Crop Protection for Small-Scale Farms in E & C Africa—a Review

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CROP PROTECTION FOR SMALL FARMS IN E. & C. AFRICA - A REVIEW

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CHAPTER I: INTRODUCTION

1. BACKGROUND

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In most countries of E. & C. Africa, agricultural production is carried out overwhelmingly on small-scale farms. Small scale farming families account for the large majority of the population in these countries. On many of these farms, a single family is the only labour available, and inputs such as pesticides and machinery are not affordable.

However, in many of these countries, there is an urgent need to improve the productivity of food crops within these constraints. Extensive yield losses are inflicted upon these crops on small scale farms by insects, weeds, diseases and nematodes. Improvement of crop protection practices is therefore seen as an important means of raising yields.

Much of agricultural research into plant protection in the tropics has focussed on chemical control of cash crops, particularly in large farms and plantations. Where pesticides are used on small scale farms these are often inappropriate types, mishandled, mismanaged, and dangerous to both the user's health and the environment. The improvement of food crop protection on small scale farms by low input means has only recently become a focus of research. Very little is known of the crop protection related issues in farming systems of this region. In order to determine appropriate crop protection practices and research, there is a need to analyse these complex agroecosystems from biological, technical, ecological, social and economic points of view. Such an analysis was carried out of farming systems in Embu district in Kenya in 1987 by the Commonwealth Science Council (CSC) (1). A workshop was held in the Embu district where systems analysis techniques were combined with farm visits and a detailed study of the area. This workshop was used to identify constraints to improving crop protection, to encourage an interdisciplinary approach and to provide a rigorous means of thinking about current and future problems and how to deal with them. The workshop brought together an interdisciplinary group of scientists from the E. & C. African region involved in research and extension on crop protection for small scale farms. Following analysis and discussion of the varied farming systems in Embu and comparisons with systems in other countries in the region, major research gaps concerning crop protection for small scale farms were defined. These included:

(1) Intercropping, its use to control incidence of weeds, diseases, insect pests and nematodes and appropriate control methods in intercropping systems.

(2) Maize stalk borer - does it contribute to extensive yield losses?

(3) Efficient control of weeds.

(4) The role of nematodes in maize, bean and banana productivity.

(5) Pesticide safety and management.

The development of a coordinated collaborative regional research project concerning the resolution of these major issues was therefore recommended (1).

This project was planned and developed further at a CSC project planning meeting in Harare in March 1988 (2). At this meeting, selected experts in the field presented thorough reviews of research concerning the major problems identified in this region. These reviews provided necessary background information to further research in the E. & C. African region and allowed the identification of areas where more research was required.

This volume represents the collection of review papers. It is intended as a handbook for the scientists involved in the CSC research programme but should also be of interest to other scientists involved in crop protection for small scale farms in Africa.

The need for environmentally safe methods of plant protection is expressed in the second part of this chapter by Mrs N R Gata and within this context she outlines and briefly discusses appropriate methods of plant protection for small scale farms.

Chapter 2 provides an extensive review of intercropping and its relation to crop protection and recommends appropriate research.

Chapter 3 discusses major weed control problems in the region and in particular looks at potential control methods for Striga and also at intercropping practices.

In Chapter 4, Dr S Z Sithole reviews the available information on yield losses in maize due to maize stalk borer and identifies the need for further information using standardised and quantitative procedures.

Chapter 5 discusses pesticide safety, management, storage and disposal.

In Chapter 6, Mr Peter Johnson of the Department of Agricultural, Technical and Extension Services of Zimbabwe, expresses the need to learn from farmers of their approaches to crop protection and in general how their farming systems work. This information should be the basis for further development and extension of successful crop protection practices.

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2. THE ROLE OF INTEGRATED PLANT PROTECTION IN SMALL SCALE FARMING AND IN THE PROTECTION OF THE ENVIRONMENT

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INTRODUCTION

Human beings are one of the most environmentally demanding biological species. Humans depend on the land for shelter, spatial distribution and for the provision of plants and animals for food and other utilities. The rivers and water masses provide humans with life saving water, while the atmosphere provides life giving gases. Humans form part of the complex ecosystem with the rest of the environment in which plants and animals co-exist. Both the physical and biological elements of the environment form a delicate balance which provides checks and balances for maintenance of the required equilibrium for self substance.

However, human beings, with their manipulative brain and, acting on the permission of the Creator as the Bible states, decided to bring the whole environment (physical and biological) to their advantage and to use the resources there - in for their benefit. However, somewhere along the line, mankind have failed to appreciate that the Creator had put the environment to what he considered wise use by humans. This should mean the use of environmental resources in such a way as to maintain a stable equilibrium in various ecosystems that constitute the environment.

Man as the cause of environmental disequilibrium

The unwise use of environmental resources by mankind has brought about gross environmental disequilibrium. The human population has overshot itself and exceeded the levels that can safely be sustained in some environments in Asia, Latin America and Africa. With the increase in human population , resource requirements by humans also increased, setting up a spiral of competition between humans themselves and between humans and other animal species. This competition for resources such as food, shelter and water in some areas has brought about depletion or near depletion of such resources as forest, water resources and indigenous plants. As a result of the ever-increasing clearance of forests of grow enough food and provide fuel and timber, mankind has precipitated drought conditions which in turn have decreased crop production with a consequential reduction in availability of food for both humans and other animals. The compound effects of over-population and depletion of plant life leading to baring of soil, has caused soil erosion and loss of soil fertility through rain wash, leaching and overcropping. Thus, an ever-increasing environmental imbalance has been set in motion where pests and diseases have less hosts outside what man and his domestic animals require. Consequently, man came into competition with pests and diseases for his crop plants, domesticated animals and other plants in man's economy.

Mankind seeking solutions to problems of his making

Mankind has endeavoured to correct or arrest the situation. Many different approaches have been used to try and prevent abuse and/or depletion of environmental resources. Some measures have taken single aspects of the environment as targets for correction using unidisciplinary approaches such as proper tillage as means of soil conservation, pest control in field crops, afforestation, prevention of soil wash and erosion using contour ridges or through establishment of plants.

However, the latter approaches have not managed to effectively arrest the overall environmental degradation and the fast depletion of the life saving resources because factors involved in environmental ecology are multiple and require a holistic approach to seeking solutions to problems. It is pleasing to note that environmental problems are now being taken seriously and there are calls for multidisciplinary approaches to seeking solutions.

Van Emden (8) writing about pest control and its ecology, stated that there is more to pest control than applying poisonous chemicals. To obtain maximum impact in pest control, it is necessary to visualise the total environment of crops not only including soil, weather, insects and plants but also the social, economic and industrial environments with which the crops are inexorably enmeshed (See Figure 1). Methods of pest control used will affect our food supply.

In the past, the title of this paper would have been "crop pests and disease management or control", that is, limiting the scope of this discussion to pests, diseases and crops. Yet pests and diseases have hosts in both crops and non crop plants; and pests, diseases and plants are also a part of our overall environment. The theme of this seminar paper is therefore, a step in the right direction towards a holistic approach to solving problems of man and his environment by further investigating the plant kingdom and the realms of integrated plant protection. It is hoped that scientists will make a concerted effort to put the plant kingdom in its proper perspective in the environment with both crop and non crop plants featuring within integrated plant protection. The welfare of plants should now be considered, not only in the light of protection against pests and diseases but other injuries should also be considered. Injury and destruction of plant life can be caused by human and other animal activities or by adverse environmental conditions. Any of these can tip the pest and pathogen ecological balance against plant life, resulting in plant damage or destruction.

Man has possibly been the greatest single factor in the injury and destruction of plants in recent history. By tampering with the environment through the multitude of human activities man has adversely affected climatic conditions to the detriment of, not only plant life but, to that of himself and other animals. Consequently, man's efforts to produce food through crop production have met with stiff competition from pests, diseases, weeds and climatic hazards. Man, therefore, has had to devise various ways of protecting what, he has at various stages considered plants of his economy.

Ideally, all plants forms should be protected. However, man must select certain animals and plants to protect. Similarly, mankind has also to choose which plants and animals to eliminate in order to minimise competition for resources. The choice in the delicate environment is very difficult and in many cases, wrong choices are made, resulting in serious plant pests and disease outbreaks. Man, at different times, has plants he considers of economic importance which may include silvicultural plants, aesthetic plants, fruits and flowers, medicinal plants and, of course, plants providing food and fibre. Essentially, plant protection is a system, where man must manipulate factors such as those shown in Figure 1 so that the incidence of pests and diseases remains below the economic threshold levels. It must be emphasised that such manipulation of environmental factors must not cause serious imbalances.

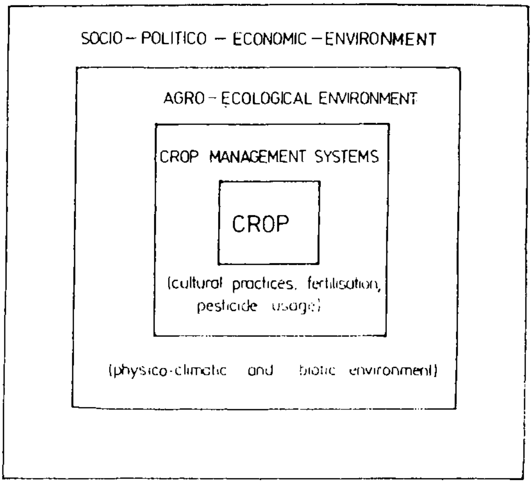

Figure 1: Interrelations of crops, crop management systems, the agroecosystem and the socio-politico-economic environment

THE IMPORTANCE OF DIFFERENT PLANT TYPES

(i) Non crop plants

Non crop plants are important components of the environment, being the primary producers in the food chain. Forest trees provide fuel, timber and are essential in the process of rain formation. Other non crop plants provide human food, shelter, timber and fuel, medicines and, help prevent soil erosion.

(ii) Crop plants

Crop plants can be divided into food and non food crops. Both types are economically important to mankind.

(a) Non food crop plants

Non food crop plants include cultivated forest plants, cultivated medicinal, aesthetic and shelter or hedge plants. There are also a variety of non food crops grown for cash and/or foreign currency earnings. Some plants are grown to protect or stabilise fragile soils, while others are grown to feed livestock.

(b) Food crop plants

Out of some 80,000 known edible plant species, man at one time or another is said to have used 3,000 for food, with 150 of them being cultivated to some significant level. Less than 20 crops are said to currently provide 90 per cent of the world's human food (Innovative Biological Technologies for Lesser Developed Countries: Workshop Proceedings, 1985). Because food is a primary requirement of man, both plant and animal species that provide this basic necessity have been greatly protected by mankind, using at his disposal.

PLANT PROTECTION

Ever since man noticed that plants were prone to damage or destruction by various agents (including man himself), the latter devised and engaged in various methods to protect plants he considered economically important. The levels of protection have depended on the levels of importance of the particular plants in the society. For example, forest plants have a wider economic impact on the society as a whole, while one field crop may be personal property in short economic terms (although individual field crops taken on national terms will also have an impact on the society as a whole). Therefore, there exists plant protection practices at international, national and individual farmers' levels.

(a) Protection of plants through international understanding

It has become the interest of nations the world over to protect as much vegetation over the earth's surface as possible against the ravages of human and other animals. International pressure has jogged national minds and prompted national governments to enact laws against international trafficking in plant life and unwanted destruction of plants including forest and bush clearing. There are also phytosanitary and quarantine regulations which operate between nations to prevent importation and exportation of plants infested with pests and diseases that may lead to plant damage in the importing countries.

(b) Protection of plants by national governments

National governments have awakened to the levels of serious environmental degradation and destruction of flora and fauna in their own countries by setting up agencies at both policy and implementation levels to safeguard environmental resources. Zimbabwe has set up a Ministry of Natural Resources and Conservation whose responsibility is to protect and conserve plant and animal life and to educate and co-ordinate other ministries on the proper uses of the environmental resources. The Zimbabwe Ministry of Natural Resources and Conservation and its various departments work hand in hand with other ministries/departments to implement laws against unwanted destruction of plant life. The Plant Protection Research Institute of the Department of Research and Specialist Services is a policing and/or implementation agency of the Government's regulations against:

(a) removal or destruction of protected plants.

(b) importation or export of infested plant material that would endanger plant life in Zimbabwe or in the other importing countries respectively.

(c) spread of plant pests and diseases within the country.

(d) protection of plant damage by pests and diseases.

Plant Protection Research Institute is also linked to the International and Regional Migratory Pests Organisations which advise, monitor and or co-ordinate control activities.

The Department of National Parks and Wildlife in the Ministry of Natural Resources in Zimbabwe is responsible for the protection of crop plants against Quelea birds, elephants and other wild life species. Some plants are designated rare and threatened with extinction and, are protected by law from any forms of removal or damage. Forests or bush clearance by mechanical or forest fires are restricted or prohibited depending on the circumstances involved.

(c) Protection of plants for individual farmer's benefits

Plant and animal species that provide the basic necessities - food and cash for mankind - have commanded a great deal of human interest, time, effort and other resources to produce and protect. Such is the importance placed on the desired food and cash crops, that man has sometimes cleared vast areas of land to give way to mono or selected mixed cultures of crops for years on end.

The consequences of this tampering with the environment has been the culturing of pests and diseases of these specific crops over the years to levels of economic significance or to epidemic proportions necessitating protection of the crops.

Efforts to correct the crop pest and disease problems have taken various twists in the evolution of pest management strategies, with sometimes significant short term benefits. However, because the strategies adopted have not always taken cognisance of the interrelationships between the flora and fauna in the environment, long term solutions have not been always achieved. If anything, the ecological imbalances caused by some of the adopted cropping systems accompanied by unidisciplinary selective pest and disease control methods have exacerbated and or compounded pest problems. The following are some of the pest management strategies used.

(i) Cultural control practices

When man grows plants for his benefit, minimum or no competition between his required plants with undesirable plant species is permitted. Man protects his crop plants from competition for space, light, water and nutrients by eliminating or controlling the numbers of other plant species. This can be effected by mechanical weeding or by the use of selective herbicides. Crop plants are also protected from competition by scheduling time of planting, by using intercropping methods to give competitive advantage to the crops or, by the use of varieties selected or bred for superior competitive qualities. Good agronomic conditions are also used to give crop plants competitive advantage over undesired plants. These may include flooding to kill weeds and fertilisation to suppress weed species sensitive to certain fertilisers.

Crop plants can be protected from adverse climatic conditions such as rainstorms/blizzards etc. by building barriers or growing them in protected areas such as glass or green houses.

Cultural control practices are also used to protect plants from damage by pests and diseases. Cultural pest control methods entail the manipulation of cropping practices to weaken the mobility of or dislocate the lifecycle of the pest or pathogen. The latter practices involve the use of sanitation, crop combinations and rotation, tillage methods, crop nutrition, irrigation, fallow and, the use of trap crops. The use of resistant varieties can also be considered under the cultural practices used to control pests and diseases. Similarly, farmers are sometimes advised to avoid growing susceptible crops in pest infested areas or during peak pest activity periods/seasons. For example, in Zimbabwe, summer wheat is discouraged in order to avoid pest-carry overs. Cotton stover in Zimbabwe has to be destroyed by a nationally announced date to avoid pest build-up. However, it is not always possible to effectively stop farmers from growing crops they require for one reason or the other.

