the second detection of this beetle in Africa (the first being in Tanzania in 1982). *P.t.'s* attack on Togolese maize granaries posed new and special problems, not only on a practical level, but on a methodological level as well. Due to the characteristic pattern of damage caused by this beetle, alternative methods for determining dry-weight losses had to be applied. The basis of loss assessment in the count and weight method, the standard volume/weight method and the 1000-grain mass method was the individual kernel, whose damage after parasite infestation could be quantified by comparison to undamaged kernels. This type of analysis was no longer possible in the case of infestation by *P.t.* This beetle feeds not only on the kernels but also on the cob and produces such large quantities of frass that with increasing infestation individual kernels are no longer even rudimentarily identifiable and thus cannot be analysed. Often, damage to the cob itself is so extensive that it becomes impossible to identify the number of kernels missing on the cob. Assessment of these losses according to the count and weigh method or the standard volume/weight method using remaining identifiable kernels or places where kernels are missing, would lead to severe under-representation of actual losses.

On the basis of suggestions presented by Hayward (1983) for loss assessment in millet after Trogoderma infestation, we developed the sample weight method.

For determining losses after *P.t.* infestation, a standard sample of the kernels from 100 healthy ears was plotted against a working sample of 100 ears selected at regular intervals. For establishment of the baseline sample, 200-300 ears were taken from each of the test-granaries where *P.t.* infestation had been detected. Damaged ears were rejected. Of the undamaged ears, 100 were retained, individually sealed in plastic bags and kept under observation for four weeks to detect hidden infestation. Ears in which infestation developed during the four-week observation period were rejected and replaced. For assessment of the baseline dry weight of the 100-ear kernel sample, the ears were shelled and the weight of the kernels of each ear was determined with a precision of 0.1 g. These individual weights were noted and the overall fresh weight was calculated. After three measurements of moisture content in the baseline sample, the dry weight could be determined.

The ears of the working sample, as in the preparation of the baseline sample, were husked and shelled; frass, dust and insects were removed by sieving and the overall weight of kernels of the 100-ear sample was determined.

For calculation of the dry weight, the moisture content was measured and for calculation of the dry weight loss, the working sample was plotted against the baseline (Fig. 8).

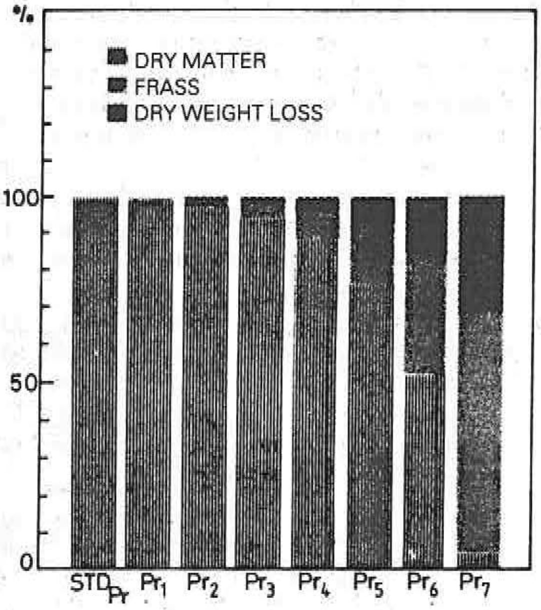


Fig. 8: Relation between a 100-cob-standard-sample and the working samples Pr_1 to Pr_n during storage

This research on loss assessment in granaries infested by *P.t.* was carried out during the 1984-85 storage season. Definitely identifiable infestation by this pest could be discovered only after 8 weeks of storage. Fig. 9 shows that the curve of losses due to *P.t.* infestation develops on a very high level. After six months of storage, mean losses of 30.2% were observed. They were thus four

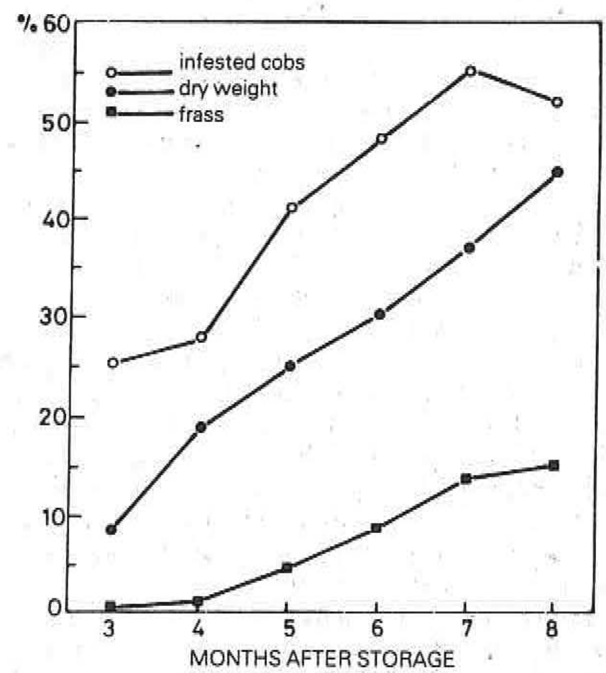


Fig. 9: Development of dry weight loss, frass and cob infestation with *Prostephanus truncatus* during storage

times greater than the total losses of 7.1% caused by parasites heretofore existing in the local ecosystem. After 8 months' storage, losses due to *P.t.* rose to 44.8%.

By this time, 52% of all ears showed symptoms of insect infestation. These ears were so heavily damaged that the remaining kernel matter was no longer fit for human consumption. Thus real losses should be considered 10% higher. A symptom is the high proportion of frass after *P.t.* infestation. An average of 26,8% of observed kernel matter loss was due to the frass component.

Pest status (other than *P.t.*) in traditional maize granaries (Figs. 10 and 11)

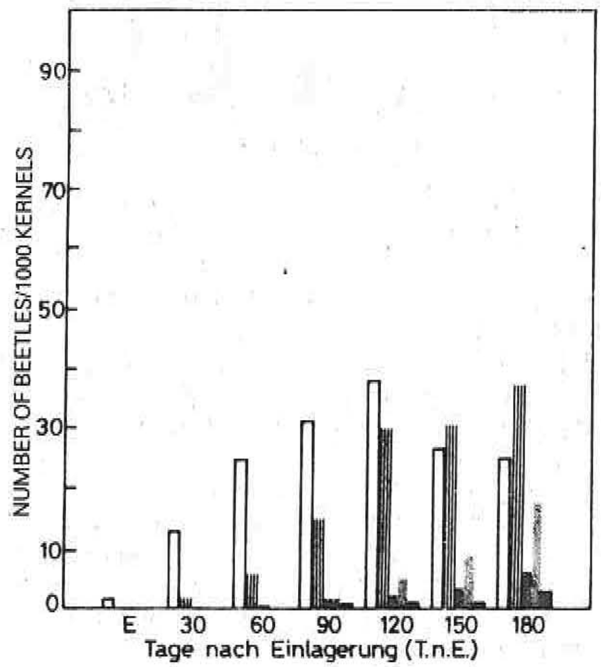


Fig. 10: Dynamism of pest population increase during the first storage season

As noted above, insect pests were seen to be the most important factor in maize losses. Particularly destructive were:

- *Cathartus quadricollis, Carpophilus* spp.
- *Sitophilus zeamais*
- *Tribolium castaneum* and *T. confusum*
- *Palorus subdepressus*
- *Echocerus maxillosus* and *Cryptolestes* spp.

C. quadricollis, with 41.9-62.1% of total infestation during both, the primary and secondary, storage seasons was quantitatively the most important species (Figs. 10 and 11). However, in view of its loss potential and its status as a secondary pest, C. quadricollis was considered to be less destructive.