(ii) Chemical control

The use of pesticides could be considered the fastest and perhaps the most dramatic way of controlling pests and diseases. However, the use of pesticide is severely limited especially in subsistence farming in developing countries. Factors that limit the use of pesticide in controlling pests and diseases are: pest resistance build up, prohibitive costs involved, lack of or inadequate knowledge in the proper usage and disposal of pesticides and the unavailability of chemicals and application equipment.

(iii) Biological control of pests and diseases

Biological control of pests and diseases involves introduction of natural enemies including competitor species. The latter are said to act indirectly e.g. soil microbes produce toxins or chemical exudates that can immobilise or inhibit growth or reproduction of pathogenic organisms.

Entwistle (3) and Tagawa et al (7) have reported control of insect plant pests by the use of viruses. In Zimbabwe effective control of the semi loopers (insects) Trichoplusia crichalcea and Plusia chalcite, the most common pests of soyabean, has been achieved using semi looper nuclear polyhydrosis virus (NPV) (1). Some plant diseases are known to be controlled by beneficial microorganisms (5). Similar examples exist in biological control of plant parasitic nematodes where Pasteuria penetrans has been found to control Meloidogyne spp although this method has yet to prove its economic application.

Biological control has been effectively used to control insect pests but has limited local application in the control of weeds. The use of competitor species is said to have important application to soil pathogens (4).

(iv) **Integrated plant protection**

Alternate to a single control strategy and a single parasite, is integrated control of plant pests and diseases. Two concepts have been developed. One, the control of more than one pest affecting a crop is considered to constitute integrated control. The second concept is defined as the use of two or more methods or techniques to control specific pests/diseases.

The term integrated pest control or management was originally used to describe the use of insecticides in such a way as to allow natural enemies of the insect pests to operate in support of the chemical control agent i.e. integrated pest control was the combining or integration of biological and chemical control methods (6). However, the term integrated control has now been broadened in meaning to include the integration of as many as required methods of control to manage, not only insects but also other plant pathogens and weeds. The latter broader concept, fits in the theme of this volume of papers.

The most common integrated pest control strategy used is a combination of one or more cultural practices with or without chemical control. For example, in Zimbabwe, farmers are aware of the performance of certain maize varieties in their specific environments. Consequently, they will choose a variety they consider appropriate and then select what they consider healthy seed (pest/disease free) for planting and, follow their long evolved cultural practices for planting and managing their crop in order to avoid weed competition and pest infestation. Alternatively, farmers may adopt research recommendations on the management of the crop. Those that can afford chemical control will integrate mechanical weed control methods with the chemical control of such pests as stem borers when they appear.

Depending on the crop and on the socio-economic standing of the farmer, more sophisticated and expensive combinations of various pest control strategies can be integrated to control specific pests, diseases and weeds.

CONSTRAINTS TO THE USE OF INTEGRATED PLANT PROTECTION STRATEGIES

Although integrated plant protection may seem most suitable for small scale African farmers, the scope of its applicability is limited by many factors including the limited range of possible technologies to integrate:

(a) Chemical control, as a component of integrated control, is limited to a very few farmers and very small range of chemicals because of the cost and availability factor as well as lack of knowledge of the proper use of chemicals. If available, it is usually limited to use in cash crops and not subsistence crops.

(b) Lack of knowledge of the range of possible packages of integrated control technologies available.

(c) The multiplicity of factors involved in integrated plant protection may pose a technological barrier to the small scale farmers, not forgetting the psychological exasperation that may result from the slow results from integrated pest or disease control in the wake of a serious disease or pest outbreak.

(d) Non-availability of integrated plant protection technology

Despite the fact that the concept of integrated pest control dates back to the 1950's, there are not many packages of practices available for small scale African farmers from research. This may be due to the different and changing cropping patterns in various parts of Africa to which the different pest populations and disease incidence may be related.

(e) Lack of research-extension linkages

As and when the integrated plant protection technology is available, farmers will still suffer from the poor research-extension linkages to effectively transfer technology.

(f) Research in integrated plant protection has generally been relegated to a secondary position compared with single pest/disease control. This could be due to the multiplicity of the dimensions involved and hence the complexity of the designs and techniques required to address the factorial objectives of the experiments. Furthermore, in most of the African countries, research training and infrustructure has been geared to disciplinary research which compartmentalises research approaches. Within the individual disciplines, research training has been further narrowed to single pest specialisation within specific crops. As if that is not enough, responsibilities of plant protection in some African countries are placed under different institutes or departments, and even worse, under different ministries. As a result, planning and actual implementation of integrated pest management research and/or programmes in the context of the environment becomes limited.

The diversity of the farming systems and the socio-economic limitations in Africa also compound the problem of implementing integrated pest management research.

One such socio-economic limitation in some of the African countries is the availability of land and land tenure systems which can determine whether or not a farmer has land and can practice crop rotation or fallow to control pests, diseases and weeds. Cultural norms and food preferences can also be locality-specific and thereby limit the extent of applicability of research.

POSSIBLE ADVANTAGES OF INTEGRATED PLANT PROTECTION

Integrated plant protection is potentially a cost effective approach to plant protection. The combination of control strategies can be selected with the primary low cost criteria in view of the socio-economic status of the target group of African farmers. This is possible through emphasising the role of cultural, agronomic and host resistance strategies are developed with the cognisance of what is acceptable and appropriate for the locality concerned at any point in time, the chances for adoption will be increased.

(a) Safety to humans and untargeted fauna and flora

Since integrated crop protection practices do not entirely depend on the use of pesticides, there are better chances for human and animal health safety.

Therefore, minimal use, or where possible, avoidance of pesticides should be the aim of integrated plant protection.

(b) Safety to environment

Environmental resources including water, gases and biosphere are the most important resources for human inheritance. Their safe-guard is one of the vital responsibilities of man for the present and future generations. Integrated plant protection provides a chance to safeguard and sustain the natural environment.

DISCUSSION

Integrated plant protection has an important role to play in small scale farming systems in Africa because it has the potential properties of flexibility, acceptability and practicability, to suit the needs and means of the African farmer. In most of the Southern African countries, the need to arrest and correct the deteriorating food situation, the precariously degraded environments and, the consequential poverty spiral is a matter of urgency. Integrated plant protection with special consideration for the protection of the environment, seems an appropriate approach to solving pest, disease and environmental problems. However, long term plans must be drawn which involve policy definition at the political level and at various levels of the government implementing agencies.

From a national point of view, government agencies charged with policing and implementing environmental activities must be properly co-ordinated to a level of amalgamating institutes performing plant protection activities. For example, weed and other pest and disease research should be integrated and, phytosanitary and quarantine services should fall under one management.

Training and retraining should be carried out in plant protection in order to equip future and existing staff with the necessary capability to work within the broadened operational sphere. There is also a need to use the Farming System Research (FSR) approach and diagnostic methodologies training should take account of this requirement which would bring the researchers to recognise the importance of the sociological factors in the farming systems they will be working in. Proper diagnostic methodologies will bring out the role of women in the food systems and hence help to integrate women in development in order to fully utilise human resources.

Integrated plant protection can play a significant role in co-ordinating research-extension and farmers' activities in the production systems of the African small scale farmers and, in improving the diagnosis of the latter's plant production problems in the context of the overall environment. By drawing on the diagnostic methodologies of FSR, integrated plant protection can bring about integration of research disciplines within prevailing socio-economic environments.

This way, it should be possible to develop technologies appropriate and acceptable to the target farmers that will also help to sustain their environmental heritage.

SUMMARY

Integrated plant protection can play an important role in the war against pests, diseases, weeds and the fast deteriorating environment. Presently, integrated plant protection is being practised to a limited extent due to various constraints.

Integrated plant protection has a potentially more significant role to play in the African small scale farming systems because the approach has room for flexibility to suit the needs and means of the user. However, policy adjustments at national levels are required to facilitate the necessary adjustments by the implementing agencies to accommodate the restructuring of institutions and the training of staff needed to operate integrated plant protection research programmes. Farmer training to improve the levels of technology adoption is also required. Strengthening of research-extension and, farmer communication is necessary to improve technology generation and transfer.

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CHAPTER II

CROP PROTECTION IN INTERCROPPING SYSTEMS

1. MANAGEMENT OF WEEDS, PESTS AND DISEASES IN INTERCROPPING SYSTEMS AND USE OF APPROPRIATE EXPERIMENTAL DESIGNS, EVALUATION TECHNIQUES AND ON-FARM RESEARCH APPROACHES

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INTRODUCTION

Intercropping or growing of two or more crops simultaneously on the same piece of land is an age-old practice in the tropics. The crops are not necessarily sown at exactly the same time and their harvest times may be quite different, but they are usually 'simultaneous' for a significant part of their growing periods. The term intercropping should only refer to situations where the crops are grown in separate rows. Where one or more of the crops are broadcast, the term "mixed cropping" should be used.

Intercropping is most commonly practised among small-scale farmers. The main consideration for mixing crops together is to reduce the risk of failure from drought, pest or disease incidence. The farmers believe that if several crops are grown at the same time, at least one will survive to harvest. There are other reasons too: frequently one can find short-duration and long-duration crops in the mixtures. This helps to spread labour needs more evenly. Food crops are usually mixed with cash crops to help ensure both sustenance and disposable income. Cereals and legumes are often mixed, probably more for dietary reasons than for any beneficial effect that the nitrogen - fixing power of the legumes convey to the associated cereal crop or to a subsequent one.

Although research on intercropping may have started to provide an understanding of why the farmers used such mixtures, and to help improve his productivity in ways relevant to his practice, it has now been shown that intercropping may have several advantages over sole cropping, including:

(a) increased efficiency in the utilisation of environmental factors (light, water and nutrients);

(b) more efficient utilisation of labour;

(c) reduction of the adverse effects of weeds, pests and diseases;

(d) insurance against crop failure;

(e) higher gross returns; and

(f) protection of the soil against erosion because of better ground cover.

This paper briefly reviews various approaches to the management of weeds, pests and diseases in intercropping systems, and suggests appropriate experimental designs, evaluation techniques and on-farm research for use in intercropping studies.

WEED MANAGEMENT IN INTERCROPPING SYSTEMS

The growing of a number of crops in close proximity to one another so that the plant density is greater than in sole cropping should result in greater competition against weeds and thus reduce the need for weeding (35). However, if the plant density of the intercrop is the same as for the component crops when grown alone, or if both are planted at their optimal densities; there may be little advantage with respect to weed suppression from intercropping. In fact, weed growth in the intercrop may be as great as in the sole-crop (35).

The weed-suppressing ability of intercrops is dependent upon such factors as the component crops selected, the cultivars selected, the plant density used, the proportion of the component crops in the intercrop, their spatial arrangement and the fertility and moisture status of the soil.

Numerous authors (4,5,11,30) have reported that the weight of weeds growing in association with a maize/mungbean intercrop is as low or generally lower than that growing in association with the sole crops. Furoc et al. (23) reported that when soybean was intercropped with maize, the presence of soybean reduced weed growth markedly. Forty days after sowing, 4.0 t/ha weeds were harvested from the sole-crop plots, whereas only 0.5 t/ha were harvested from the intercropped plots.

Even though certain crop combinations may cause a reduction in weed weight compared to the component sole-crops, there is still a need in most cases to do some weeding so that the weeds that are present do not cause yield reduction (3). It is assumed in the literature without empirical verification, that growing crops in mixtures results in a saving in labour (38). Norman (38) states that such reasoning has been based on the premise that weeding is less critical in intercropping and that some operations, such as planting of the second crop and the weeding of the first, can be combined. In 1968, Norman reported that although, theoretically, labour should be saved by intercropping, the quantitative evidence does not support this statement. According to Harwood (25), intercrop combinations require less input in weed control. This can only be so if there is a reduction in weed weight in the intercrop combination compared to the sole-crops. Suppression of weeds in intercrop compared to the sole-crop may have a beneficial effect on the subsequent crop as well. A common practice in Nigeria and other parts of West Africa is to sow cowpea into established maize during weeding about a month after the maize has emerged so that the presence of the cowpea would result in fewer weeds, and fewer weed problems, in subsequent crops. In Colombia (12), in sole and intercropped maize and bean, one weeding was needed to give adequate control compared to the sole-cropped maize.

Methods of weed control

Weed control may be a greater problem in intercropping than when the component crops are grown alone (35). The major methods of controlling weeds in intercrops are manual or mechanical. Mechanical weeding is difficult or even impossible in certain spatial arrangements, such as the random planting of legumes between rows of maize or when the row spacings of the component crops are too close to each other. Erbach and Lovely (20) stated that when crops are grown side by side in alternate rows, equipment must be operated more precisely to prevent damage to the adjacent crop. Cultivation is greatly facilitated if the component crops are planted in the same row or in rows that are spaced equidistant and are sufficiently far apart to allow passage of the cultivating implement and its power source (35). Miller (33) reported that weed control methods utilising mechanical cultivation or herbicides appeared less satisfactory for intercropped maize and bean than for the same crops when they were grown separately. This was caused by the problem of plant and row spacing in intercropping and by the scarcity and high cost of herbicides possessing acceptable selectivity for both maize and beans. Herbicides are often crop specific. Thus it has been difficult to find compounds that will control a broad spectrum of weeds without causing damage to the component crops in the intercrop system (35). The spatial arrangement of different crops makes chemical control of weeds difficult. Young et al (51) stated that technical considerations severely restrict herbicide utilisation in intercropping while Moody (35) noted that as the number of crops that tolerate a herbicide increase, so must the number of weeds that are not controlled. Thus, the more complex the intercropping system, the less is the likelihood of finding herbicides that will effectively control weeds without causing crop damage (34).

Experiments conducted primarily at research stations have identified some herbicides that are suitable for use in simple crop associations. Butachlor applied pre-emergence has been used successfully in maize/mungbean (4,5) and maize/cowpea (39) intercrops to control many weed species. Pamplona and Imlan (39) observed that when butachlor was applied, yields from the intercrop were equal to those obtained with a single hand-weeding but significantly lower than those from the weed-free check. In a maize/groundnut intercrop, only trifuralin was not toxic to both crops (40). In India, alachlor has been used successfully for weed control in maize/soybean intercrop. The same herbicide at 1 kg/ha gave 85% weed control when sorghum or maize were intercropped with cowpea (16). In Colombia (12), excellent weed control has been obtained in maize/bean intercrop when alachlor and linuron were applied alone or in combination at high rates.

Weed management research in intercropping is still in its infancy. Probably because no systematic and co-ordinated research to improve the efficiency and productivity of intercropping has been undertaken. The study of plants growing in mixtures is a complex topic in itself, and an additional complexity is provided by considering weeds. There is little or no theory of weeds and their control in intercrops to which reference can be made in planning a research programme. As intercropping is gaining importance, especially in tropical rainfed farming, and as weeds are one of the major factors in determining the success of a new cropping system, a well directed weed-management research strategy for intercropping is absolutely essential. Two approaches need to be considered immediately:

(a) ecophysiological studies leading to the manipulation of intercropping systems to obtain better management of weeds;

(b) studies involving evaluation of various weed control methods for a few selected intercropping systems.

Ecophysiological studies

It is not clear whether or not intercropping suppresses weeds more efficiently than sole-crops. It is clear, however, that all weed-related aspects in intercropping revolve around "competition". Therefore, there is a need to investigate competitive ability of various intercrop systems in relation to the competitive ability of the component crops under sole-cropping. Differential competitive ability is dependent on many physical, biological and cultural factors. These factors should be identified and manipulated to obtain better weed management.

Some of the areas that need to be researched immediately are:

(a) the weed-suppressive ability of the intercrop system. Does it favour or disfavour weed growth when compared to sole-cropping?

(b) the major weed problems of the system. Does the system encourage the build up of particular weed species?

(c) the physical, biological and cultural factors which increase the weed suppressing ability of the system.

(d) methods of manipulating these physical, biological or cultural factors in order to increase the weed suppressing ability of the system.

(e) the management practices which affect weeds.

Field trials should be conducted to determine the weed competitiveness of different component crops or cultivars, or both, and also the intercrops involving these crops. This initial screening process would help the production agronomists to select only those systems that are efficient in weed suppression and also to examine ways of manipulating the system to obtain better weed management. One of the basic needs of "competition studies" is the availability of fairly uniform fields with uniform weed growth or fields where weed seeds can be planted along with the crop or intercrop.

Another approach is to study the representative systems under the farmers' present weeding regimes. This latter approach would also indicate the relative productivity of the system under farmers' present systems. Using the farmers' present management levels would provide true relative advantage figures for intercropping rather than often misleading advantage figures obtained against a background of good protection measures, which vary from crop to crop and from system to system.

Weed management studies

With a change in the cropping pattern, there is sure to be a change in the environment of the crops as well as the ecology of the weeds associated with them. Further, the planting pattern used in intercropping affects the yields of the component crops and the weeds, even though, in some cases, their population (and proportion) may remain the same. Intercropping may eliminate some weed species that are not able to cope with such a system but, likewise, other weed species that do not occur under sole-cropping may be favoured by intercropping. Therefore, there is a continuing need to develop and evaluate improved weed control methods for different intercrop systems. Some of the questions that need to be answered are:

(a) what is the critical weeding time for intercrops? When, and how many times, and how long should the intercrop system be weeded?

(b) do crop mixtures require more labour for weeding? Do crop mixtures help alleviate the labour problem?

(c) can mechanical weeding be practical in intercrops as done in sole-crops? What modifications are necessary? How can we develop improved tillage systems for intercrops? When should we do interrow cultivation in the intercrop?

(d) what is an "acceptable" level of weed competition? Which weed must be controlled, and which weeds could be left alone?

(e) by continuously practising the same control methods, are we creating favourable conditions that encourage growth and dominance of certain species? What modifications in the present weeding systems are necessary to avoid this? What modifications in cropping systems are necessary? Can we use crop rotations to avoid problem weeds?

(f) can herbicides improve the productivity of the intercropping systems? Are they economical, at least in the long run? Which herbicides are useful? When and how should these be applied?

In improved intercropping systems, because of many factors such as row arrangements, plant population, spacing, fertility, and land and water management, the weed control methods presently being used by the farmers may need to be modified. It is essential to know exactly what the farmer is doing with respect to weed control in his present system and to highlight the differential weed control requirements of the improved system. The tools used for weeding or interrow cultivation also need to be determined.

Complete weed control cannot be achieved by using any one method alone. Whenever possible, the most effective weed control methods that are available should be used in combination. The basic weed research philosophy in intercropping should be the manipulation of the environment in such a way that it favours a community of "crop" plants and not a community of "weed" plants. The broad research objectives should be to identify weed management problems and effective measures of weed control. To do this, we must concentrate more on the ecology of major weeds and obtain a greater understanding of the biology of each species in association with surrounding plants. This would not only assist us in managing our weed/crop community in the intercrop system but also enable us to predict possible future serious weed problems.

PEST MANAGEMENT IN INTERCROPPING SYSTEMS

Monocultures, although thought to be often highly productive and efficient, have been criticised for their genetic uniformity and increased pest susceptibility. Unlike monoculture, the regulation of insect pests in multiple crop systems by physical means (protection from wind, hiding, shading, alteration of colour or shape of the stand etc.) and biological interference (production of adverse chemical stimuli, presence of predators/parasitoids, etc) have been emphasised (29,37,44 48). These workers included some examples of the behaviour of insect pests in mixed/inter- and strip-cropping systems, but some of this has been of theoretical and academic interest.

In the tropics, intercropping has been an important component of small-farm agriculture, and one of the reasons for the evolution of these cropping patterns may be reduced incidence of insect pests (1, 3, 10, 15, 21, 46, 47). Factors such as increased parasitoid and predator population, availability of alternate prey, decreased colonisation and reproduction in pests, chemical repellency, masking feeding inhibition by odour from non-host plants, prevention of emigration in pests, and optimum synchrony in the relation between pests and their natural enemies are quoted as likely to be important in efficient pest regulation in intercropping. But there is much uncertainty.

Certain pests colonise one particular crop in a given ecosystem, which then serves as a diversionary host, protecting other more susceptible or economically valuable crops from severe damage (31). In Nigeria, unsprayed cowpea is less subject to insect damage when intercropped with sorghum rather than sole cropped (41) and a similar situation prevails in maize/cowpea intercropping in Tanzania (27) and also in South-Western Nigeria (8). Thus the preference of certain polyphagous pests for cereals may enable subsistence farmers to produce an economically viable yield of legumes.

Some pests can attach and feed on several plant species and can move from one host to another when one of the host plant species matures. It is generally considered that, along with the pest species, the parasitic and predatory fauna also move (22,45). Gavarra and Raros (24) found more predatory spiders in a maize/groundnut system than in sole-cropped maize. This was partly attributed to improved supply of soil micro-fauna in the mixed planting to support early instar spiderlings.

Growing of several crops together may or may not mitigate for a stable interaction between pests and their enemies. The continuity of vegetative growth offers a chance for longer term stability of predatory/prey interaction, e.g. it is thought that this keeps Heliothis armigera (Hubner) a minor pest in Southern Uganda (14). In an equable climate, H. armigera breeds throughout the year on a wide range of crops and wild plants, and the complex of native plants in a semi-wild environment seemingly stimulates "perennial" stability, which ensures that the pests remain a minor problem even in unsprayed conditions. However, in Southern Tanzania, the dry season induces diapause in Heliothis which limits successful biological control (42). In these circumstances, the planting of maize with cotton increases the abundance of H. armigera because the pest multiplies on maize and migrates to cotton without a check by natural enemies.

In a maize/bean intercrop in Colombia (1), adult populations of the most important pests of beans, Empoasca kraemeri, a leaf hopper, and Diabrotica balteata, a polyphagous insect, were reduced by 26% and 45% respectively. Spodoptera frugiperda incidence as cutworms in maize was reduced by 14%. Also intercrops had 23% less infestation of fall army worms as whorl feeders. Planting dates of maize and beans also had an influence on the population dynamics of pests. Advancing planting of maize (30 days) reduced bean pests significantly and advanced planting of beans (30 days) reduced maize pests significantly (1).

Intercropping and pesticides

Given the current economic status of many crops, pest suppression with pesticides is clearly a strategy with limited application in intercropping. Problems will arise in application of pesticides in intercrop situations. Often it is difficult to prevent drift reaching the non-target crops. Differences in crop height, susceptibility and maturity, and inconveniences to the applicator while spraying or dusting with existing machinery are other problems of pest suppression with pesticides in intercropping and require alternatives. Given this situation, the need for methods of control other than use of pesticides is emphasised in intercrop subsistence farming.

Pest management strategies

Prevention of losses caused by pests at all stages in intercrops will initially require a study of the nature of the pest problems in a region, followed by identification of the factors responsible for increased losses caused by pests. Quite clearly, there are levels of pest abundance at which it could be advantageous to modify normal intercropping practices and to select appropriate cultivars more tolerant to pest attack and to utilise escape mechanisms by careful selection of cultivars.

Data are lacking on the extent and factors governing the natural control of key pests in most intercrop situations. The basis of the management of a whole pest complex in an intercrop system should be a planned manipulation of the various factors which influence the economic injury level so as to minimise the economic effect of the pests. It is necessary that entomological research in intercropping should be intensified. Principles will have to be established using relatively few crop combinations initially and increased plot sizes and replication. Large crop plots need to be used to monitor differences in pests, parasitoids and yield losses, if they exist, and comparisons made with "off-station" situations. Plant type, plant population, various crop and row proportions, planting configuration, crop shading, fertiliser levels and methods of application and various other local cultural practices in both existing and proposed intercrop systems are major factors in insect population dynamics and need investigation.

It is important that production research in intercrop situations goes hand-in-hand with pest management research. Pest management in intercropping systems should be an important element in the development of cheap and feasible management practices for the intercrop situation. Crop sanitation, optimum seed rate and plant stand, destruction of "overwintering" pests by timely ploughing and stubble destruction, observance of fallow and homogeneous planting dates, and choice of pest-tolerant cultivars must be combined.

The ultimate goal of pest management in intercropping systems should be to reduce loss of crop yield and quality rather than merely to reduce pest numbers. Compensatory ability is often an important attribute of intercropping systems since one crop may benefit from damage or loss of stand in the other crop, thus maintaining an overall stability of production.

DISEASE MANAGEMENT IN INTERCROPPING SYSTEMS

Cropping systems influence not only the population dynamics of insect pests but also epidemics of plant diseases. With a few exceptions, intercrops suffer less diseases than pure crops with the same overall density (7).

There are several mechanisms whereby disease reductions are achieved in mixed stands. Probably the four most important one are (7):

(a) in a pure stand of plants with uniform susceptibility to a particular pathogen, the replacement of a proportion of these plants by resistant ones reduces the amount of tissue which may become infected and this in turn reduces the amount of inoculum available for subsequent dispersal within the stand;

(b) replacement of susceptible plants by resistant ones results in a decline in the density of the remaining susceptible plants and thus an increase in the average distance that inoculum has to travel between one susceptible plant and another. Increased distance is often associated with factors which reduce the spread of inoculum;

(c) resistant plants may interfere with the passage of inoculum between susceptible plants;

(d) cross protection phenomena may play some part.

Although a few studies have clearly shown a reduction in infection rates in mixed stands, when compared with pure stands (8,9), little attempt has been made to determine the relative contributions which these four factors make towards reducing disease.

The relative importance of the reduced density of susceptible plants (through factors a and b) and the resistant plants which act as barriers to the spread of inoculum (factor c), as regards the reduction of disease rates in intercrops, may be determined by comparing the effect on infection rates when susceptible plants are replaced by resistant ones. This has the effect of simply reducing the density of susceptible pure stands under conditions in which cross-protection cannot occur.

Most times, however, the total plant density of intercrops is higher than that of either sole-crop. This induces a change of micro-climate, especially where low-growing crops are interplanted between tall species (shelter effect). In many cases, the relative humidity is increased, i.e. the micro-climate becomes more favourable for fungal and bacterial diseases. The susceptibility of the crop species, primarily the dominated one, might also increase due to reduced isolation.

Beneficial effects of intercropping on plant diseases are most likely to occur with soil-borne diseases. Intercropping also affects epidemics of air-borne diseases. A significant reduction of cassava bacterial blight by intercropping cassava with maize, melon or other crops is reported from Nigeria (2). This is probably due to the earlier and better soil cover provided by the intercrops which, at least to some extent, prevented the splashing of bacteria from the soil onto cassava leaves. While the apparent infection rate of cassava mildew is increased by interplanting maize, it is reduced by interplanting a low crop such as beans. This is a surprising result, since one would assume that maize acted as a barrier, and reduced the spread of inoculum. At the same time, angular leaf spot infection was reduced on intercropped beans (36).

As for cowpeas, incidence of cowpea mosaic virus and cowpea chlorotic virus was not affected by associating cowpea with maize or cassava. Infection was lowest, however, in intercrops with plantain, due to reduced activity of the vectors. While intercropping has no effect on the frequency or severity of Cercospora leaf spots, intercropping with plantain, cassava and maize significantly reduced the severity of Ascochyta leaf spots.

These examples demonstrate how intercropping influences the frequency and severity of diseases. This potential should be used when developing cropping systems for smallholders. As the influence of cropping systems on epidemics of disease depends on too many variables, it cannot be predicted. Therefore, experiments with different crop associations have to be done and appropriate cropping patterns have to be developed for different ecological zones.

EXPERIMENTAL DESIGNS AND STATISTICAL ANALYSIS FOR INTERCROPPING SYSTEMS

Experimental designs

Experiments with intercropping systems are more complicated than those with sole-crops. This is true for the experimental design as well as for the final statistical analysis. Probably, this has been a major reason why many researchers have been hesistant to start experiments with such cropping systems. Although substantial experimental programmes of intercropping research have been initiated within the last decade, little thought seems to have been given to the problems of designing experiments specifically to investigate intercropping. Most researchers appear to have used very simple experimental designs similar to those they have previously used for monocrop experiments. The statistical understanding of experimental designs and the availability of computing facilities have, however, greatly improved since monocropping research was at the stage which intercropping research has currently reached and a much wider range of experimental designs is available to the researcher. One reason why the range of experimental designs should be broader is that the involvement of two or more crops in an intercrop means that the set of possible experimental treatments is far larger than for a corresponding monocrop experiment. Among the particular aspects of intercropping experimentation which require thought are:

(a) the need to define the objectives of an experimental programme precisely, and to attempt to satisfy these objectives through a sequence of specific experiments;

(b) the extent to which intercropping experiments should involve monocrop plots;

(c) the need to investigate the effects of many factors and their interactions at an early stage of an experimental programme;

(d) the large size of many intercropping experiments which therefore require efficient use of available space and careful control of experimental error.

As a general guide, the designs should reflect the need to conform to examine objectives efficiently rather than the need to conform to conventional designs which may be easier to layout and analyse. One of the main problems is that although the intercropping treatments themselves often form a balanced factorial arrangement, the control treatments are usually 'additional'. This means that split plot designs are not possible and greater reliance may have to be put on simple randomised blocks.

One simple but very important point is that experiments must include proper 'controls' (i.e. sole-crop treatments). As a general rule, controls should be included for all crops being examined in order that a valid assessment of yield advantages can be made. In many intercropping experiments carried out to date, this has not been done. An exception may be where intercropping aims to achieve a full yield of a 'main' crop with some additional yield of a second crop. In this situation, a control for the second crop could be eliminated on the basis that intercropping is an alternative only to a sole 'main' crop. Without jeopardising the aims of the experiment, controls should be kept to a minimum so that the maximum possible proportion of the experiment is allocated to intercrop treatments. As an example, the simplest possible design of two sole-crops and one intercrop gives only one third of the plots as intercrop treatments. The 'efficiency' of this design could be improved by incorporating more intercropping treatments of the same two crops.

It has become standard to consider interaction effects of different factors in monocrop experiments. Statistical theory suggests that at the early stages of an experimental programme, the economic benefits of factorial experiments are particularly strong. Therefore, an experimental programme should include large factorial experiments which have investigated single factors. In intercropping, there are rather more factors than in monocropping because of the existence of two component crops so that it really is very worrying that so many of the current experiments on intercropping examine only a single factor or include a second factor in a subsidiary role.

The important ideas of blocking in intercropping are the same as in monocropping, that is to recognise sets of plots which are likely to behave homogeneously. Many existing experiments on intercropping which do include two factors use a split-plot design. The number of occasions when a split-plot design is appropriate are few. The only good reasons for using a split-plot design is that some treatment can only be applied to large plots, whereas a large plot is not necessary or desirable for other treatments.