For optimal comparability of the samples, pest densities were measured on the basis of 1000 kernels. During the primary storage season, the infestation density of *C.q.* attained its maximum with ca. 38 individuals per 1000 kernels, 120 days after storage. There-

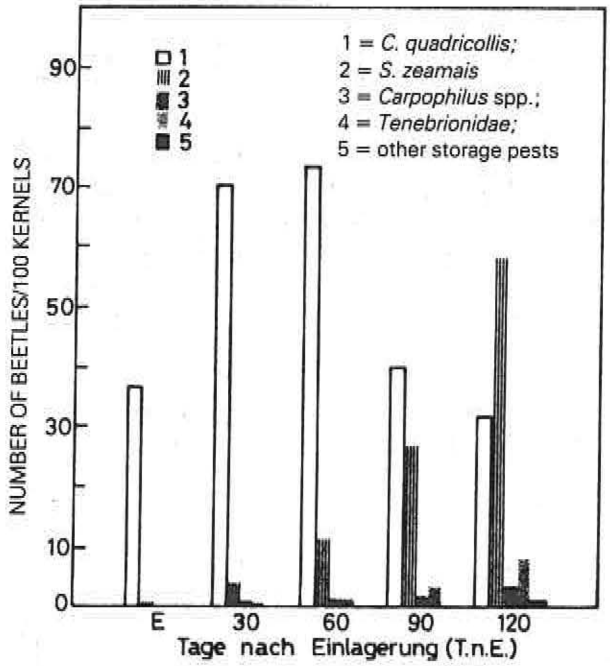


Fig. 11: Dynamism of pest population increase during the second storage season

after, density was reduced to 25 insects/1000 kernels through the end of the observation period.

Before the outbreak of *P.t.* in Togo, the primary pest, S. zeamais, was by far the economically most important storage pest. During the observation period, its population increase proceeded more slowly than did that of *C.q.* But after the 120th day of storage, *S.z.* also became the quantitatively most important species and attained a. mean proportion of 38.5% of total infestation. After this date, only a modest increase of *S.z.* density to 37 insects/1000 kernels was observed through the 180th day.

Infestation intensity of *Carpophilus* spp. remained on a low level throughout the storage season. A maximum density of only 6 insects/1000 kernels was to be found.

Although *Tenebrionidae* appeared only after the second month of storage, large populations were able to develop in certain granaries. *P.s.* in particular, with the exception of the permanently smoked granaries, was regularly to be found in very high numbers.

Significant numbers of *T.castaneum* were only to be found in hybrid strains. *E.m.* had an unusual distribution among the *Tenebrionidae,* typically appearing exclusively in the "Kedelins" of the Akpossi region. On the average, the overall density of the *Tenebrionidae* rose to 18 insects/1000 kernels, 180 days after storage.

Out of all other species which could be identified as storage pests, only *Cryptolestes* spp. had acquired quite an importance by the end of the storage season.

Discussion

On the basis of the above results and of related publications, it can be concluded that during maize storage on the small farm level, lower losses occur than had commonly been thought. According to representative studies, quantitative losses after insect and rodent infestation during a 6 to 9 month storage period are around 5% (Lepigre and Pointel, 1971; Rawnsley, 1969; Reader, 1971; Schulten, 1975; Adams and Harman, 1977; De Lima, 1979; Golob, 1981; De Lima, 1982; De Brere *et al.*, 1982; Boxall and Gillet, 1984).

Our research in Togo, based on the count and weigh method and the standard volume/weight method, comes to essentially identical conclusions. In these studies, average weight loss after insect infestation was assessed after six months at between 0.2% and 11.8%, depending on maize variety and storage, dry weight losses rose to 5.1%. Additional losses due to microorganisms were not observed during storage. Mean losses due to rodents were only on the order of 0.4%.

With the incursion of the *Bostrichidae P.t.* indigenous to Central America, one must reckon with far higher losses. During an observation period of 3-6 months, weight losses of up to 34.6% were reported in Tanzania by Golob and Hodges (1982). Giles and Leon (1974) report losses in Nicaragua of up to 40% after six months' storage. Hoppe (1986) reports on losses in Honduras of over 30% after 6-7 months. Recent investigations by Keil (1987 short communication) in Tanzania showed a result of 17% losses after 4 months' storage.

Our results, based on the newly applied sample weight method — with weight losses due to insects, microorganisms and rodents amounting to 30.2% after a 6-month storage period — agree with the above-mentioned observations.

However, the extent to which the sample weight method is adapted to precise measurement of losses is yet open to further investigation. It is certain that methods which emphasize loss assessment against a baseline imply use of samples that are as homogeneous as possible. This fundamental prerequisite was not always taken into account. For instance, concerning the number of kernels per sample, a standard deviation of 5152 with a mean number of 31,338 kernels per sample could be observed. With such heterogeneous material, a high margin of error must be taken into consideration.

Loss assessment through the standard volume/weight method must be regarded in the same way. Globally, baselines were established for all test granaries with a very high correlation coefficient. Nonetheless, in the case of very low or very high loss development, an over- or under-estimation of data can occur. These imprecisions of the standard volume/weight method can be partially explained by the rising standard deviation dependent on high moisture content (effect of adhesive forces) and on degree of damage. With an increasing proportion of broken kernels in the working sample, one can expect an increase in substance per volume unit which leads to an underestimation of loss data.

Most problematic was the use of the 100-grain mass method, not only because of heterogeneous kernel sizes (mean thousandkernel mass was ca. 313.1 g + SD = 51.7 for healthy kernels), but also due to the difficulty of analyzing the broken kernels in the case of heavy damage. Although three size categories were introduced for evaluation of broken kernels, results according to the 1000 grain mass method led to a high overestimation of losses.

No doubt the count and weigh method, where each ear of the 100ear sample is individually analyzed, is the method requiring the most effort. However, in our opinion, it also provided the most solid and differentiated results, particularly in view of the separate analysis of all sources of damage. No doubt Adams (1976) and Harris and Lindblad (1978) are rightly criticising this method for its incapacity to detect hidden infestation due to, for instance, *S.z.* Equally problematic is quantification of damage to the small kernels at the tip of the cob in relation to the weight of the large undamaged ones, which can lead to negative loss data. Despite these weaknesses, we consider this method — under the above-mentoned conditions — the best adapted for loss assessment, especially with the modification proposed for this method by the TDRI of Slough (Boxall, 1986).

Generally speaking, we come to the conclusion that, due to the enormous variability of local post-harvest conditions, no single method can be applied for every conceivable situation. Each special situation has its particularities which must be taken into consideration in the choice of the methodology to be applied. The researcher has the obligation of precisely documenting each modification, so as to guarantee the comparability of his data with those of other authors.

References

Adams, J. M. (1976). A guide to objective and reliable estimation of food losses in small scale farmer storage. *Trop. Stored Prod. Inf.*, **32:** 5-12.

Adams, J.M. and Harman, G.W. (1977). The evaluation of losses in maize stored on a selection of small farms in Zambia with particular reference to the development of methodology. TPI publication G 109, 148 pp.

Boxall, R.A. and Gillett, R. (1984). Farm level storage losses in Eastern Nepal. *Trop. Stored Prod. Inf.* **50:** 20-25.

Boxall, R.A. (1986). A critical review of thė methodology for assessing farm-level grain losses after the harvest. TDRI-Report No G. 191, viii + 139 pp.

De Bree, M., Raboud, G., Sieber, J., Perdomo, J.A. and Velasquez, J.E. (1982). Proyecto Post-Cosecha. Informe sobre los primeros resultados. Ministerio de Recursos Naturales: Cooperacion Suiza Al Desarrollo, Honduras.

De Lima, C.P.F. (1979). The assessment of losses due to insects and rodents in maize stored for subsistence in Kenya. *Trop. Stored Prod. Inf.*, **38:** 21-26.

De Lima, C.P.F. (1982). Strengthening of the food conservation section (Ministry of Agriculture and Cooperatives). Project SWA/002/PFL Final Report, FAO, Rome.

Giles, P.H. and Leon, D.S. (1974). Infestation problems in farm stored maize in Nicaragua. Proceedings of the 1st International Working Conference on Stored Products Entomology Savannah, Georgia, USA; Oct. 7-11th 1974, 68-76.

Golob, P. (1981). A practical apparaisal of on-farm storage losses and loss assessment methods in Malawi, 1: The Shire Valley agricultural development area. *Trop. Stored Prod. Inf.*, **41:** 5-13.

Golob, P. (1981). A practical appraisal of on-farm storage losses and loss assessment methods in Malawi, 2: The Lilongwe Land development program area. *Trop. Stored Prod. Inf.*, **41:** 5-13.

Golob, P. and Hodges R.I. (1982). A study of an outbreak of *Prostephanus truncatus* (Horn) in Tanzania. TPI-Report No. G **164:** vi + 23 pp.

Hoppe, T. (1986). Storage insects of basic food grains in Honduras. *Trop. Sci.*, **26:** 25-38.

Hyward, A. (1983). La mesure des pertes du mil infeste durant le stockage. Symposium sur la protection des stocks cerealieres en zone sahélienne, Actes du séminaire de Dakar, 1983; 100-106.