Many intercropping experiments require large "general areas" around the harvested portion of each plot. As many experiments on spatial arrangement of intercrops need to examine a wide range of special treatments. All these requirements make systematic designs potentially extremely important.

Statistical analysis

A straight-forward procedure, and one that is usually necessary to some degree, is to analyse the crops separately. This can be done using a 'reduced' design which simply involves ignoring the sole treatments of the crop not being considered. This is particularly useful for examining parameters which are only applicable to one of the crops.

No intercropping situation can be fully analysed without combining the crops in some way, however, and this is where difficulties arise. A straight addition of yields is usually meaningless where they are of very different types. In some instances, yield can be reduced to some common biological denominators such as yield of protein, dry matter, digestible nutrients etc. A more realistic alternative is to assign a monetary value to each crop. But it must be appreciated that a normal analysis of variance then gives a comparison only between actual treatments. This can be useful but where the assessment of an intercropping advantage depends on a comparison with a combined sole-crop yield, the analysis of this comparison is not included. A particularly useful procedure would be a straight analysis of variance of Land Equivalent Ratio (LER) values because the expected combined sole-crop yield is always equal to one. However, the nature of the distribution of LER values seems to be uncertain and thus the statistical validity of this procedure is at present doubtful.

EVALUATION OF INTERCROPPING YIELD ADVANTAGES

As yields of different crops cannot be compared directly with each other, and therefore not simply added together, special methods have been developed in the past, but the discussion here is limited to basic principles and the current methods. One possibility is to compare component yields with their sole-crop yield for every crop in the mixture and add the ratios together. Another possibility is to compare the land area needed to obtain similar component yields in sole and intercrops. Evaluation can be made on the basis of constituents such as calories, fat, crude protein, lysine, methionine (6) or on the basis or net income. All these potential possibilities have their advantages and disadvantages and the method to be used depends on the objectives.

The Land Equivalent Ratio (LER)

Several different concepts have been developed to assess yields of intercrops, such as the relative coefficient (17), the competition index (19), the relative yield total (RYT) (18), the aggressivity (32), and the competitive ratio (50) but the use of the Land Equivalent Ratio (26) has become common practice in intercropping studies because it is a relatively simple concept. The Land Equivalent Ratio may be defined as the relative land area under sole crops that is required to produce the yields achieved by intercropping. It is usually stipulated that the "level of management" must be the same for intercropping and sole-cropping.

An important concept inherent in the use of LER's is that, whatever their type or level of yield, different crops are placed on a relative and directly comparable basis. Although based on land areas, LER also reflects relative yields (the relative yield total is numerical to LER), i.e. the LER can be taken as a measure of relative yield advantage. The ratio is calculated in the following way:

$$LER = LA + LB = \frac{YA}{SA} + \frac{YB}{SB}$$

where LA, LB are the LERs for the individual crops; YA, YB are the individual crop yields in intercropping; and SA, SB are their yields as sole crops. A ratio of > 1 signals no yield advantage, and a ratio of < 1 yield advantage. A LER of 1.2 indicates a yield advantage of the intercrop over the sole crops of 20%, i.e. sole-crops would require 20% more land to achieve the yield obtained by the intercrop.

In this way, LER represents the increased biological efficiency achieved by growing two crops together in the specific environment. The LER term is usually applied to combined intercrop yields but can equally be applied to the intercrop yield of each component crop (LA + LB = LER). The following example should help in better understanding of the concept and use of the Land Equivalent Ratio.

	Maize (kg/ha)	Groundnut (kg/ha)
Treatment 1: sole maize	5225	-
Treatment 2: sole groundnut	-	1221
Treatment 3: maize/groundnut intercrop	4702	513

$$\text{Maize/groundnut} = \frac{\text{Intercrop maize yield}}{\text{Sole maize yield}} + \frac{\text{Intercrop groundnut yield}}{\text{Sole groundnut yield}}$$

$$= \frac{4702}{5225} + \frac{513}{1221} = 0.90 + 0.42$$

$$= 1.32 = 32\% \text{ intercropping benefit or advantage}$$

As the LER is a relative figure, it does not reflect the absolute yields. Large values can be obtained because of high yields in intercropping but also because of small yields in corresponding sole-crops. Therefore, absolute yields have to be given together with the LERs. The LER represents the biological efficiency of an intercropping system and allows a comparison of one, or with sole-cropping. In practice, however, the intercropping combination with the highest LER is not always the best one, as far as the farmers' needs are concerned. In most situations, component crops are not equally acceptable and one crop is needed or preferred more than another one. When assessing the yield advantages of intercrop combinations, farmers' requirements should not be neglected, otherwise the research aimed at improving the intercropping situation is not based on sound objectives.

Criteria for assessing yield advantages

It is not always appreciated that different intercropping situations may have to satisfy rather different requirements if yield advantages are to be achieved. Yet it is important to recognise these different requirements, not just to ensure that advantages are validly assessed, but also to ensure that research aimed at improving the intercropping situation is based on sound objectives. Three different situations can be distinguished (49):

(a) where intercropping must give full yield of a 'main' crop and some yield of a second crop. This situation is largely ignored in literature, yet it is often applicable where the primary requirement is for a full yield of some staple food crop. This has been well recognised in most parts of East and Central Africa where the primary objective of many intercropping combinations is to produce a full yield of a staple cereal and to maximise yield of the second crop without reducing yield of the main crop;

(b) where the combined intercrop yield must exceed the higher sole-crop yield. This is the criterion which has traditionally been used for assessing yield advantages in grassland mixtures. It is based on the assumption that unit yield of each component crop is equally acceptable and therefore the requirement is simply for maximum yield regardless of the crop from which it comes. This criterion also assumes that growing only the higher yielding sole-crop is a valid alternative to growing both;

(c) where the combined intercrop yield must exceed a combined sole-crop yield. This criteria is based on the assumption that a farmer usually needs to grow more that one crop; e.g. to satisfy dietary requirement, to spread labour peaks, to guard against pest and disease incidence risks and market risks, etc. In this situation, a yield advantage occurs if intercropping gives higher yields than growing both the component crops separately. In fact, the combined intercrop yield does not now have to outyield the higher yielding sole-crop since, by definition, growing only the latter is not an acceptable alternative to growing both crops. This is much the commonest situation in practice. Unfortunately, it is also a situation in which the magnitude or even the existence of a yield advantage is not readily apparent. Part of the problem is that component crops which are often very different in type, or level, of yield must be put on some comparable basis. A more difficult aspect is that any assessment of yield advantage involves the comparison of an intercropping situation in which the component crops are competing with each other and a sole-crop situation in which they are not. Such a comparison must take into account the competitive relationship between crops.

Net income of intercropping systems

The net income has served for a long time as the basis for comparing different cropping systems. It has the advantage that it compares not only the biological efficiency of cropping systems but also takes into account the fact that inputs, mainly labour in this context, are limited and have to be used in different amounts for different cropping systems. There are several disadvantages to this method and it is therefore being replaced more and more by the LER. The calculation of net income assumes that the farmer is producing for the market and can change his cropping pattern with changing price relations. But this is not always correct because the multiple production goal of the majority of smallholders is not maximisation of cash income, i.e. they do not produce mainly for the market but, at first, they have to meet the subsistence needs of their families. Except for genuine cash crops, only surpluses are marketed. Another disadvantage is that market prices change with time and from region to region. Therefore, the use of net income criteria allows the comparison of cropping systems only with limited areas and over limited periods.

Yield stability

When discussing yield advantages and explaining the concept of the LER, the impression may be given that the only advantages of intercropping are higher yields or higher net incomes, and that research on intercropping is only concerned with increasing yields. Apart from ecological and socio-economic aspects, a major advantage of mixed cropping is yield stability, i.e. reliable food production over the years.

When improving cropping systems, especially in areas with climate and pest or disease epidemic hazards, it is not the maximum yields under favourable conditions but acceptable yields over a number of years which are of interest. In fact, intercropping systems give more stable yields than sole-cropping systems. This is one of the main reasons why farmers still prefer this system.

There are several reasons why intercrops give more stable yields than sole-crops. One basic principle of intercropping is compensation. When one component crop suffers from drought, pests or diseases, and does not develop properly, the loss of this crop is compensated at least partially by the other component crop(s), since there is now less competition for resources. No compensation could be obtained, on the contrary, if a farmer has planted sole-crops only. He would obtain no yield or only a small yield from one field, while the yields of the other crops would remain unchanged.

ON-FARM EXPERIMENTATION OF INTERCROPPING SYSTEMS

Research on intercropping, if it is to serve the small-scale farmers, has to be organised along lines different from the approach used in the past. Besides investigating basic questions, more importance must be attached to adaptive research. Promising cropping systems have to be adapted to the specific agro-ecological zones and economic and socio-cultural conditions. This cannot be done entirely on research stations but requires on-farm experimentation. The farmer should participate actively at the stage of planning of experiments. Only continuous contact with the farmer will ensure that the methods developed are accepted by the majority of the farmers in the end. On-farm experimentation passes through different phases with an increasing participation of the farmer, from research managed, researcher executed, through research managed-farmer executed, to farmer managed-farmer executed trials. On-farm experimentation must be much simpler than station experiments, i.e. with a reduced number of treatments and replications to enable the farmer to realise differences between treatments. Farmer-managed trials should be nearly of field size, as only this will force farmers to take real decisions as regards the timing and quantity of inputs (mainly labour).

CONCLUSIONS

To improve intercropping system, not only a higher productivity but also a reduction of crop losses due to pests, diseases, and weeds must be aimed at. Higher plant populations and early ground cover by one of the component crops can contribute directly to weed control. The reduction of pests and disease, however, depends much more on the species and varieties in the association, crop ratios, relative planting time and also on agro-ecological conditions. Not enough is known yet to make full use of the potential of intercrops in this respect. There is no doubt that the reduction of yield losses will only be small and not comparable to those achieved by means of chemical crop protection.

In spite of these limitations, the potential of intercrops for reducing yield losses must be regarded as one of the main advantages of these cropping systems, in particular because chemical crop protection is no real alternative in smallholder food production.

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2. A REVIEW OF THE USE OF INTERCROPPING IN DISEASE CONTROL

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CONTENTS

INTRODUCTION

Intercropping, that is, the growing of two or more crops simultaneously on the same area of land, is widely practised by small farmers in tropical countries. This system, at one time regarded as primitive, is now perceived to have significant advantages. Of these, better use of available land and reduced risk of losses from diseases, pests and weeds are of particular importance (11).

It is not surprising that diseases tend to be less severe in intercrop systems (Table 1). It is a part of the conventional wisdom of plant pathologists that large scale cultivation of genetically uniform crop plants favours the development of disease epidemics. By the same token it is to be expected that mixed cropping or intercropping should reduce the risks of epidemic disease.

The question must be asked, however, whether the reduction in disease achieved by intercropping is sufficient to preclude the need for other control measures. The answer to this question may well vary for different locations, different intercrop components and for different diseases. A subsidiary question but one of great importance is whether the benefits of intercropping can be improved by detailed modification of the system eg by choice of more suitable crop cultivars or by modification of the planting pattern.

Answers to these questions are urgently needed. They may enable better agronomic practices to be introduced and also enable attention to be focussed on specific diseases which require the introduction of additional control practices.

Research into disease development in intercrop systems is not likely to be easy but it need not be an entirely "hit or miss" affair. In the past two decades there has been intensive research into the interaction between pathogens and heterogeneous plant populations. These studies provide important clues concerning the mechanisms whereby epidemics are diminished in severity and indicate how intercrop systems may be modified to improve disease control.

MULTILINES AND MIXTURES

In Europe and North America the major small grain cereals (wheat, barley, oats) are inbreeders and cultivated varieties are genetically highly homogeneous. Moreover, individual varieties are planted on a vast scale offering the maximum opportunity for epidemic development of pathogens. Control of foliar pathogens, particularly rusts and powdery mildew, by means of resistant varieties has been bedevilled by pathogen mutation. As fast as the plant breeder introduces genes for resistance so does the pathogen produce mutant forms capable of overcoming them. To deal with this dilemma, plant breeders and plant pathologists have attempted to develop new strategies of exploiting host resistance. Broadly speaking these fall into two groups: (i) increasing diversity within the crop and (ii) increasing diversity between crops. The first has a relevance for intercropping: the latter does not.

To increase diversity within crops, two approaches have been attempted. The first is to use multilines, i.e. mixtures of near-isogenic lines differing only in specific resistance genes. This approach was advocated by Jensen (16) and Borlaug (2). Browning & Frey (4) developed the first multiline in oats to combat crown rust (*Puccinia coronata*). The benefits in terms of reduced disease development and increased yield were clearly demonstrated. Nevertheless multilines have not been widely adopted, largely because of the time required for their development. For this reason Wolfe (28) who was particularly concerned with powdery mildew of barley (*Erysiphe graminis* f. sp. *hordei*) chose to use mixtures of existing cultivars containing different resistance genes in an attempt to reduce its severity. In the present context the work of Wolfe and his colleagues is of particular importance because, in addition to showing that disease progress was reduced in cultivar mixtures they also attempted to elucidate and quantify the mechanisms involved (8).

Before these studies were undertaken a number of mechanisms had been proposed to account for the reduction in disease in multilines and mixtures. Some (19,4) considered interception of spores by resistant plants was of major importance whilst others (5,6) placed emphasis on reduction in density of susceptible plants. A further mechanism suggested was induced resistance or cross protection (3,17). From their studies Chin & Wolfe (8) were able to conclude that all three mechanisms operated in cultivar mixtures designed to control powdery mildew of barley. Their relative importance, however, varied depending on the stage of crop and epidemic development, and on the host and pathogen genotypes.

Although most of the studies on pathogen development in heterogeneous plant populations have been concerned with race-specialised pathogens it is important to note that mixture benefits also occur with non-race specialised pathogens as shown by Jeger *et al* (14) for the interaction between *Septoria nodorum* and cultivar mixtures of wheat. In this situation cross protection probably does not play a significant role; barrier and density effects are presumed to be the principal mechanisms involved.

In mixtures of crop species it is to be expected that all three mechanisms identified by Chin & Wolfe (8) (and possibly others so far unidentified) may play a part in reducing disease severity.

Table 1: Published reports of effects of intercropping or mixed cropping on disease severity, 1981-1986. (Source: Review of Plant Pathology).

Crops	Diseases increased (I) or decreased (R)	Reference
Beans/maize	*Pseudomonas phaseolicola*(R) *Collectotrichum lindemuthianum*(R) *Xanthomonas phaseoli*(R) *Elsinoe phaseoli*(R) *Phoma exigua* var *diversispora*(R) *Erysiphe polygoni*(R)	Rheenan *et al*. (1981)
Potatoes/lupins Potatoes/beans	Potato diseases significantly reduced when intercropped(R)	Steiner, (1982)
Maize/legume	*Ustilago maydis* increased by 50% in mixed crop(I)	Hegewald (1984)
Cocoyams/plantain	*Sclerotium rolfsii* on cocoyam(R)	Igbokwe *et al*. (1984)
Pigeon pea/sorghum	Pigeon pea sterility mosaic virus (I)	Bhatnagar *et al.* (1984)
Okra/pumpkin	Yellow vein mosaic virus in Okra(I)	Khan & Mukhopadhyay, (1985)
Cocoa/coconut Cocoa/*Leucaena*	Pests and diseases less with coconut as shade trees than with *Leucaena leucocephala*(R)	Smith (1985)
Vigna mungo/*V.radiata*	Yellow mosaic virus on both *V.mungo* and *V.radiata*(R)	Dasgupta & Chowdhury, (1985)
Cotton/*Vigna radiata* Cotton/*Vigna mungo*	Stenosis in cotton(R)	Padaganur *et al*, 1985
Oat/barley/wheat	*Puccinia coronata*(oats)(R) *Erysiphe graminis*(wheat)(R) *Helminthosporium teres*(barley)(R)	Dzietror, 1985
Beans/maize	Web blight of beans(R) Espinosa (1986)	Rosada May & Gracia
Chickpea/linseed	Wilt of chickpea (*Fusarium oxysporum* f.sp. ciceri)(R)	Chattopadhyay & Bagchi (1986)

PLANTING PATTERNS

In multilines and cultivar mixtures of cereals, individual genotypes are randomly distributed but this is not normally the case with intercropping. Variation in planting pattern may be considerable, and it is important to enquire whether different patterns significantly influence disease development. Recent studies using both computer simulation and field experimentation offer some clues. Computer simulation of situations in which the distribution of susceptible and non-susceptible individuals is varied (20, 21) have indicated that clustering of susceptible individuals, even though they comprise the same proportion of the population, decrease the benefits of the mixture effect. Support for this conclusion has been provided by field studies using intraspecific mixtures of beans and maize (22).

These results have obvious implications for intercropping systems and indicate that investigation of planting patterns is likely to be rewarding.

CONCLUSIONS

Evidence from many studies on diverse intercrops indicates that in general disease is likely to be less severe than in pure stands. Experimental data from multilines and cultivar mixtures of small grains (wheat, barley, oats) of maize and of beans all show that genetic diversity depresses the rate of epidemic development of pathogens. Because the basic mechanisms contributing to the mixture benefit are becoming better understood, the effects of mixtures on disease development can now be analysed in these systems by computer simulation.

It may well be that the situations presented by intercropping are more complex than in multilines and cultivar mixtures but as understanding of intercropping effects increases there seems no reason why it should not be possible to provide computer models which will enable refinements to be made.

At the present time two specific recommendations can be made which should enhance the benefits of intercropping in terms of disease reduction. First, intercropping should minimise clustering of individual components as far as possible: second intercrop components should, if possible, be genetically diverse.

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3. INTERCROPPING AND ITS USE IN CONTROLLING STEM BORER COMPLEX

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CONTENTS

INTRODUCTION

Plant diversity has long been known to affect both the diversity (7,11,12) and stability (10,17,21) of the herbivore community. Studies comparing the abundance of specialist herbivores in simple and diverse communities have documented that the density of herbivores is greater in monocultures of host plants than in more diverse habitats (1,4,5,9,12,15,18).

In studies conducted at the International Centre of Insect Physiology and Ecology (ICIPE), by Amoako-Atta and Omolo, (3) and Omolo and Seshu Reddy (8) intercropping was found to be one of the major cultural components of a pest management package. They identified the best crop combinations to minimise stem borer populations and to stabilise productivity by reducing yield loss. The best was sorghum interplanted with cowpea. This was followed by maize intercropped with cowpea, then maize intercropped with cowpea and sorghum. The worst combination was maize intercropped with sorghum.

Smith (16) cautioned that the same kind of diversity can be harmful in one instance and beneficial in another. Therefore one cannot generalise unless tests have been conducted in different ecological zones for a number of seasons.

The objective of this study therefore was to demonstrate that intercropping was one of the major cultural methods of controlling pests and to test and/or confirm this in three different ecological zones representing major agricultural ecosystems in East, Central and Southern Africa.

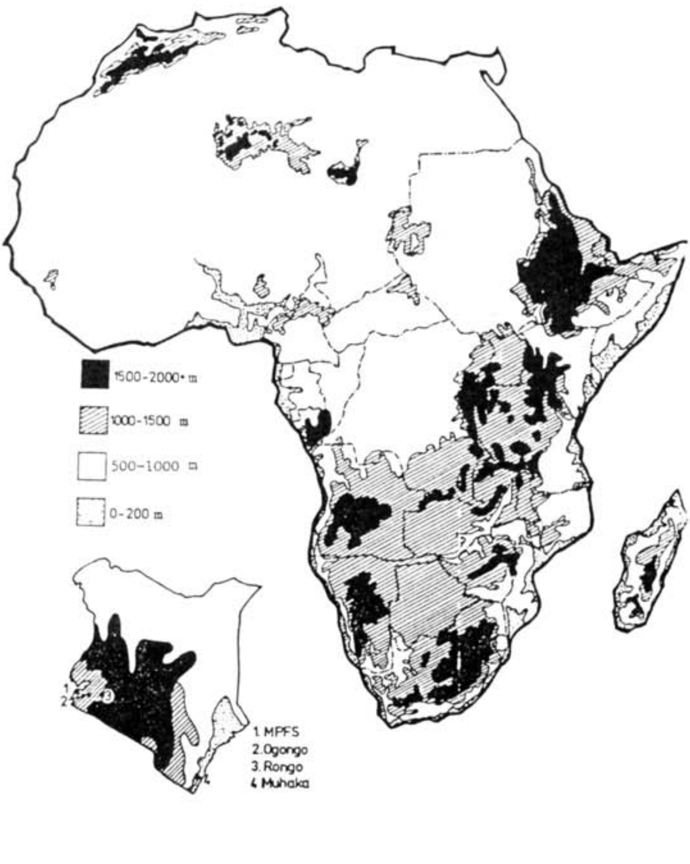
MATERIALS AND METHODS

Most of this research was conducted at the International Centre of Insect Physiololgy and Ecology (ICIPE), Mbita Point Field Station (MPFS) on the shores of Lake Victoria in Western Kenya, at 0°26' 0° 28' South and 34°-14' -34° 17' East at an altitude of 1170m. Eight different cropping systems were compared in a randomised block design. These consisted of monocrops of maize, cowpea and sorghum, intercrops of maize + cowpea, maize + sorghum, sorghum + cowpea and with all these crops interplanted in alternating rows and mixed within the row. The experiments were planted at the ICIPE - Mbita Point Field Station and also in farmers' fields at Kirindo and Ogongo in Lambwe. Each treatment plot measured 24 x 21 m with 3 m pathways between plots which were sub-divided into 56 sub-plots or sampling units of 9 m^2 each. A complete description of the experimental layout and sampling techniques have been reported elsewhere (Amoako-Atta <u>et al</u>., 1982).

The variety of maize used was "Katumani", a local East African Variety which grows to approximately 180 cm at Mbita Point Field Station and matures in about 100 days. It is considered drought tolerant. The cowpea was "Ex-Luanda", a semi-erect local cowpea variety, well established in the Lake Victoria region, with a relatively short maturity period of about 70 days. It is a type particularly suitable for areas with erratic, short duration rainy seasons. The sorghum variety used was "Serena", a high tillering, drought tolerant population type suitable for lowland areas (below 1530m), which grows to approximately 120 cm with a maturity period of 110 to 120 days. In this study a "crop unit" of one maize plant was considered equal to two sorghum plants or to three cowpea plants (22). The plant populations with the different intercropping patterns were adjusted, using the substitutive model (23) to maintain a uniform carrying capacity per unit land area for each cropping system.

The experiments were conducted in three major ecological zones in Western Kenya: ICIPE, Mbita Point Field Station (low erratic rainfall with intensive stem borer population) as shown in Figure 1.

Figure 1: Maps Showing Testing Sites in Kenya and the Major Agricultural Zones in East, Central and Southern Africa.



The method of assessing yield loss under natural conditions was based on the procedure described by Judenko (6). In this the yields from sets of plants growing under identical conditions attacked or free from attack are assessed and compared. The land equivalent ratio (LER) was used as a yield index. The target pests studied were Chilo partellus (Swinhoe), Busseola fusca (Fuller), Sesamia calamistis (Hmps.) and Eldana saccharina (Wlk.) on sorghum and maize and Maruca testulalis (Geyer) on cowpea.

The parameters assessed were the percentage of plants attacked, yield per hectare expressed in terms of land equivalent ratio, and percentage yield lost due to stem borer infestation. The experiment was conducted during both the major season (March - July) and the minor season (September - December) in 1982, and during only the major season at Kirindo in 1981 and 1982.

RESULTS AND DISCUSSION

There were significant differences in the mean percentage of plants attacked, productivity and estimated yield loss due to stem borers between the different cropping systems. The intensity of attack of maize differed between the two seasons (Figure 2). The levels of borer attack on maize in the maize monocrop had already reached > 30% at 28 days after germination (DAG) in the minor season whereas it was not until the 56 DAG in the major season that such differences were observed (Fig. 2). The cropping pattern also affected the pest species composition (Fig 2). Stem borer colonisation and establishment on maize plants in the monocrop and maize-sorghum intercrop were earlier (> 28 DAG) and increased with time between 28 and 84 DAG (Fig. 2) but at 98 DAG the levels of borer attack within all cropping systems were not significantly different from each other. The incidence of Heliothis armigera coincided with maize cob setting (> 56 DAG) but no definite pattern emerged. Chilo partellus was consistently the dominant stem borer observed attacking maize. Although B. fusca, S. calamistis and E. saccharina were recorded (Fig. 2) their frequency of occurrence was not influenced by the cropping pattern. Attack by stem borers other than C. partellus was in all cases less than 20% of the overall borer attack. Intercropping systems of all cereal/cowpea combinations significantly reduced the level of C. partellus attacks (Fig. 1). This suggests that the presence of cowpea adversely affected the establishment of C. partellus up to 56 DAG resulting in reduced population build up or attack on maize.

The intensity of stem borer attack on surghum in the different cropping systems was significantly higher in the minor season (Fig. 3) than in the major cropping season (Fig. 3). No stem borers were recorded in the 14 DAG sampling during the major cropping season. The stem borer colonisation and establishment in all the cropping systems was delayed in the major cropping season up to until 70 DAG (Fig. 3). After then the pest attack increased so rapidly that by that by 98 DAG, there was no significant difference between levels of borer attacks within the different cropping systems. During the minor season, the cropping systems with cowpea had stem borer infestation and colonisation significantly delayed. This again suggests that systems with cowpea had reduced borer attack (Fig. 3). Maruca testulalis attack was confined to within 30-70 DAG, corresponding to the period from flower bud initiation to pod maturation. Maruca attack of cowpea in the sorghum and cowpea dicrop was significantly less than the other cropping systems.

The overall pattern of stem borer attack on farmers' fields at Kirindo, was similar though considerably lower than that at the Research Station (Fig. 4).

Figure 2: Stem Borer Attacks on Maize at MPFS in 1982

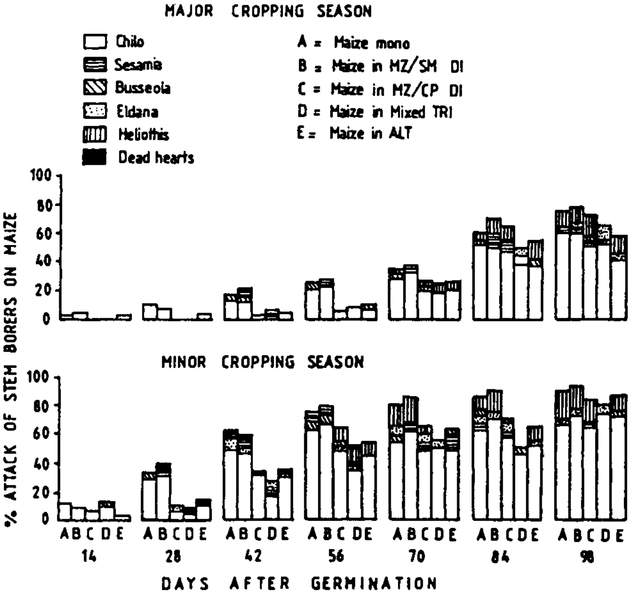


Figure 3: Stem Borer Attacks on Sorghum at MPFS in 1982

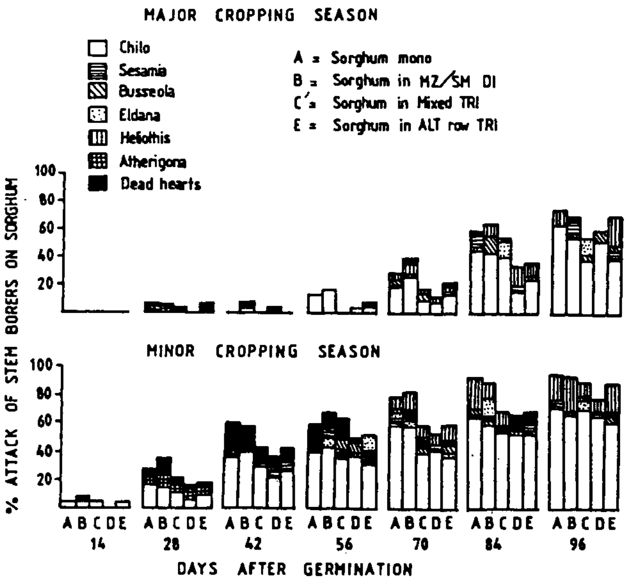


Figure 4: Stem Borer Attacks on Maize at Kirindo in 1981

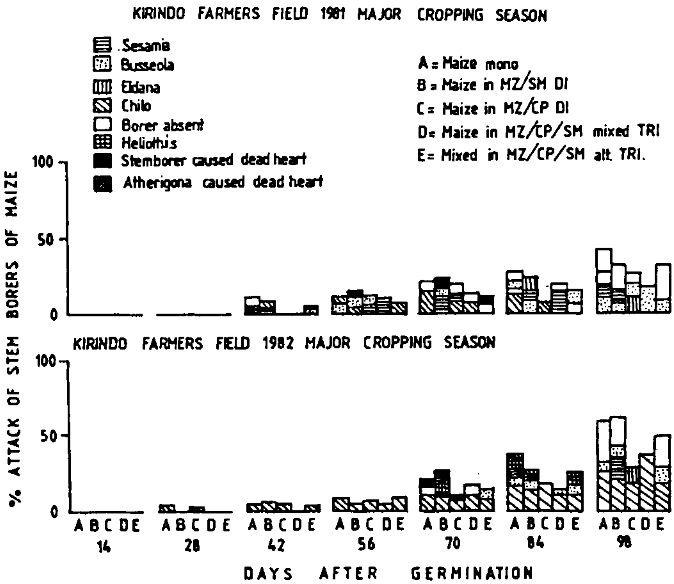


Table 1 gives the overall percentage borer attack of maize, sorghum and cowpea and land equivalent ratios (LER) for the three locations. The combined (for all locations) data show that maize as a sole crop (20.66%) and maize and sorghum grown together (21.45%) both suffered significantly more attacks than maize intercropped with cowpea (14.93%) or maize intercropped with sorghum and cowpea (15.09%). Similarly, sorghum sole crop and sorghum intercropped maize suffered 21.35% and 21.64% attack respectively, both significantly higher than sorghum intercropped with cowpea (14.76%) or sorghum intercropped with maize and cowpea (14.49%). The attack on cowpea by Maruca was much higher on sole cowpea (35.45%) than on cowpea intercropped with sorghum (22.16%) or with maize and sorghum (27.12%). All the intercropping systems had an advantage over sole crops in terms of LER, which was > 1. This meant that intercropping sorghum or maize with cowpea increased productivity by 10% while the maize, sorghum and cowpea system improved production by 17%. The least productive combinations were sole cropped sorghum and maize, where the LER value was < 1. In general, the intercropping advantage in two crop combinations was lower than in previous experiments. This could have been due to low yields resulting from heavy borer attack at Mbita Point Field Station in those years. In summary, sorghum and maize in monculture or planted together suffered more borer damage than sorghum, maize or sorghum and maize intercropped with cowpea, suggesting that cowpea protected cereals from cereal stem borer attack. Similarly, the cereals also protected cowpea from pod borers.