Lepigre, A.L. and Pointel, J.G. (1971). Protection of maize stored in traditional Togolese granaries. *Trop. Stored Prod. Inf.*, **21:** 7-12.

National Research Council (1978). Commission on International Relations. Post-harvest food losses in developing countries. National Academy of Sciences, Washington, D.C., viii + 202 pp.

Reader, R.A. (1971): Survey of damage to maize under village conditions. Lilongwe Land Dev. Proj., Malawi, No. **6:** 45 pp.

Rowley, J.Q. (1984). An assessment of losses during handling and storage of millet in Mali. *Trop. Stored Prod. Inf.* **47:** 21-23.

Schulten, G.G.M. (1975). Losses in stored maize in Malawi and work undertaken to prevent them. Bull. Eur. Mediterr. Plant Prot. Organ., **5** (2): 113-120.

Storage Methods in Relation to Post-Harvest Losses in Cereals at Farm and Village Level

Alfred Richter

I would like to extend my exposé to cover also dry pulses and groundnuts which make up, together with cereals, the greater part of grains stored at farm and village level.

To begin with, we should make a distinction between, on the one hand, countries with a rather good road network and more or less workable grain marketing institutions where farm storage has much decreased and in some cases nearly vanished and on the other hand, countries where the isolation of producers and absence of good marketing institutions have helped to conserve the traditional storage methods on the farm and, occasionally, in the villages. As examples of the first type of countries I would indicate Kenya and Zambia and of the second type Chad and a large part of the Sudan.

Furthermore, the storge problems of grain are diametrically opposite in countries really adapted to grain production by their agroecological conditions and countries where other crops provide more easily the bulk of the daily food of the people. As typical of the first group of countries I would indicate Senegal, Mali and Niger and the second group all the countries of the Zaire river basin. Between these extremes one can find a range of combinations as in Cameroon, Rwanda and Burundi, where the basic food supply comes, about half and half, from tubers and plantains as starchy crops and cereals and dry pulses as grains. In countries where grain production is really dominant and which are classified as semi-arid and arid countries, regular food supply, and food security depends not only on the production, but to a very high degree also on the successful storage of the grain.

Agroclimatic conditions in some countries make a satisfactory harvest possible in only every second year or following an even more irregular pattern. In such cases, it is certain that food supply and food security are 50% dependent on good storage.

In humid countries cereals such as rice and maize grow easily but drying and storage cause serious problems and their production is gradually losing importance and tending towards, mainly, the supply of fresh maize cobs for direct consumption.

Whenever traditions have remained undisturbed, farmers in arid and semi-arid countries achieve quite impressive performances in grain storage and we can add that the kind and the varieties of grain have been selected not only for their field performance but also for their storage qualities.

These qualities were outstanding with the more traditional cereals such as various sorghums, millets and some local maize varieties. The best-known examples are white sorghums grown throughout the sahelian-soudanian belt where they are specially put aside for long-term storage in underground pits and other well adapted storage structures to last three, four or even more years without noticeable losses. Whereas with other grain, even the best farmers have failed to avoid storage losses when left without modern inputs. This is particularly true of white and coloured beans which are badly attacked by up to three different species of dried bean beetles, sadly a discouragement to the production of this protein providing crop. Groundnut conservation also becomes a more and more hazardous undertaking when the groundnut beetle invades a groundnut production area. Recently farmers have been encouraged to plant modern high yielding varieties which often have poor storage qualities. If farmers are left with unimproved storage techniques or no early selling possibilities, this venture can turn out to be a sad disappointment and real set-back for them. Traditional methods, still to be found in some sahelian countries enabled farmers to store grain for four years with almost no loss and that without the use of so-called modern storage inputs such as chemical products and modern silos. These methods used granaries of mud, plant materials and sometimes pottery as well as underground pits. Local experience had often developed repellents for insect pests such as ashes, weeds, dusts and smokes.

Factors contributing to good storage quality are:

- Harvesting of grain during a pronounced dry season, which facilitates drying of the harvested grain;
- predominance of hard grain which discourages insect pests;
- unthreshed storage which has a further discouraging effect on insect pests;
- use of traditional proven, repellents such as ashes, weeds and dusts;
- storage structures which allow complementary drying, but prevent rehumidification in the next rainy season, such as good mud, or pottery, granaries and pits. Well made storage structures defend the grain against flood water, rodents and birds.

What are the changes that have come about in the last 25 years to alter this rather safe storage situation at the farmer's level?

- Cycles of severe drought have exhausted the system;
- Falling production per caput and per unit of surface has failed to keep the stores full;
- Farmers have been encouraged to sell so-called surpluses to grain boards and similar institutions;
- Increased monetary requirements have pushed the farmer to sell more than his own family's food security considerations should allow, to grain boards, traders and direct consumers;
- Higher yielding varieties, with poor storage qualities, have been released. The farmer can only consume them fast, sell them fast or lose;

- Last but not least, the knowledge of how to build efficient granaries with local materials is fast disappearing from the village and farmers are left with an ill-adapted uniform system of bag storage without having mastered the technical requirements of this kind of storage.

The deteriorated food situation of most African countries called for projects to restore or install a healthy situation at farmer's and village level. It was felt that the farmers suffered most in that worsened situation. Governmental institutions might be able to acquire their grain but are unable to recirculate it to the villages at reasonable costs when the latter are disaster stricken. Therefore, food security must be brought back to farmers and villages by means of the general improvement of grain handling and storage at their level.

The first generation of projects during the seventies and into the early eighties were poorly prepared and almost all unsuccessful as they focussed too narrowly on the construction of farm-size small silos built of cement or cemented mud bricks or even of steel drums and large bins.

These silos had serious technical imperfections, were too costly and were not durable enough. This was true of projects implemented by FAO, by bilateral technical co-operation agencies and by NGOs. Nowadays these silos can be seen in various places in Africa: historical monuments to failure in a special kind of project.

These projects also did something to foster the widespread use of chemicals against stored pests with varying emphasis from one agency to another.

Since the early eighties, in response to the lessons learnt from early projects, more pragmatic approaches are under way in some countries. They start from in-depth studies of the traditional techniques and aim at improving these, often taking various characteristics one by one. Thus they may start by improving the rodent-proofness of a particular design of granary and then proceed to improving its water-tightness and making it increasingly proof against insect pests and atmospheric humidity. The farmer has to learn, and will learn, that with low-cost improvements he can gradually do much to obtain better storage of his grain.

A second approach to bringing responsibility for food security back to the village is represented by what are called cereal banks or communal granaries and similar systems. This approach has been initiated mostly by NGO's and again the initiative came from outside the rural community itself. Usually representatives of the NGO's came to the villages, saw the lack or inadequacy of storage facilities and proposed the creation of cereal banks. In most cases the NGO's involved provided financial assistance for the construction of the store and an initial supply of grain in a season of food shortage when no farmer could sell or lend excess grain to the new village cereal bank.

It might be thought that there was no harm in this kind of undertaking: in reality there was. In too many cases the personnel of the NGO's involved were not knowledgeable in the problems of grain storage in tropical countries. Often, the stores were just four-walled houses with a tin roof and a door. It was not appreciated that such a building is much less safe for grain than traditional structures such as mud silos and underground pits. There is no protection against rodents, insects or water vapour. Sophisticated cement brick constructions suitable for fumigation were proposed by the main German technical co-operation agency. These meet the technical requirements for good storage, but they are far too expensive and therefore out of the reach of villagers.

In conclusion it must be admitted that this latter approach was also marred by many failures and many lessons had to be learnt out of the mistakes made. For instance, the full involvement of the villagers in the management of such stocks has to be insured and workable solutions have to be found and adopted for periods of food abundance. After periods of drought, when grain production is coming back to normal levels, there will usually be abundance of food in the villages. Even poor unproductive farmers have access to cheap, new grain. There is no demand any more for the one or two year-old grain of the cereal bank. But the grain of the bank has a book value consisting of at least the original purchase price plus an allowance for storage costs and losses. How can financial and physical losses be avoided by the cereal bank in such cases? Only by proper measures being taken either to conserve the stock well or to dispose of it. Failure to take either of these steps has been the main reason for the collapse and close-down of cereal banks in many cases.