Yield loss in maize was significantly less only when it was intercropped with both sorghum and cowpea (5.51%). Yield loss in sorghum intercropped with cowpea was significantly less (6.92%) than sorghum as a sole crop (16.67%) or intercropped with maize (21.12%). When intercropped with maize and cowpea,

Table 1: Mean Percentage Attack by Crop Borers*

Cropping Patterns	MAIZE				SORGHUM				COWPEA			Land Equivalent Ratio (LER)
	MPFS	OGONGO	RONGO	COMBINED	MPFS	OGONGO	RONGO	COMBINED	MPFS	RONGO	COMBINED	
Mz	39.37	19.32	3.28	20.66[a]								1.0[a]
Sm					40.41	21.50	2.14	21.35[b]				1.0[a]
Cp									60.3	10.6	35.45[c]	1.0[a]
MzSm	41.89	20.05	2.41	21.45[a]	40.76	22.5	1.66	21.64[b]				0.91[a]
MzCp	31.09	12.74	0.95	14.93[b]					50.5	5.22	27.86[b]	1.05[b]
SmCp					30.46	13.49	0.34	14.76[a]	41.0	3.32	22.16[a]	1.09[b]
Mz/Cp/Sm	30.85	13.14	1.28	15.09[b]	27.34	12.69	3.44	14.49[a]	48.4	5.85	27.12[b]	1.17[c]
Mean	35.80	16.31	1.98		34.74	17.54	1.89		50.05	6.26		

Mean values followed by same letter are not significantly different at $P = 0.05$.

Table 2: Yield Loss Assessment in Farmers Fields on Maize Sorghum and Cowpea

	Percent yield loss in maize due to stem borer	Percent yield loss sorghum due to stem borer	Percent yield loss in sorghum tillers due to stem borer	Percent yield loss in cowpea due to pod borer
maize	10.22[a]			
sorghum		16.67[c]	30.2[a]	
cowpea				30.5[c]
maize/sorghum	12.0[a]	21.12[c]	15.85[b]	
maize/cowpea	10.56[a]			23.05[b]
sorghum/cowpea		6.92[a]	11.95[b]	14.22[b]
maize/cowpea/sorghum	5.51[b]	11.35[b]	24.0[a]	18.85[b]
Mean	9.57	14.01	20.5	21.65

Mean values followed by same letter are not significantly different at $P = 0.05$

sorghum losses were significantly less (11.35%) than as a sole crop or when intercropped with maize. Sorghum tiller damage showed significant differences as well. In sorghum intercropped with cowpea, tiller loss was significantly less (11.95%) than in sorghum as a sole crop (30.2%) or intercropped with maize and cowpea (24.0%). In the case of cowpea pod borers, yield loss was significantly greater under monoculture (30.5%) than when it was intercropped with sorghum (14.22%), maize (23.05%) or with both sorghum and maize (18.85%) (Table 2).

Intercropping has always been an important component of small farm agriculture in the tropics. Sorghum and legumes grown together are among the most important traditional systems of tropical agriculture. With the introduction of maize, particularly the new high yielding hybrids, intercrops of maize and beans or of maize and sorghum are often planted. Lower susceptibility to pests and diseases is among the several advantages attributed to these systems (19,20). Altieri et al (1) reported that intercropping maize with beans reduced pest populations compared to monocultures of the same crops. Similarly, Singh and Singh (13,14) reported that the presence of the legumes green gram, black gram and pigeon pea reduced the succession and build up of insect pests in sorghum and pearl millet. These findings are supported by the results of this study, where the presence of cowpea reduced stem borer incidence on maize and sorghum, an advantage not shown by any cereal intercrops lacking the cowpea component.

In summary, the incidence of stem borers is increased when maize and sorghum, both of similar plant type and host range for stem borers, are intercropped. On the other hand, intercropping with cowpea, which is not a host of stem borers, considerably reduced the incidence of stem borers on both maize and sorghum. The presence of both cereals also reduced pod borer incidence in cowpea. This study has confirmed its main objective which was to show that, in accordance with Amoaka-Atta et al (1983), insect pest colonisation, population build-up and establishment was related to the cropping system and the cropping season.

CONCLUSION

Crop combinations of sorghum and maize appeared to promote whereas sorghum and cowpea hampered colonisation and build-up of insect pest populations. Within a cropping system, similarity of plant type and host range for a particular insect pest appear to increase the incidence of that pest. Intercropping has pontential as an important cultural method of insect pest management in tropical agriculture.

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CHAPTER III

WEED PROBLEMS AND THEIR CONTROL

A REVIEW OF MAJOR WEED CONTROL PROBLEMS IN EAST AND CENTRAL AFRICA WITH PARTICULAR EMPHASIS ON STRIGA AND INTERCROPPING PRACTICES

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CONTENTS

INTRODUCTION

Weeds are the most neglected of the major groups of crop pests, despite being responsible for estimated losses of 25% of potential yield in the developing countries. Manual land preparation and cultivations to control weeds can account for 50% of the total time required to produce crops and tie up millions of man-days of labour which might otherwise be available for more productive and rewarding activities.

It is paradoxical that ever-present weeds attract less research, extension and training activities than pests such as locusts, armyworm and quelea birds which are present intermittently. This is not to imply that resources provided for the study and control of other pests is excessive, but that weed science in the developing countries is undercapitalized.

There may be several reasons for the failure to recognize the importance of weeds:

(a) damage to crops by weeds is less conspicuous than damage caused by insects, diseases and other pests. The effects of weed competition on an otherwise healthy crop are not as apparent as a few nibbled or diseased leaves;

(b) there is a fatalistic acceptance that weeds will always be present, regardless of what is done to eliminate them;

(c) cultural and social barriers can prevent effective dialogue on weed problems and methods of control between the male-dominated extension service and the women who often do the weeding.

Labour constraints during the first few weeks after sowing a crop, when it is most vulnerable to competition, are a common cause of poor weed management. Herbicides have potential but their use may be prevented or constrained by a number of factors. They may not be readily available. Farmers may not be able to afford them or have access to suitable equipment. In many cases there is little or no knowledge or information on their use. Sexist attitudes can also be a factor where men are reluctant to invest cash and resources in traditional women's activities.

Weeds occur as a consequence of cropping practices. Sedges, for example, are often associated with irrigated crops and perennial weeds can become prevalent where zero-tillage is practised. It is logical, therefore, that weeds are affected by the types of crop management being employed and this is the basis for integrated weed control. Weeds can be alternate hosts of insects, diseases, other pests and also for the predators of these pests. Hence, the control of a weedy host has implications for control of pests and their predators and, ultimately, crop yields. The control of an insect may afford some protection to the weed host as well as the crop. The concept popularly known as integrated pest management can be very complex and daunting to use by small-scale farmers.

COMMON WEEDS OF EAST AND CENTRAL AFRICA

Common weeds of the region are well-documented: inexpensive publications containing descriptions, photographs and/or line drawings of weeds are available for Kenya (10,18), Malawi (4), Tanzania (10,18), Uganda (10,18), Zambia (19) and Zimbabwe (7). As many as 200 species are described in these publications, of which 30 species are described or mentioned in every book (Table 1). Nearly all of the 30 species have a pan-tropical distribution.

Table 1. **Common and Ubiquitous Weeds of East and Central Africa**

BROAD-LEAVED SPP.	GRASSES	SEDGES & COMMELINA
Annual species		
Acanthospermum hispidum	Dactyloctenium aegyptium	
Ageratum conyzoides	Eleusine indica	
Amaranthus hybridus	Rottboellia cochinchinensis	
Bidens pilosa	Setaria pumila	
Datura stramonium	Setaria verticillata	
Euphorbia heterophylla		
Euphorbia hirta		
Galinsoga parviflora		
Gynandropsis gynandra		
Nicandra physalodes		
Oxygonum sinuatum		
Portulaca oleracea		
Solanum nigrum		
Sonchus oleraceus		
Striga asiatica		
Tagetes minuta		
Tribulus terrestris		
Trichodesma zeylanica		
Perennial species		
Oxalis latifolia	Cynodon dactylon	Commelina benghalensis
Solanum incanum	Imperata cylindrica	Cyperus esculentus
		Cyperus rotundus

Individual species of weeds are not necessarily problematical in their own right. It is more usual to see them as components of a mixed flora where competition with the crop for nutrients, water and light can arise from the growth of few or many species. This is often the case in fields where weed control is done by cultivations. Herbicides can be excellent aids to hand labour but when used as a replacement for this labour, especially if the same product is used repeatedly, resistant weeds become established and the species diversity of the flora becomes smaller. This can be seen in wheat and barley where repeated use of 2, 4-D has promoted annual grass weeds, and in coffee plantations where paraquat tends to encourage perennial grasses and sedges. Individual species, even at relatively low densities, do become important if they act as alternate hosts for nematodes, diseases, insects and other pests and for the predators of these pests. Some species can also be valued by farmers as food for themselves and their livestock, raising the question, "are these plants weeds if they are useful?"

SELECTED PROBLEM WEEDS AND THEIR CONTROL

There are several species of weeds of considerable importance in East and Central Africa which are difficult or expensive to control. They are natural targets for research aimed at all levels of agriculture. Methods appropriate for estates growing cash crops may be inappropriate for use by subsistence farmers.

When devising priorities for research programmes, it is clearly important to have some idea of the magnitude of the problem and the likelihood and possible benefits of success. For some weeds, such as perennial grasses, the technology for control exists but the challenge is to find methods appropriate to most farmers. For others, such as the parasitic Striga species, there are no known methods of reliable control which are appropriate to the majority of farmers who are afflicted. Whilst it is obviously desirable to solve the intractable problems, it is questionnable whether a single country's scarce resources and manpower should be committed to trying to do so when success seems remote. Collaborative programmes with shared commitment and resources could be a better justification for pursuing research on difficult species. Striga is a weed which is suitable for this type of research, with its requirement for technologically advanced facilities and good field sites.

Examples of problem weeds in the region are given below.

Annual grasses

Common grasses of the region are given in Table 1 but other genera which contain common weed species are Avena, Brachiaria, Bromus, Chloris, Echinochloa, Eragrostis and Lolium. Some of the common grasses are of particular importance as weeds.

Avena fatua L.

A. fatua is the commonest species of wild oat in the region, existing in several types and as hybrids with cultivated oats. A. sterilis L. ssp. ludoviciana (Dur.) Nyman, A. sterilis var. maxima Perez Lara. and A. sterilis var. macrocarpa Moench are also present (18). In Zimbabwe, A. fatua is occasionally a weed of irrigated cereals and is the only serious weed of agricultural land to have been legislated against in the Noxious Weed Act (7). It is not yet a permanent weed in Zambia but has the potential to become a serious problem (19). It is present in all the wheat- and barley-growing areas of Tanzania and Kenya, infesting 30,000-40,000 ha of cereal land in the latter, causing total crop loss where weed densities are high.

The biology and distribution of Avena spp. in East Africa is worthy of study because of the existing and potential danger to cereal crops.

Preventive control needs to be practised to avoid introducing seeds of wild oats to uncontaminated areas by means of farm machinery, animal feedstuffs, gunny bags etc. Small infestations in fields should be removed by hand roguing but large populations will probably need to be treated with one of the proprietary herbicides (e.g. chlorfenpropmethyl, diclofop-methyl, difenzoquat, flamprop-isopropyl, etc.) alone or in mixtures with other herbicides (17).

Bromus spp.

Bromus pectinatus Thunb. is a tufted annual grass, locally important as a weed of highland cereals in Kenya and Southern Tanzania. B. diandrus Roth is a related weed. There is concern that these species are becoming more serious and there is need for research on their biology and control. Some herbicides are available but Bromus spp. are difficult to control and appear to be gaining in status worldwide.

Rottboellia cochinchinensis (Lour.) W.D. Clayton

This grass, known also as R. exaltata L.f., itchgrass, guineafowl grass, shamva grass and mulungwe, is one of the most serious weeds of sugar cane, maize and other annual crops in the region, particularly on medium to heavy soils of good fertility (7, 19).

Seeds of Rottboellia only live for 3-4 years, so control is theoretically possible by preventing seeding for that period of time. This has proved difficult in practice as Rottboellia is resistant to most herbicides which are applied in maize. Pendimethalin is safe in maize but performance against Rottboellia is variable. There is scope for using herbicides in other crops rotated with maize, such as trifluralin in sunflower, but it is advisable to follow chemical treatments with supplementary hand-weeding to remove 'escapes' (17).

Rottboellia is susceptible to cultivations within three weeks of emergence but, after that time, the development of prop roots gives stability. Seeds are vulnerable if they are not buried in the soil, offering scope for control by zero-tillage and fallowing.

Setaria spp.

Several species of Setaria occur as weeds in East and Central Africa but the most serious are S. pumila (Poir.) Roem & Schult.[= S.pallide-fusca (Schumach.) Stapf & Hubbard] and S. verticillata (L.) P. Beauv. Both have a cylindrical 'fox-tail' inflorescence but that of S. verticillata attaches itself readily to clothing and animal hides. They can be found in most crops but are particularly serious in wheat and barley in Kenya and Tanzania.

Both species can be controlled by cultivations when young and good control is possible with a range of herbicides. The dried inflorescences of S. verticillata deter rats when placed over the openings of grain-storage bins (7).

Perennial grasses

Perennial grasses are probably the most important weeds in East and Central Africa, seriously affecting crop production in large- and small-scale agriculture. Digitaria abyssinica (A. Rich.) Stapf and Cynodon dactylon (L.) Pers. are the most important species but other significant problem species are Imperata cylindrica (L.) Raeuschel, Panicum maximum Jacq., P. trichocladum K. Schum. and Pennisetum clandestinum Chiov.

Cynodon dactylon

C. dactylon [= star grass, couch grass (in Zambia and Zimbabwe)] has horizontal creeping stems which can be underground (rhizomes) or on the surface (stolons). C. nlemfuensis is very similar in appearance but only has stolons. C. dactylon propagates from seed, rhizomes or stolons, rapidly colonizing land cleared of weeds and other vegetation.

It is a problem in all types of agriculture and most crops where it competes vigorously. It is also suspected of being allelopathic, i.e. being able to suppress the growth of neighbouring plants by means of toxic exudates.

Desiccation of rhizomes and stolons by means of dry season cultivations is a method of control but cultivation of soils at this time can be difficult, if not impossible. Forked hoes can be used to dig out the rhizomes with minimal damage to crop roots but it is a very laborious exercise. Cutting, grazing, burning and flooding offer little or no scope for control but long-term fallowing may have potential. A few herbicides have selective activity against C. dactylon in annual crops, including fluazifop-butyl (in beans, cotton, groundnut and soybean) and sethoxydim (in cotton, groundnut and soybean). A wider range of products is available for use in perennial crops and for land preparation before crops are planted. Glyphosate is one of the best herbicides but, like many other products, its relatively high cost deters small-scale farmers from using it.