Fortunately lessons have been learnt. I have seen cereal banks using well designed, traditional mud silos and adopting arrangements to dispose of, and to replace, the content of the cereal bank even when there is no demand at village level. For instance, one solution is that farmers give surplus grain to the bank on a loan basis. They have to replace the grain in the bank after a reasonable storage time, if there is no demand for the bank's grain at the village level. Were the banks to buy the grain outright, it would be impossible to motivate the farmers to change the stock.

The magnitude of losses in storage at farmer's and village level

Many projects have undertaken studies to assess the post-harvest food losses, since the grain held by far-from these to national losses, since the grain held by farmers is in most countries still the greatest national food stock (in spite of the existence of grain boards and other big central storage units). Numerous manuals, including highly sophisticated assessment methods, (e.g. Harris and Lindblad) have been issued, but they are only of limited value.They represent only "case studies" indicating if a particular farmer, in a certain environment, with a stated grain to store, behaves in a particular manner and uses a defined technology and set of inputs, then his losses can be calculated.

A highly determining factor is added when storage time is taken into account. In practice, in one and the same village, the best farmer will have very little or no losses and others may have losses of 30 to 50%.

Speaking generally on an African scale, losses are smallest (under 5% per year) in sociologically undisturbed areas in arid and semi-arid countries and highest in sociologically disturbed (or modernised) areas in the most humid countries. An unsold bag of maize in Ghana, southern Cameroon, Kenya or Tanzania will usually be destroyed in less than one year, or will have been down-graded as fit only for chicken feed.

Storage time is an essential factor and its variations cause a serious arithmetical problem in comparing figures. In years of food shortage, storage time will be shorter and losses lower. In years of abundance storage time will be longer and losses correspondingly higher. Higher post-harvest losses will also occur in years of abundance due to the consumption pattern tending to favour more wasteful preparation methods. For instance, making clear beer (filtered) out of cereals is a waste of 50% of the initial energy content of these cereals. On the other hand, in times of food shortage more cereals are consumed as porridges, with little or no losses in preparation. Whether, or not, and how grain is dehulled before grinding into flour is another factor affecting the loss rate from zero to 40%, in addition to the losses occurring in the granary. The introduction of small, power-grinding mills has been very beneficial when they are used for millet, sorghum and maize as a previous dehulling is no longer required. Artisanal, or industrial parboiling of paddy may reduce nutrient losses to almost nothing, whilst mechanical polishing equipment may spoil up to 30% of the consummable part of the rice grain.

Food loss magnitude figures due to storage can only be given for particular cases which have been studied. I would like to list some of those cases which have been studied (Losses due to wasteful preparation methods are not included):

- Maize storage in Southern Togo: 8% of losses for every month of storage time (findings of the GTZ project on PHFL);
- White sorghum storage in Burkina Faso: 3% losses per year (findings of FAO project and research of the national grain board);
- Maize storage in the Northern Western province of Cameroon: 10% losses in 6 months without chemicals, 2% when chemicals are correctly used (findings of FAO project);
- Red sorghum storage in Northern Cameroon: 3% losses in 9 months (findings of the provincial grain board);
- Red sorghum storage in Central African Republic: 6% losses in 6 months (findings of USAID PHFL project);
- Red sorghum storage in Rwanda and in Burundi: 2% losses in six months (findings of research by the national agricultural university together with FAO);
- Maize storage in Burundi in the presence of the Greater Grain Borer, unshelled cobs: 30 to 50% losses in 6 months (findings of FAO project);
- Coloured bean storage in Rwanda and Burundi: rejected by consumers after 6 months storage time for reasons of hardening and change of taste due to chemical alteration of the grain (findings of USAID research project in bean storage);
- White bean storage in Central African Republic: 50% of losses after 6 months due to attacks by dried bean beetles (findings of USAID PHFL project).

The list can be completed by other information from more studies but will never allow a comprehensive statement for the PHFL situation in Africa as a whole.

Observed correlation between the magnitude of losses and storage time indicates that losses rise disproportionately as storage time increases. A rather safe storage time of 3 to 6 months usually covers the dry season following the harvest. Entering the next rainy season would dramatically increase losses. In practice loss figures are fortunately much lower than the percentages given because the consumption of grain is almost steady from the harvest on, thus the amount of grain stored is continually decreasing and high losses are only sustained towards the end of the storage period on a small quantity of grain.

ANNEXES

Useful elements for storage technicians

Tables

1: Maximum weight of water steam in 100% saturated air at rising temperatures, an important element to appreciate the danger of possible water condensation in silos and other rather air tight grain containers.
2: Maximum allowed moisture content of different grains for long term storage.
3: Equilibrium of moisture content of grain versus relative air humidity for different cereals at different temperatures.

Table 1. Maximum weight of water vapour in 1 kg of dry air at different temperatures

Air temperature (centigrades)	Maximum weight of water vapour (in g)
0	3.9
10	7.9
20	15.2
30	28.1
40	50.6
50	89.5
60	158.5
70	289.7
80	580.0
90	1559.0

Table 2. Maximum moisture content for long-term storage

Maize	13%	Cow-Peas (*Vigna sinensis*)	15%
Wheat	13%		
Millet	16%	Pea nuts	7%
Sorghum	12.5%	Cocoa	7%
Paddy	14%	Copra	7%
Rice	13%	Palmkernels	5%
Beans (*Phaseolus vulgaris*)	15%	Coffee	13%

Table 3. Grain equilibrium moisture content

Material	Temp.	Relative Humidity (%) 10	20	30	40	50	60	70	80	90	100
Dry beans	4.5						12.8	14.4	17.0		
Haricots	10						13.8	15.3	18..0		
	25	5.6	7.4	8.6	9.8	11.2	12.9	14.9	17.5		
	37.9						12.10	14.12	17.1		
	54.5						12.4	14.3	18.5		
Rice rough	0		8.2	9.9	11.1	12.3	13.3	14.5	16.6	19.2	
Paddy	20		7.5	9.1	10.4	11.1	12.5	13.7	15.2	17.6	
	22.8	4.9	7.3	8.7	9.8	10.9	12.4	13.5	15.9	19.0	
	25	4.6	6.5	7.9	9.4	10.8	12.2	13.4	14.8	16.7	
	30		7.1	8.5	10.0	10.9	11.9	13.1	14.7	17.1	
	43.8						10.3	12.3	14.3	16.5	
Rice milled	25	5.1	7.6	9.0	10.3	11.5	12.6	12.8	15.4	18.1	
	37.9	4.9	7.0	8.4	9.8	11.1	12.3	13.3	14.8	19.1	
Maize	0				11.0	12.5	14.0	15.8	18.0	21.8	
	10	6.6	8.0	9.3	10.8	12.2	13.8	15.2	17.5	21.8	
	21			7.1	8.3	9.8	11.4	13.2			
	25	5.1	7.0	8.3	9.8	11.2	12.9	14.0	15.6	19.6	23.8
	32.2	4.9	6.6	7.7	9.3	10.8	12.4	14.0	16.2	19.3	
	49				8.6	10.0	11.2	13.1	14.9		
Sorghum	15.5		7,5	9.5	10.7	11.8	12.9	14.0	15.5		
	25	4.4	7.3	8.6	9.8	11.0	12.0	13.8	15.8	18.8	21.9
	32.2		7.10	8.7	10.2	11.8	12.2	13.1	14.8		
	49		6.6	8.0	9.4	10.7	11.6	12.7	14.3		
Wheat	15.5		6.1	7.8	9.6	10.7	12.7	13.8	15.3		
	25	5.8	7.6	9.1	10.7	11.6	13.0	14.5	16.8	20.6	
		32.2	5.3	7.0	8.6	10.3	11.5	12.9	14.3		
	49		6.2	7.4		9.6	10.4	11.9	13.6		
	50	4.0	5.8	6.7	8.1	10.0	10.8	12.6	15.1	19.4	

Source: D. Dichter (1978) (modified)

Figures

1: Life conditions for grain deteriorating agents at variable temperatures and degrees of water steam saturation of the air.
2: Life conditions of insects at variable temperatures.
3: Raise of grain temperatures with extreme moisture levels
4: Grain moisture and relative air humidity equilibrium curves for some selected cereals at 25°C.
5: Behaviour of rice grain when exposed to dry air ventilation (example 1) or to air with rather high relative humidity (example 2).