Digitaria abyssinica

D. abyssinica [= D. scalarum (Schweinf.) Chiov., couch grass (in East Africa)] is probably the most important weed of Kenya, Tanzania and Uganda. Death or severe injury to annual and perennial crops can occur with bad infestations (10, 18) and it has been suspected that damage can be due to allelopathic properties of this weed. Propagation is by rhizomes but dispersal by seeds is also possible.

As with C. dactylon, dry season cultivations are a possible, though usually impractical, method of control. Glyphosate can be used very effectively against D. abyssinica but with the same constraints as for Cynodon.

Perennial sedges

Over 50 different sedge (Cyperaceae) weeds are found in East African crops (17) of which the most important are Cyperus rotundus L. (purple nutsedge) and C. esculentus L. (yellow nutsedge). Several bulbous sedges are of local importance in East Africa, including C. blysmoides C.B. Cl., C. bulbosus Vahl var. melanolepis Kuk., C. grandibulbosus C.B. Cl. and C. usitatus Burch. (18). Common annual sedge weeds include C. iria L. and C. difformis L. but they are less important than the perennial species.

Cyperus esculentus

This species occurs in many tropical, sub-tropical and warm-climate countries where it is a weed of virtually all crops and in all levels of agriculture. It propagates by means of seeds and tubers which break from the ends of many rhizomes.

Cultivations give only temporary suppression of shoots germinating from tubers and are not a practical method of exhausting food reserves to kill the perennating organs. Frequent cultivations, until the crop has formed a canopy, will minimize competition but control is only temporary and rapid regrowth occurs when the crop is removed.

Nutsedges do not compete well with vigorous cover crops but there is little scope for this method of weed management.

Few herbicides kill nutsedges but several give useful suppression, during which time the crop can become sufficiently well established to suppress later weed growth. Products which can be used in maize and/or beans include bentazon, butylate, 2,4-D, metolachlor and EPTC. Glyphosate is one of the best herbicides for controlling C. esculentus because it can kill the tubers when applied at the correct time.

Cyperus rotundus

This species is generally more tropical in its distribution than C. esculentus but it is widely found as an important weed of most crops in East and Central Africa, especially where irrigation is employed and minimum tillage is practised. Propagation is by means of tubers which are linked to each other and the parent plant by slender rhizomes. Propagation by seed is thought to be insignificant.

Desiccation by winter tillage helps to reduce populations in Zimbabwe (7) but, in East Africa, the dry seasons are probably not long enough. Tillage at this time is also be difficult for farmers who can use only hand labour.

Few herbicides give more than temporary suppression of C. rotundus in maize and/or beans and these include butylate, 2,4-D, EPTC and vernolate. In perennial crops, it is also possible to use bromacil, dichlobenil, MSMA and terbacil. Glyphosate gives the best control of C. rotundus but it must be applied at a time when it can be taken up and translocated to the tubers connected to parent plants.

Broad-leaved weeds

Many broad-leaved weeds cause problems in the region. Some species, such as Ageratum conyzoides L. and Galinsoga parviflora Cav., have been common problems for many years. Others, such as Acanthospermum hispidum DC., show signs of increasing their range and becoming more important than in the past. As herbicide usage expands, minor weeds may be elevated to become species of some importance if they are resistant to the treatments. Such is the case with Parthenium hysterophorus L., a species which is becoming increasingly troublesome in minimum-tilled coffee in Kenya. For most of the problem broad-leafed weeds, control is possible at a price but two common genera, Oxalis and Striga contain species which defy control by methods which are economical and practical.

Oxalis latifolia

The Oxalis genus contains several weed species in Eastern and Central Africa, including O. abercornensis Knuth, O. anthelmintica A. Rich., O. barrelieri L., O. cornicultata L., O. corymbosa DC., O. obliquifolia

A. Rich., O. radicosa A. Rich., O. semiloba Sond. and O. trichophylla Bak., but it is O. latifolia Kunth. which is of major importance.

O. latifolia is widely distributed in the region where it occurs as a weed of many crops. It tends to be most serious in nurseries and gardens but is often a problem in field crops such as cotton in Uganda. It commonly occurs as a ground cover in coffee plantations but there is no agreement as to whether this is desirable or not. Little is known of crop losses due to O. latifolia but grain reductions of 24% have been observed in maize (17).

Control of O. latifolia has proved to be difficult. Cultivations alone do not seem to be appropriate, neither does slashing. Organic mulch gives temporary suppression but black polythene gives good control where it can be used. O. latifolia is shade tolerant but can be suppressed by dense crop stands and grass pastures. Eradication of this weed is possible by soil sterilization but this is impractical on all but small areas used for high value crops. Trifluralin, EPTC and oxadiazon are the most reliable of herbicides to be used against O. latifolia and control, under some conditions, has been obtained with bromacil, chlorfenac, dichlobenil, diuron, linuron, oxyfluorfen and simazine. Glyphosate can be used to give control but only after several applications in one season.

Good control of Oxalis appears to be dependant on timing of treatments, whether they be cultivations or herbicides. Some studies have been made on the biology of O. latifolia but these need to be continued and related to practical situations.

Striga spp.

Striga is a genus of parasitic weeds which contains some of the most serious weeds in Africa. S. hermonthica (Del.) Benth. (purple witchweed) is of widespread but localized importance in Kenya, Uganda and Tanzania, mostly on sandy soils of low fertility, where it is parasitic on maize, sorghum, finger millet, pearl millet and sugar cane (10,15,18). S. asiatica (L.) Kuntze (= S. lutea Lour., red witchweed) is found throughout East and Central Africa where it parasitizes upland rice and the crops listed for S. hermonthica, again on soils of low fertility (7,10,15,18,19). S. forbesii Benth. (giant maize witchweed) is less common but occurs as a parasite of Setaria sphacelata (Schumach.) Moss (= Nandi setaria pasture grass) and of rice and sorghum in Tanzania (18) and of maize in Zimbabwe (7). S. gesnerioides (tobacco witchweed) is commonly found in East Africa but shows little sign of becoming the serious pest of tobacco and legume crops that it has in other countries (17). A strain of S. gesnerioides was locally important as a parasite of tobacco in Zimbabwe but it has not caused trouble in recent years (7). S. aspera (Willd.) Benth. and S. euphrasioides Benth. occur in Tanzania and Malawi as occasional parasites of rice, maize, sorghum and sugar cane (15).

Yield losses due to Striga vary with the level of infestation but total crop failure is possible in the worst situations. Small-scale farms tend to be more afflicted with Striga than are large, mechanized estates, a fact which may be equated with better cultural practices such as crop rotations, use of fertilizers and improved varieties, etc.

At present, there are no completely reliable and practical recommendations for the control of Striga that can be given to small-scale farmers. Crop management practices and other methods of controlling Striga are summarized below but reviews of this subject have been prepared by several authors (5,6,8,13,15,16). An integrated approach employing two or more of these methods is most likely to succeed. The methods used to control S. asiatica and S. hermonthica are broadly similar so no distinction is drawn between them.

a. Cultivations

Cultivations are largely ineffective for controlling Striga. Hoeing can remove Striga but only by damaging the crop roots. After shallow cultivations, Striga can produce tillers from the broken or cut stem.

b. Hand-pulling

Seed production is halted and viable seed populations in the soil are diminished by repeatedly pulling Stringa from the ground before it produces seed. In practice this means pulling every two weeks but other frequencies of pulling have also been shown to benefit the crop (6). It takes many years to eliminate Striga by this laborious method but it is a simple procedure for a small-holder and his family. Because Striga continues to grow and mature on the stubbles of harvested crops, it is important that the parasite and stubbles be pulled out before seed is produced.

c. Trap and catch crops

Many plants produce exudates which stimulate the germination of Striga seeds. Trap crops do this without becoming parasitized, thus luring Striga into suicidal germination. Soybean, lucerne, sunn hemp and cotton can do this for S. hermonthica whilst soybean, field pea, cowpea, sunflower, linseed, castor bean and cotton can do likewise on seeds of S. asiatica. It is possible to deplete the Striga seed population over several years by including trap crops in rotation with susceptible crops. However, complications arise where a trap crop stimulates germination of, for example, a "sorghum strain" of S. hermonthica but not the "millet strain".

Catch crops also stimulate Striga germination but, unlike trap crops, are themselves parasitized. They include such plants as wild sorghums and Sudan grass [Andropogon sorghum (L.) Brot.]. These crops are utilized by planting them at a high seed rate before the main crop is sown and then destroying them, together with the attached Striga plants after 5-8 weeks and before the parasite produces seed. Land can gradually be cleared of Striga if catch crops are grown repeatedly but it necessitates sacrificing part or all of the growing season.

d. Nitrogen fertilizer and manuring

Striga tends to be less damaging to crops under fertile conditions. The exact timing of application is not critical, so long as the crop responds. Very high levels of nitrogen would be required to completely suppress Striga but even relatively modest levels can help to reduce the harmful effects of the parasite. The reasons for this response are not fully understood but there is evidence that crops produce less stimulant and become more tolerant of *Striga*. Farmyard manure and compost are reported to reduce *Striga* densities and improve crop yields.

e. Crop spacing

There is some evidence that increasing the space between sorghum plants on heavily infested land can decrease infestations on the crop. This may be explained by the fact that less stimulant is produced in a unit area of soil.

f. Date of planting

Early-sown sorghum in Sudan tends to be attacked more by *Striga* than the crop sown later in the season. This may be related to soil temperatures and rainfall: by the time that the late crop is sown, rain reduces soil temperatures to below the optimum needed for preconditioning and/or germination of the *Striga* seeds.

g. Irrigation

Striga rarely persists in wet or irrigated land so it can be suppressed by applying supplementary irrigation. Conversely, water stress can accentuate the severity of *Striga* attack.

h. Early maturing crop varieties

Crop varieties which can mature early may be able to escape the most damaging effects of *Striga* whilst also acting as catch crops. There is evidence that better yields on *Striga*-infested land can be obtained with early maturing finger millet, maize and sorghum.

i. Resistant crop varieties

Some crop varieties are resistant to *Striga* attack because they produce little or no root exudate to stimulate the germination of the parasite's seeds. Other varieties stimulate germination but resist penetration of their roots or do not allow normal development of the parasite after attachment. Selection and breeding programmes are endeavouring to exploit these forms of resistance. Cultivars of sorghum which show resistance include N-13, Framida, SPV 103, IS 9830, Dobbs, SB19 and Serene. Bulrush millet cultivar Serere 2A-9 is less susceptible to *Striga* than other types but varietal resistance in maize is not known.

The breeding of resistant varieties is likely to be one of the best methods of overcoming *Striga* as it requires little or no inputs from the farmers who suffer most from this pest.

j. Biological control

Organisms which damage *Striga* include a weevil (*Smicronyx umbrinus*), a butterfly larva (*Precis* sp.) and a range of fungal diseases but no practical biological control techniques have yet been developed.

k. Synthetic germination stimulants

Ethylene and an ethylene-releasing compound, 2-chloroethane phosphonic acid, stimulate the suicidal germination of Striga seeds when injected into the soil. This method has been used successfully against S. asiatica in the USA but would be difficult technology to adopt in the Striga-infested areas of Africa. Synthetic analogues of the naturally occurring stimulant, strigol, have been tested with some success but these products are not commercially available.

l. Antitranspirants

Recent research by Prof. G. Stewart and his colleagues at University College, London have shown that an antitranspirant applied to S. hermonthica causes rapid death of the parasite. It is suspected that preventing transpiration in the parasite causes it to overheat. Research is continuing on this novel method of control and a search is being undertaken for inexpensive, readily available compounds which can be used as antitranspirants.

m. Herbicides

Limited success has been achieved in the control of Striga with herbicides but practical methods applicable to poor, small-scale farmers are elusive. Products with reported activity include 2,4-D, MCPA, ametryn, atrazine, linuron, butylate, chlorfenac and 2,3,6-TBA. Methyl bromide can be used to fumigate the soil but it is of little practical value.

WEEDS AND INTERCROPPING

Weed management in intercrops has been the subject of very little research (2). Even so, it would be difficult in this paper to adequately review all the information available on weeds and intercropping, so outline remarks are given and the reader is advised to seek more information in the literature cited and, in particular, from references (1,2,12).

What is intercropping?

Intercropping has been defined as the growing of two or more crops simultaneously on the same land in different but proximate stands. The crops may be grown in distinct rows or intermingled with no row arrangements. Multiple cropping is defined as the growing of more than one crop on the same land in a year (1). Hence, by these definitions, intercropping is a form of multiple cropping. Both are traditional systems of farming used throughout East and Central Africa, commonly, but not exclusively, practised by subsistence and small-scale farmers. There is a considerable volume of literature available on multiple cropping and intercropping, much of which has been conveniently reviewed (9).

There are several reasons why farmers intercrop, including insurance against crop failure, better and more efficient use of labour, prevention of soil erosion and protection against crop pests (1).

Relationships between weeds and intercropping

The desire to control weeds may have influenced the evolution of cropping patterns (1,11) and there is evidence that weeds are often a greater problem in single crops than in multi-crop associations. However, if the plant density of the intercrop is the same as in the component crops grown alone, or if both are planted at their optimal densities, there may be little advantage with respect to weed control from intercropping. In some cases, weed growth where intercrops are grown may be as serious or even worse than where sole crops are planted (11).

The weed-suppressing ability of intercrops is dependent upon factors such as the characteristics of the component crops and the selected cultivars, plant density, proportions in which the component crops are grown, their spatial arrangement, and the fertility status of the soil. Other environmental and biological factors may also play important roles (2). Intercropping has potential as a means of weed control because it offers the possibility of a mixture of crops capturing a greater share of available resources than in monocropping, pre-empting their use by weeds (2). Conflicting results are reported for the effects of intercropping on weed growth, not only between different intercrop combinations but also within them and it is evident that no clearcut statement can be made as to whether intercropping reduces weed growth (11). Some examples which illustrate this point are given below.

a. The competitive ability of maize is enhanced if it is intercropped with mung bean (3). As the level of weed control is reduced, the relative advantage of intercropping increases to a point where its productivity is 75% greater than that of monoculture.

b. A 50-75% reduction in weed infestation can be achieved by intercropping pigeon pea with crops like sorghum, millet, cowpea and field beans. Sorghum-based intercropping systems are 25% more efficient in keeping down weed growth than single crop systems. However, intercropping systems based on pigeon pea do not improve their competitive ability over their respective single crops (14).

c. Growth of weeds in an intercrop may be severely depressed or hardly affected, relative to crop-free control treatments. Moreover, weed growth in intercrops may be lower than in all the component monocultures, lower in one of the monocultures, or equal in the intercrop and monocultures (12).

d. Mung bean gives better control of weeds than groundnut and sweet potato when they are intercropped with maize at low maize plant populations and wide row spacing but not at high maize populations (3).