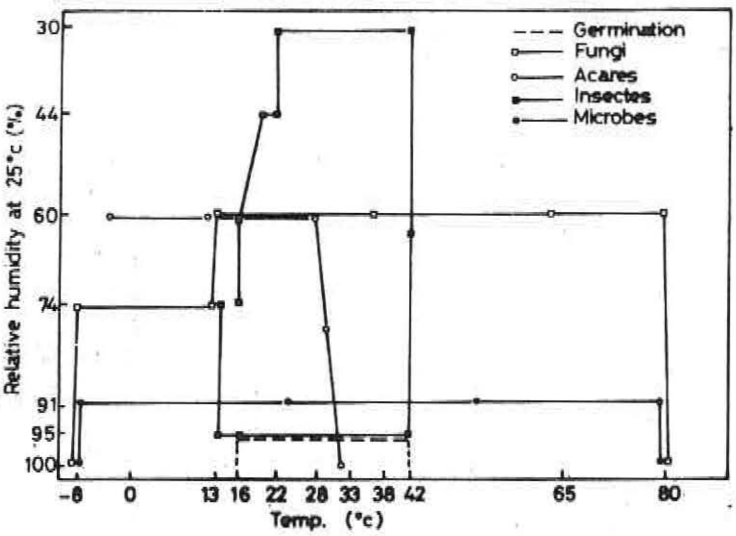


Figure 1. Different conditions of life

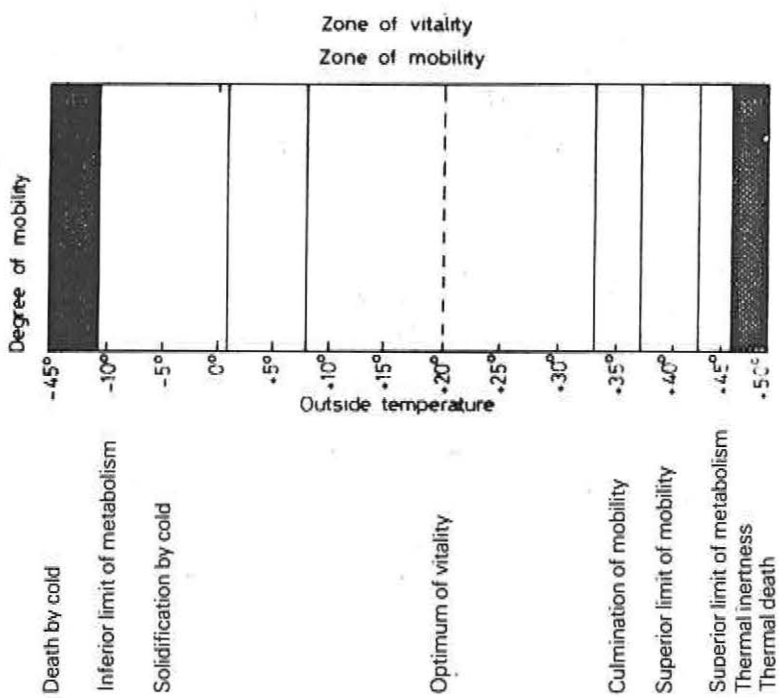


Figure 2. Mobility dependance scheme of an insect vis-a-vis the ambient temperature as well as the limitations of its vitality (after: KEMPER extract of HERMANN, 1963)

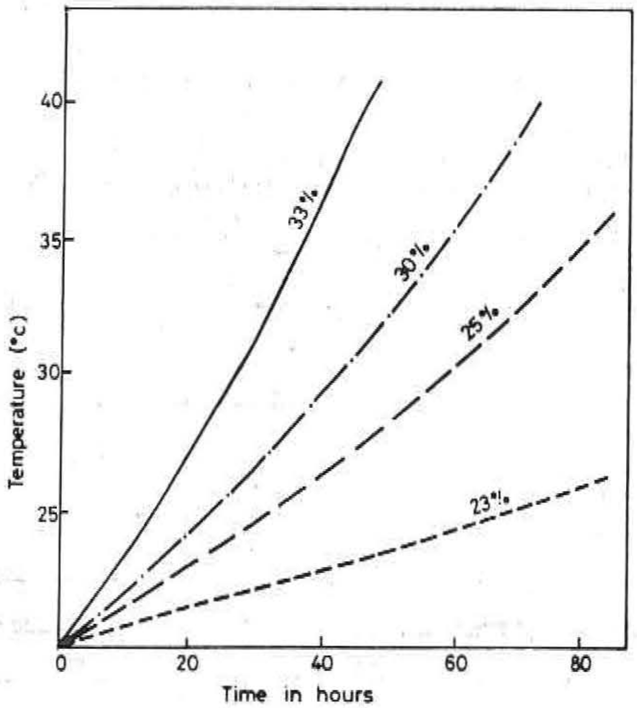
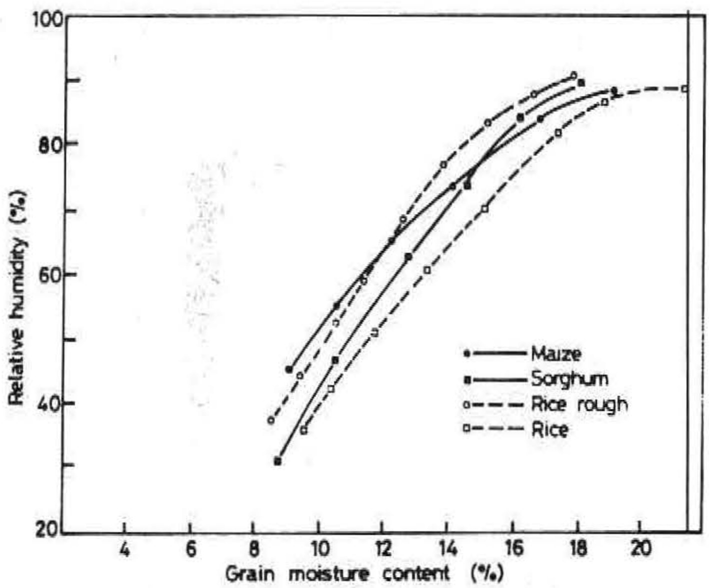


Figure 3. Temperature evolution of bulk grain (maize) according to its humidity



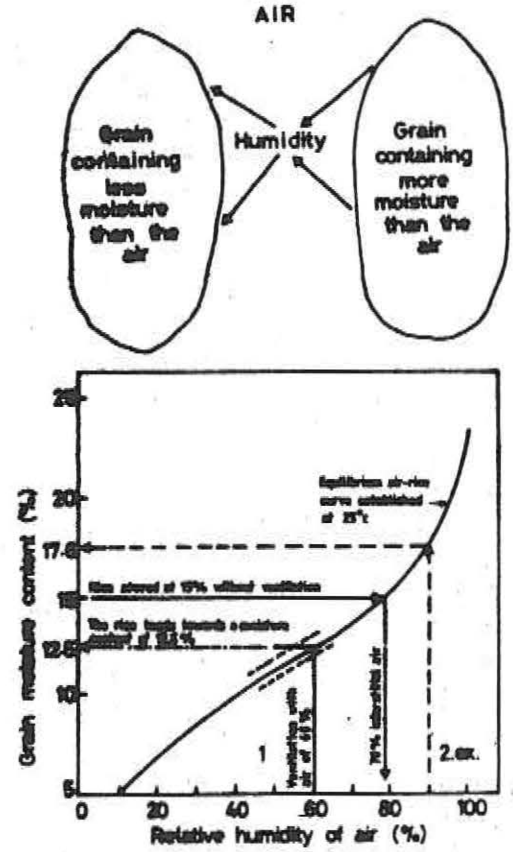


Figure 5. Example of moisture content/relative humidity equillibrium curves

Storage Method in Relation to Post- Harvest Losses in Cereals

J.A. McFarlane

Introduction

In this paper the term "storage method" is used in its broadest sense. The methodology of storage, including particular methods or techniques, derives from and relates to the objectives for storage. These may be stated in general terms as follows: (i) to have commodities available for use when required and in an acceptable condition; (ii) To have the stored commodities located in a place, or places, that are sufficiently convenient for their eventual use or distribution; (iii) To obtain an appreciable economic benefit which may or may not be financial.

With regard to these objectives, decisions upon the particular storage method are not enough. The methodology must also encompass decisions on the scale and location of storage facilities and, where possible, on the intended duration of storage. These factors are here referred to as the pattern and period of storage and particular methods are referred to as techniques of storage.

Storage methodology is thus an aspect of storage management, which is the science of cost-effective storage organisation. The efficiency of storage management will largely determine the magnitude of the losses which occur in storage; efficient management will keep losses within a range that is economically acceptable to the particular purposes of the storage system. The system itself will largely predetermine the extent to which such losses are susceptible to reduction. Whether or not they are reduced in practice will depend upon management decisions regarding the probable cost-effectiveness of technical improvements; taking into account any actual or possible changes in the immediate objectives for storage. Such changes may occur from time-to-time within the system or may in some cases originate outside the system. A move to increase procurement by raising the buying price would exemplify the former case. A governmental requirement to increase storage capacity, or an effective demand for improved quality, would exemplify the latter case.

These general principles of storage methodology apply not only to commercial storage systems but also to storage at the farm level. A relatively uneducated farmer may be unable to express them precisely but, in most instances, he or she would attempt, instinctively, to manage storage along these lines.

In both on-farm storage and off-farm storage a key issue that requires management decisions is the pattern (location and scale) of storage. Storage periods are commonly predetermined, within limits, by the purposes for storage. Storage techniques are commonly chosen on the basis of past experience including, in many cases, traditions which may be more or less obscure: commercial storage traditions being, sometimes, no less obscure than those which influence domestic storage. Thus, a conventional limitation of stack height, in circumstances where an increased height is technically possible, may stem from past experience of practical problems which might now be overcome. On the domestic scene, the common practice of storing maize cobs in cribs over the cooking hearth serves some purpose when the quantity of grain is fairly small. It is certainly beneficial when a bunch of cobs is suspended in the smoke of the fire: both for drying purposes and for the control of insect infestation. Whether or not it gives any significant benefit when quite large quantities of cobs are so stored is a more doubtful question.

Storage techniques, including the form of storage structures and containers, are much influenced also by the local availability of suitable materials, manpower and investment capital. In this respect on-farm storage is commonly more tightly constrained than centralised storage; whether this be in the public or private sector. Centralised storage facilities ("buffer" stores) are commonly located near urban centres, where labour and skills may be more readily available, and are often financed, directly or indirectly, from resources that are more substantial than those available to the average farmer.

Storage Losses

Losses in stored cereals, in developing countries, have been reviewed by Tyler and Boxall (1984). Table 1 presents a summary of data for African countries from that source.

Table 1. Data from comprehensive studies of storage losses. (Extracted from Tyler and Boxall, 1984)

	Crop	Period (months)	Weight Loss (%)	Country
On-farm storage (Normal)	Maize	7	1.7 – 5.6	Zambia
	"	Up to 9	3.3 – 3.8	Kenya
	"	"	< – 6.6	Malawi
	"		4.4	Swaziland
	Sorghum	"	1.2 – 2.2	Malawi
On-farm storage (With "LGB")	Maize	3-7	8.7	Tanzania
Off-farm storage	Millet	8	1.0	Mali

Notes: All estimates include loss due to insects; some also include losses due to rodents and mould. Where these are distinguished they appear relatively small in comparison with the loss to insects.

The estimate for maize in Tanzania applies to the situation in Tabora region as it was immediately prior to the introduction of the current Larger Grain Borer ("LGB") control programme.

The information in Table 1 illustrates two main points. First, that comprehensive studies of storage losses have been relatively few. This applies to other regions as well as Africa. Second, that where they have been made the studies have not always been completely comprehensive in their attention to losses other than weight loss due to insect damage. There are many reasons for this, of which the practical difficulties in carrying out comprehensive studies of this nature are perhaps paramount. The great shortage of details or losses in centralised storage is partly due to the added difficulty of ensuring satisfactory competition of studies, however well- planned, that involve large-scale operations. Nevertheless, there is a fairly general opinion that enough time and energy have been spent on academic loss-assessment studies.

There is now sufficient knowledge to justify a more positive approach. Further work should be directed to those situations in which an objective assessment of losses can be directly followed by an appropriate and cost-effective programme to reduce losses where they are susceptible to reduction. With such an approach (see also Tyler and Boxall, 1984) the first aim should be to assess the losses in relation to the total costs of the modifications and possible innovations required to bring about their reduction. In the past, many programmes to assess losses appear to have been done only to provide a basis for speculative and often over-optimistic demands for nation- wide campaigns to reduce losses by an arbitrary percentage. Until it is demonstrable, to those responsible for grain storage, that loss-reductions are both technically possible and clearly beneficial, in all respects, no campaign is likely to succeed without draconian measures to enforce it. The situation in Tanzania, described elsewhere (P. Golob, at this Workshop) provides a valuable example of the successes which can be achieved where the storekeepers, farmers in this case, are themselves predisposed to changes by their own recognition of the serious nature of a new storage problem.

It does not follow from this that storage improvements are possible only when there is a new and greater pest problem. However, in the absence of a new pest problem some other external change is commonly needed. This might be an increase in the cash value of a commodity, an increased opportunity to market the commodity profitably at its existing price, or an increased demand for better quality in the commodity. In practice, financial incentives for quality improvements are lacking in many marketing systems.

All of these factors should be the concern of agricultural development planners. More attention should perhaps be paid to the importance of fully comprehensive development planning to achieve reduced losses and higher quality in food grains. An increased awareness of the causes and significance of losses, which is often seen as the catalyst for storage improvements, is unlikely to produce results without a concommitant change in some other, more pragmatic, factor.

Storage Techniques

The range and variety of storage techniques currently available and applicable to African conditions are shown in Table 2. Those applicable to on-farm storage are highlighted.

Table 2. Storage techniques available and applicable in Africa

Storage in bulk	Storage in bags or small containers
Cribs: - inside the dwelling < - outside << < with/without "smoking" << with without pesticide	Conventional bags - unstacked or open stacking < << -normal stacking < << < with/without pesticides << covered/uncovered
Underground pits: (incompletely airtight)	Sealed pots, gourds etc.: (incompletely airtight)
Small storage bins: - airtight - with pesticides	Hermetically sealed containers: (completely airtight)
Sealed bunkers: - with fumigants - with other pesticides	Wrapped bags in sealed pits or bunkers:
Conventional bins: -unaerated <	Large tightly-built bagstacks: (thermal "self-disinfestation")
- aerated < < with/without pesticides	Permanently sheeted bagstacks: - with conventional fumigants - with CA
Butyl bins:	
Concrete bins or pits: - normal or semi-airtight < - with fumigation or CA - with/without pesticides	
Welded steel bins: - without CA - with CA	

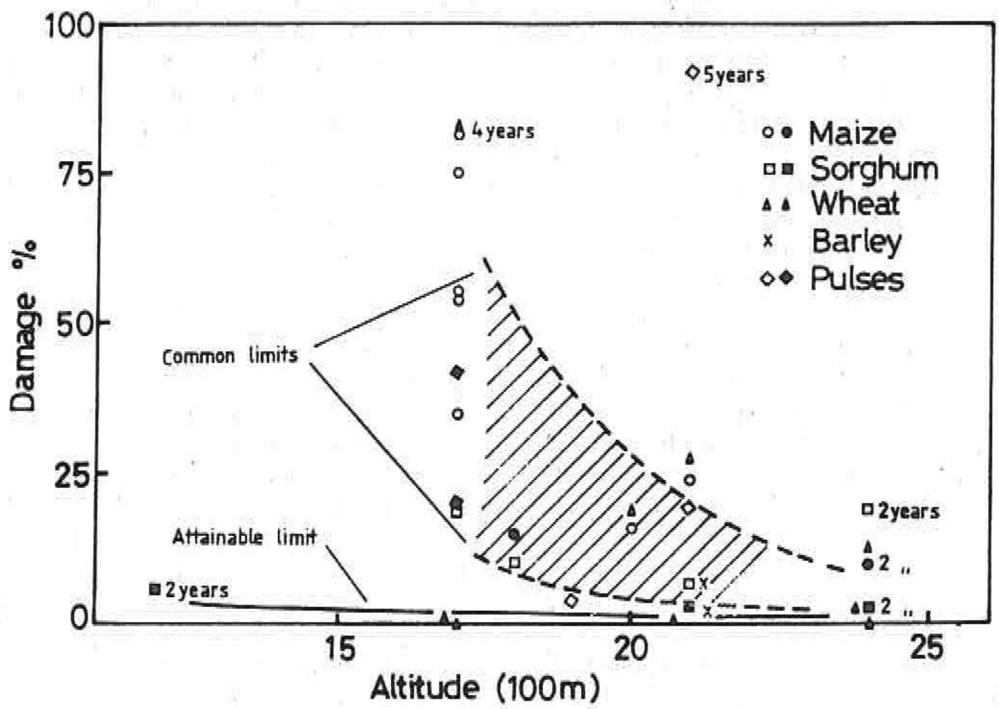
Key
< Techniques commonly applicable to on-farm storage in Africa.
<< Techniques not commonly applicable to on-farm storage in Africa.
Note: The term "pesticides" here refers to all materials that may be used to control pests in stored grains, whereas "fumigants" refers particularly to the proven fumigant gases. The use of modern biocontrol techniques (e.g. behavioural interference; augmented control by predators and parasites) is regarded as potentially applicable, in various situations, as a supplement to other techniques.

The nature and levels of storage losses associated with these various techniques can be indicated on the basis of past experience. In general the available evidence, published and unpublished, suggests that losses to stored cereal grains in centralised storage are in the region of 1-2% per annum, irrespective of the technique used. The corresponding figure for on-farm storage is around 4-5%, for maize, and rather less for other cereal grains especialy the small-grained millets and "teff" (*Eragrostis abbyssinica*). Losses in excess of the indicated range occur sporadically in both on-farm and off- farm storage. These are generally caused either by shortcomings in management or by unexpected, adverse conditions. They provide no basis for overall programmes to change storage techniques. However, they do warrant efforts by extension services to promote management improvements of one kind or another. Management "shortcomings" are not uncommonly due to lack of faith in technical possibilities for increasing the profit margin and "unexpected" circumstances are rarely entirely unpredictable. They can sometimes be off-set by suitable safeguards built into the management system (see for example Kenneford and O'Dowd, 1981, on the management of emergency storage structures).

Extension agents are commonly frustrated in their efforts to arouse general awareness of a postulated need for storage improvements. They should, perhaps, focus their attention more deliberately upon situation-specific problems in which they might assist more in the prediction of eventualities and in the intelligent assessment of options: with particular attention to the costs and benefits which might accrue from technically feasible improvements.

Abnormally high losses do sometimes occur more generally. In the Sudan, sorghum losses in private commercial godowns are a classic example. In Ethiopia, limited observations (McFarlane, 1969) suggested that cumulative losses in crib-stored maize cobs generally approached 15% in those regions where maize was stored on the farm. A possible factor in this was the apparent lack of incentive for the farmers to take care of their crop in the traditional manner. Many of the farmers in this case were "share-cropping" tenants who may have had very little proprietory interest in the grain. The same study, however, also indicated quite clearly the significance of regional climatic differences: especially the differences in ambient mean temperature that are associated with altitude (Figure 1). In general, variations in storage losses at the farm level are more closely related to climate than to the chosen storage technique. However, the choice of technique, and in particular the choice between storage in the house and storage in an outside structure, is itself influenced by climatic conditions in those situations where security against theft is not an over-riding consideration.

There are, however, some clear differences in the nature and extent of storage losses between the various storage techniques listed in Table 2. The storage of shelled maize in woven sacks will lead to accelerated damage by grain weevils (*Sitophilus* spp), grain beetles and warehouse moths. The storage of sound, dry cobs in traditional cribs generally retards damage by these



insects, while permitting rather more damage by the grain moth. Retention of the cob sheath gives added protection against weevils but there may be other reasons why some farmers prefer to remove the sheath before storage. In contrast to the maize losses shown in Table 1, which relate to maize stored on the cob, I have recorded a 20% weight loss for 8 months storage of shelled maize, in jute sacks, in simulated farm-storage conditions in Nairobi (McFarlane, 1975). Shelled maize treated by admixing a suitable synthetic insecticide powder, however, stores very well and in the trial referred to the weight loss was thus restricted to 1-2%. The arrival of the Larger Grain Borer (*Prostephanus truncatus*) in Africa has complicated the matter and has further emphasised the need for insecticide admixture in the storage of shelled maize at the farm level. In centralised storage, gas fumigation is commonly an alternative option and this treatment, supplemented by protection against reinfestation, can avoid the need for insecticide admixture. Other grain protectants, including wood ash and abrasive powders such as diatomite, are also of considerable value in on-farm storage but they are generally much less effective than the synthetic grain protectants (Golob, 1984).

Airtight storage in underground pits is common in several African regions; especially for the storage of sorghum (in Ethiopia, Sudan and Somalia) at the farm level or by grain traders. The nature of the losses associated with this technique are indicated by Gilman and Boxall (1974) who also comment on the mycotoxin hazard, which may sometimes be overlooked. However, this storage technique, when applied to reasonably large bulks of grain, can effectively minimise insect damage over long periods and may restrict other forms of damage, including mould damage, to a relatively small percentage (McFarlane, 1969). Problems of moisture redistribution within the pits, and consequent peripheral mould damage, may occur. These may be increased by ambient, daily temperature fluctuations which will affect the upper parts, especially when pits are incompletely filled. Some peripheral or superficial mould damage is almost inevitable, in any such structure, even when sophisticated construction methods are used. It is for this reason that large storage pits are generally more efficient, for grain quality maintenance, than small pits where the surface/volume ratio is relatively high.

A more sophisticated form of airtight storage, using metal drums which are potentially more completely airtight than any underground pit, is sometimes used and may be cost-effective in some circumstances; especially for seed storage which can be done safely in airtight conditions provided that the grain is dry and the containers are kept reasonably cool. Cost-effective airtight storage for food grains is more likely to be obtained with improved pits. Some relevant trials are currently underway in Rwanda (Hanegreefs, personal communication).

Patterns and Periods of Storage

The common pattern of cereal grain storage in Africa, i.e. the location of the stored grains, leaves 70% or more of the grain in storage at the farm level; the remainder being stored regionally in "buffer" depots operated by grain marketing authorities, private traders and grain processors.

There are some exceptions. In Zimbabwe, for example, the proportion of the maize crop procured by the marketing authority is greater than in many other African countries and is currently increasing. In Sudan, a large part of the sorghum crop is procured, mainly for export, by private traders. In Kenya, and perhaps elsewhere, the wheat crop is almost entirely procured by the marketing authority and is stored in buffer depots or at wheat mills.

Storage periods are generally in the range 6-12 months but here again there are exceptions. At the farm level, in those areas climatically suited to the production of a second crop, the periods may be shorter, around 4-6 months. The southern half of the coastal strip in Kenya and some areas around Mt. Kenya, Mt. Kilimanjaro and the Ruwenzori range are examples. In Ethiopia and the Sudan considerable quantities of sorghum may be stored for 1-2 years or longer by trader-farmers, commonly in large underground pits. In some cases long-term storage of sorghum is clearly a speculative investment with eventual profit, in times of grain shortage as the objective. In such circumstances quality conservation is not a major concern but with this storage technique quality and quantity are, in practice, conserved moderately well. The same cannot be said of the levels of quality and quantity conservation achieved by some traders in the Sudan where considerable stocks of sorghum are held in conventional warehouses and suffer very heavy damage by the Khapra beetle (*Trogoderma* sp.) in relatively short periods of storage.

Storage as a long-term safeguard against the risk of periodic grain shortages ("strategic storage") is a matter of concern to national governments as well as a means of profit to speculative traders. Many countries in Africa have undertaken or are planning programmes to this end. Kenya, for example, began to maintain a considerable maize grain reserve (initially about 100,000 tonnes) in the early 1970s. At that time it was intended that it should be held largely in specially constructed semi-underground pits, the "syprus" bins, at Nakuru and Kitale. these, technically, provide a good means of long-term storage but their operational management posed many problems. While it is conceptually possible to store grain hermetically for very long periods, with negligible loss of food value, such grain is likely to show some alterations in appearance and will therefore lose market value except when released at times of acute grain shortage. Since such events are highly unpredictable it was considered necessary that the grain reserve should be renewed ("turned over") at intervals not exceeding 3 years and more frequently if possible. This led to major problems in the provision of additional grain-handling equipment to facilitate the loading and unloading of the bins and greatly increased the cost of the enterprise.

The effect of climate on storage period, in so far as the period is determined by crop frequency, has been noted already. The interaction of climate and period will also affect storage technique: including the storage structure which, in very dry climates, may be practically superfluous. For example, very large stocks of grain are held reasonably safely in open-air stacks in Sudan. In humid climates or during a rainy season, some form of protective cover or enclosure will be essential. Where the storage period spans a wet season and a dry season some adjustments in storage management may be needed and, at the farm level, storage structures may need periodic modification (Golob, 1984).

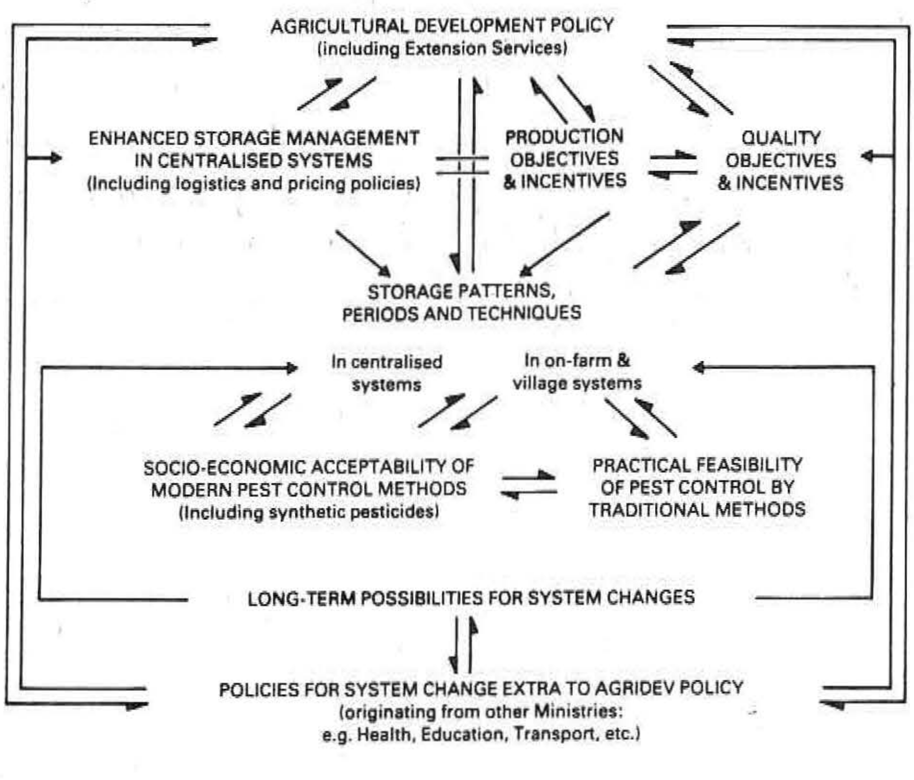
The relationship between climate and storage pattern also warrants consideration. This applies particularly to centralised storage where, within an administrative region, there may be considerable climatic variation. This affords some opportunity for storage organisations to choose locations for storage with regard to climate as well as to transportation problems. In general, the latter consideration tends to override others. For most purposes, this is probably sensible so long as the organisation is able to provide the necessary equipment and management experience to cope with the technical problems which may arise at locations where the climate is least conducive to grain conservation. However, agricultural development plans that entail new storage developments should perhaps give more attention to the influence of climate on grain storage losses when considering the question of storage location.

Ambient temperature variations have a further significance in the choice of storage technique and in the effect of technique upon the potential storage period. There are many locations in Africa where the ambient temperature at night and in the early morning is much lower than it is during most of the day. Considerable daily fluctuations in temperature occur at altitudes above 500 m and where these give early morning air temperatures below 20°C there are useful possibilities for grain cooling by selective aeration (Gough and McFarlane, 1984). The idea for insect pest control is to cool the grain to about 15°C but cooling to 17-18°C would help considerably. This technique is most applicable in the case of centralised storage where the use of mechanically aerated storage bins should be feasible. Nevertheless, some thought might be given to ways and means of providing periodic forced aeration in traditional storage structures, for use at the village level.

Storage in Relation to Agricultural Development

Norton (1986) has drawn attention to the need for a "strategic approach" to pest management problems in agricultural development planning. The same need applies to the problems of grain storage organisation and management, which include storage pest management.

Agricultural development plans greatly affect national storage requirements but it is possible that they do not always sufficiently encompass those aspects of storage management which are most likely to need analysis and further planning: i.e. the questions of storage pattern and period. If these matters are sufficiently taken into account and if the development plan is sufficiently long-term then definitive decisions on the techniques of storage should be more easily made. No particular technique is necessarily more efficient and cost-effective than any other. Choices between techniques, if they are intended to select those that are most appropriate and potentially cost-effective for particular situations, should be made on the basis of comprehensive analysis and long-term planning. Table 3 shows in diagrammatic form the various interacting factors to be considered in the analysis.



Many issues warrant thorough analysis within the indicated framework. Two issues that are of common interest to most countries in Africa are: (i) the choice between increased centralised storage and the maintenance of substantial on-farm storage; (ii) the choice between increased staple food crop production, aiming at national self-sufficiency, and increased cash-crop production, aiming to achieve an enhanced national economy and a stronger trading position.

Both of these are highly contentious issues which I cannot attempt to resolve. I draw attention to them as examples of key issues which have a major bearing on long-term economic development in Africa and which are susceptible to analysis.

So far this paper has dealt with various aspects of the storage management of locally produced cereal grains. Current requirements for the importation of food grains commonly relate to famine relief purposes. In the long-term, some African countries might, conceivably, move towards a situation in which tropical produce was traded increasingly for food grain supplies and other imported goods. Both of these circumstances warrant attention to certain technical problems that affect the movement of cereal grains and similar commodities between different climatic zones.

One particular problem arises from the nature of durable commodities and their characteristic equilibrium between ambient relative humidity and moisture content. This is influenced by temperature and while the effect on moisture content is deceptively small (a grain temperature increase of 10°C lowers the "safe" moisture content by about 0.7%) this effect can have considerable influence on the suitability of grain for storage. Thus, grain stored in cold climates may be safely shipped, in the country of origin, with a moisture content around 15% wet weight. The same grain, if heated to tropical temperatures without sufficient opportunity to lose moisture by aeration, would be unfit for storage. It could be made fit, by further drying to around 13%, and if this was done quickly enough there would be little or no damage by moulds. However, significant mould growth and consequent grain damage can occur on damp grain within 48 hrs and in the handling of grain shipments that is a very short time.

In practice, many consignments of grain are shipped to warmer climates without serious trouble. The grain, which typically remains largely at its loading temperature throughout the voyage, readjusts its mc/rh equilibrium after unloading and as it slowly warms up. It will then tend to lose moisture unless prevented from doing so by high ambient humidity at the port or by any restriction of aeration. However, some consignments have suffered damage, not only recently but occasionally in the past, and in certain cases this has been attributed to the cause described here. The problem may be of increasing significance because of changes in grain shipment techniques and in the speed of grain handling at ports, including tropical ports. The introduction of sealed shipment containers, including portable grain barges (lighters), which may be loaded and unloaded as such, may be of particular significance. It is likely that solutions to the problem may be found, through suitably modified grain-handling procedures at the port of entry, and the ODNRI is currently undertaking a study of the problem to identify appropriate and cost-effective grain management practices.

References

Gilman, G.A. and Boxall, R.A. (1974). The storage of food grains in traditional underground pits. *Trop. Stored Prod. Inf.* **28**: 19-38.

Golob, P. (1984). Improvements in maize storage for the small-holder farmer. *Trop. Stored Prod. Inf.* **50**: 14-19.

Golob, P. (at this Workshop) Current status of the Larger Grain Borer in Africa.

Gough, M.C. and McFarlane, A. (1984). Aeration of stored grains: Some psycrometric considerations. *Trop. Stored Prod. Inf.* **50**: 32-35.

Kenneford, S. and O'Dowd, T. (1981) Guidelines on the use of flexible silos for grain storage in the tropics. *Trop. Stored Prod. Inf.* **42**: 11-20.

McFarlane, J.A. (1969). A study of storage losses and allied problems in Ethiopia. ODNRI(TPI) report R 40: Supplementary account of investigations; pp. 22-50.

McFarlane, J.A. (1972). Terminal report of the British Advisory Team Crop Storage Project: Kenya 1972-1975. ODNRI (TPI) Report R584: Supplementary report on research projects; pp.38-56.

Norton, G.A. (1986). Pest management and world agriculture: Policy, research and extension. Papers in Science, Technology and Public Policy: Pub. Imperial College, London University; 28 pp.

Tyler, P.S. and Boxall, R.A. (1984) Post-harvest loss reduction programmes: A decade of activities: — what consequences? *Trop. Stored Prod. Inf.* **50**: 4-13.

Printed by AMREF, Wilson Airport, P.O. Box 30125, Nairobi, Kenya.