Weed management in intercropping systems

Just as in single crop situations, the methods employed to control weeds in intercrops can be very diverse. However, intercropping does impose constraints on the use of some methods (e.g. herbicides) whilst allowing the exploitation of others (e.g. crop competition). Examples of various weed control strategies in intercrops are outlined below.

a. Manual and mechanical methods

Manual and mechanical methods of weeding are most commonly practised in intercrops. Intercropping may or may not help to suppress weeds but controlling these weeds by hand and mechanical cultivations is difficult if the crops are not sown in rows. Tillage operations are further complicated if the critical periods of weed competition in intercropping are longer than those for sole cropping, thereby extending the weeding operations to secure optimum yields (11). Cultivations can be facilitated if the crops are conveniently spaced. For example, it has been noted that two rows of legumes planted very close to a row of maize with a distance between maize rows of one metre, allows cultivation between the intercrop rows and the weeds within them can be removed by hand (11).

b. Crop selection and spacing

Crops vary in their growth rates, spreading habit, weight, canopy structure, inherent competitive character and, by virtue of these characteristics, their ability to suppress weeds (14). By growing two or more crops together, one is able to combine the different weed suppressing characteristics of these crops. For example, quick-growing ground covers such as groundnuts can be grown with erect crops such as maize. Individually, they are susceptible to particular types of weed competition but this is reduced when these crops are grown together.

Crop cultivars may also be selected for being better able to compete with weeds. Little work has been done on this in relation to intercropping but there is evidence that some maize and mung bean cultivars are better than others (2).

Spatial arrangements and the proportions of component crops influence yields and weed growth. It is difficult to generalize about this because of the complexity of the interactions between crops and weeds but there are examples throughout the literature extolling the virtues of one system compared with others.

c. Herbicides

The use of herbicides by the types of farmers who tend to practise intercropping is a subject worthy of review in its own right. Putting aside the arguments for the against herbicides, and considering only the feasibility of using herbicides in intercropping, one can conclude that chemical weed control is possible in some circumstances. The greatest limitation is in finding products which can be safely used in all the component intercrops whilst also having activity against the weeds that are present. It is relatively easier to achieve this when one or none of the crops are present, such as before planting, than when the crops have been sown or have emerged together. However, products do exist and, taking a maize/bean intercrop as an example, they include alachlor, linuron, metobromuron, metolachlor and pendimathalin (17).

d. Integrated weed control

This is one of the best and most appropriate methods of managing weeds in crops grown alone or together. Absolute reliance upon one method of weed control can lead to the establishment of weeds resistant to that method but combining one or more different methods reduces this threat. Many permutations of weed control treatments (e.g. cultivations, herbicides, timing of weeding operations etc.) and crop management practices indirectly related to weed control (e.g. planting dates, crop spacings, crop varieties, fertilizer applications, irrigations etc.) can be identified. All farmers can benefit from integrated weed control by selecting methods most appropriate to their needs.

Weed research needed in intercropping systems

Intercropping is practised in many different ways but numerous interactions confound attempts to find simple rules for the management of these systems. Despite this, intercropping is widespread in the developing countries and, as there is a strong requirement to improve agricultural production, the problems of pest management in these systems must be addressed. Weeds are no less important in intercropping than other pests but there has been remarkably little research done on their control. Willey (20,21) has summarized the research needs for intercropping in general and Akobundu (1) has identified the following research needs for weed management in these systems.

a. Weed-crop competition

Competition within crop species and between crops and weeds needs to be understood as a basis for the efficient management of weeds and the adoption of appropriate agronomic practices. Not enough is known about optimum plant populations, spacing, fertilizer requirements and planting times. It is also necessary to identify the economic threshold level of various weed associations in the major intercropping systems.

b. Allelopathy

Crops which exert allelopathic influences on other crops and/or weeds need to be identified with regard to their suitability for intercropping systems.

c. Shifts in weed flora

It is desirable to monitor shifts in weed floras in relation to land-use pattern since an ability to predict them could be important in weed management.

d. Chemical weed control

Modifications in formulations and the use of protectants offer opportunities for the development of economical [and safe] herbicides for mixed cropping systems. Research is needed to identify appropriate herbicides and application equipment.

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CHAPTER IV

MAIZE STEM BORERS
- YIELD LOSS AND DAMAGE

A REVIEW OF YIELD LOSSES AND DAMAGE CAUSED BY MAIZE STEMBORERS IN EASTERN, CENTRAL AND SOUTHERN AFRICA

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CONTENTS

INTRODUCTION

Maize, Zea mays, is one of the most important staple cereal crops in the developing world. In 1977 the area under maize cultivation in Africa was 17 per cent of the world's total and the grain produced accounted only for 7 per cent (FAO, 14). In eastern, central and southern Africa, maize is an important source of carbohydrate for the majority of the people. Maize is important as livestock feed in the form of grain or silage. In Kenya about 40,000 hectares of land are under maize cultivation in the Coast Province (46) while 1.5 million hectares were put to maize cultivation in 1985 and 1.6 tonnes of maize were realised from the southern highland regions of Rukway, Mbeya, Iringa and Ruvuma (11,20). In Malawi maize is grown in the Northern, Central and Southern Provinces (Munthali, 1987). In Mozambique, Maputo and Gaza Provinces in the South of the country are the major maize growing areas (10). In Zimbabwe, most of the maize is grown in Agro-ecological Region I, receiving an annual rainfall in excess of 1000 mm and Region II with an annual rainfall ranging from 600 to 750mm over four months (47). In 1981 the Commercial Agricultural Sector produced 997,000 tonnes of maize while the Communal Sector (resource-poor sector) produced 100,000 tonnes (Department of Agricultural Extension and Technical Services Report, Unpublished). The maize yields from the resource-poor farmers' fields are generally very low owing to damage caused by insects, diseases, nemotodes, weeds, birds and rodents. Maize yield losses of 30 per cent are generally regarded as normal (14).

Among insect pests of maize, the lepidopterous stemborers constitute an economically important group with various species belonging to the families Noctuidae and Pyralidae (18,22,13,34,17,44,45,31,27,5,41). Stemborers occur regularly in a maize crop causing damage varying from low intensity to high according to prevalent environmental conditions. Stemborers are thought to be one of the major constraints to maize production in eastern, central and southern Africa. The maize stalkborer (Busseola fusca Fuller), spotted stemborer (Chilo partellus Swin), pink stemborer (Sesamia calamistis Hmps) and the sugarcane stemborer Eldana saccharina Wlk) are widely distributed and destructive. However, the relative importance of these stemborers with respect to maize yield reduction is variable depending on prevalent agro-ecological conditions. For example S. calamistis and E. saccharina appear to be economically important in relation to yield loss in Kenya while they are insignificant in Zimbabwe. Current research activities in eastern, central and southern Africa, with regard to the interaction between maize and stemborers seems to be directed towards the acquisition of knowledge on stemborer migration, timely insecticidal application, cultural measures, bio-control agents, use of sex pheromones, resistant maize varieties and integrated stemborer management without adequate generation of information essential to the implementation of control measures. For example, it is a prerequisite that economic damage, economic levels and economic thresholds be determined in order to develop an integrated pest management (IPM) programme. Clearly this demands the collating of comprehensive data in relation to maize yield losses ascribed to stemborers. Yield losses due to stemborers are very difficult to assess precisely owing to the number of stemborer species involved, different damage symptoms, different stages of maize development attacked and the confusing presence of other pests including diseases and nematodes. These factors make separate determination of the effect of stemborers a very difficult task (12). To date very little maize yield loss studies have been conducted in eastern, central and southern Africa. However, some studies have been conducted in East Africa, Zimbabwe and South Africa by such investigators as Ingram (1958), Rose (1962), Walker (1960, 1965, 1977) and Van Rensburg et al, 1988. Investigators of maize yield loss have confined their studies to research stations without carrying out concurrent research activities on farms, especially those of resource-poor farmers. Since objective data for thorough on-farm yield loss assessment due to stemborers is lacking, the objective of this paper is to review the stemborer-yield relationship using published and unpublished work in the region under review.

DISTRIBUTION AND BIOLOGY

Maize stalkborer (Noctuidae: Busseola fusca Fuller)

The maize stalkborer is generally considered the most widespread and destructive of all insects attacking maize in eastern, central and southern Africa (27,31,3,5). B. fusca is indigenous to Africa and prefers maize as a host although it is capable of causing serious losses to grain-sorghum. It is the dominant maize stemborer at high elevations (26). In Tanzania, B. fusca is reported to be the major pest at 400 meters above sea level (20) although this altitude is considered too low for this stemborer to be the dominant species attacking maize. However, this author has observed high infestations of the maize stalkborer on maize and sorghum in a small area at low elevation in Zimbabwe where low infestations would be expected. The cause in Tanzania and Zimbabwe is a clear indication of the capability of B. fusca to adapt itself to low-lying and warmer areas. The distribution of the maize stalkborer is depicted in Tables 1 and 2. B. fusca has two generations per year but in some seasons a third generation may occur depending on the prevailing agro-ecological conditions and the presence of suitable host plants. At the onset of the dry season, second generation larvae enter into diapause in tunnels at the bases of maize stalks to await pupation later with the arrival of rains. Moths emerge three weeks after the commencement of pupation and lay eggs on the bases of leaf sheaths. Eggs hatch within a week and the newly hatched larvae migrate to feed on tender leaves in the funnel prior to entering into the stem. Observations in southern Africa are that the larvae have a tendency to penetrate the underground part of the stem as the weather becomes colder. The assumption is therefore that the minimum daily temperature in the bases of maize stalks is higher than on the soil surface and is favourable to the survival of the pest.

Spotted Stemborer (Pyralidae: Chilo Partellus)

The spotted stemborer (C. partellus) is not indigenous to Africa but invaded the continent from India (23). Its presence in South Africa was recorded in 1958 (38). Although it causes severe losses to maize, C. partellus prefers sorghum as a host plant. In eastern, central and southern Africa, the spotted stemborer appears to be confined to medium and low elevations. However, this pest is becoming an important borer of maize at high elevations in South Africa. Revington (26) reported the recording of C. partellus attacking maize in 1958 in warmer areas of Transvaal. Quite recently C. partellus has been reported to be a threat to maize at high elevations in eastern and northern Transvaal and north-west Free State suggesting that it is adapting to cold environmental conditions very rapidly (26). The distribution of this pest in the region under review is shown in Tables 1 and 2. C. partellus has three or more generations; especially where maize is grown throughout the year. The spotted stemborer is known to complete its life cycle in 30 to 40 days (1, 15). It has a short life cycle probably as an adaptation to the conditions prevalent in its environment.

Pink Stemborer (Pyralidae: *Sesamia calamistis*)

This stemborer species is most prevalent at medium and low elevations as shown in Table 2. In the region under review very little research work has been conducted with respect to its pest status. Female moths lay eggs between the base of the leaf sheath and the main stem. Larvae hatching within 7 days work their way into the stem close to the oviposition site. Larval development takes 6 to 10 weeks in the stem and culminates in pupation lasting about 14 days prior to moth emergence.

Sugarcane Stemborer (Pyralidae: *Eldana saccharina*)

This pyralid is an important pest of sugarcane. Although it is known to attack maize, its impact on yield is not known. Newly hatched larvae feed on leaves and penetrate the stem when they are fully grown. Larval development lasts for 3 to 8 weeks and pupation takes about 7 to 14 days.

Table 1: Lepidopterous Stemborers of Maize, Sorghum, other hosts and their Distribution in East Africa (Modified after Seshu Reddy, 1984)

STEMBORER		HOST PLANTS	DISTRIBUTION
Common Name	**Scientific name**	**Host Plants**	**Country**
Maize Stalkborer	*Busseola fusca* Fuller	Maize Sorghum Pearl Millet Sugarcane Several grasses	Kenya Tanzania Uganda
	Busseola segata Bowden	Maize Sorghum Finger Millet Sugarcane Many grasses	Tanzania Uganda
African pink stalkborer	*Sesamia botanephaga* Tams and Bowden	Maize Rice Finger Millet Sugarcane Several grasses	Tanzania Uganda
	Sesamia calamistis Hampson	Maize Sorghum Pearl Millet Finger Millet Rice Sugarcane Many grasses	Kenya

Table 1: Lepidopterous Stemborers of Maize, Sorghum, other hosts and their Distribution in East Africa (Modified after Seshu Reddy, 1984) (cont'd)

STEMBORER		HOST PLANTS	DISTRIBUTION
Common Name	Scientific name	Host Plants	Country
	Sesamia Penniseti Tams and Bowden	Maize Sorghum Pearl Millet Sugarcane	Uganda
Sorghum Stemborer	*Chilo partellus* (swinhoe)	Maize Sorghum Finger millet Rice	Uganda Kenya
		Wheat Sugarcane Wild species of Sorghum Many grasses	Tanzania
Sugarcane stemborer	*Eldana saccharina* Walker	Sorghum Maize Pearl Millet Finger Millet Sugarcane Rice, Cassava	Uganda Kenya Tanzania

Table 2: Distribution of Lepidopterous Stemborers of Maize and Sorghum in Southern Africa

Stemborer		Distribution		Elevation (m) & Percentage Relative Abundance*		
Common Name	Scientific Name	Country	Economic Importance Rank**	High > 900	Medium 700-900	Low < 700
Maize stalkborer	*Busseola fusca*	Botswana	2	90	18	10
	(Noctuidae)	Lesotho	1			
		Malawi	2			
		Mozambique	2			
		South Africa	2			
		Swaziland	1			
		Zimbabwe	2			
Spotted stemborer	*Chilo partellus*	Botswana	1			
	(Pyralidae)	Malawi	1			
		Mozambique	1	5	40	70
		South Africa	1	(South Africa)		
		Swaziland	2			
		Zimbabwe	1			
Pink stemborer	*Sesamia*	Malawi	3			
	calamistis	Mozambique	3	5	40	10
	(Noctuidae)	South Africa	3			
		Zimbabwe	3			
Sugarcane	*Eldana*	Mozambique	4	0	2	10
stemborer	*saccharina*	South Africa	4			
	(Pyralidae)	Swaziland	4			
		Zimbabwe	4			

* Information arising from a preliminary investigation conducted by the author during the 1985/86 cropping season.

** 1 = high Economic Importance. 4 = low Economic Importance

DAMAGE SYMPTOMS

The damage symptoms caused by the maize stemberers (B. fusca, C. partellus and E. saccharina, are essentially the same (2).

At about 10 to 15 days after crop emergence the first generation eggs are oviposited on young plants. Young plants are thought to be more attractive to ovipositing females and hence are more susceptible to larval attack than old plants. Larvae feeding on leaves cause elongated 'windows' and 'shot-holes' and may result in the reduction of the photosynthetic tissue area when infestations are very heavy. However, it is often observed that the rate of infestation is less for the first generation than the subsequent generations. During a growing season, stemborer generations overlap with the consequence that the pest is continually causing damage to newly developed sheaths and young leaves. Leaf-feeding continues until the larvae have reached the second or third instar stage when they penetrate into the stem (39).

Stem penetration by larvae occurs from about 8 to 15 days after hatching. The point of larval entry into the stem varies and very important in relation to the position of the apical meristem and the damage symptom caused by the pest. When larval entry into the stem occurs after floral initiation and the apial meristem has moved up to a position far removed from entry point, the damage symptoms observed are shot holes, elengated windows, entry holes and stem is at the apical meristem, meristematic tissue is destroyed with the consequent formation of a 'deadheart' symptom in which the apical meristem loses its dominance. When this occurs, the lateral meristemetic tissues become active and the affected maize plants may produce suckers. In the absence of deadheart formation, stemtunnelling activity continues and stems may become weak. In the event of a wind of high velocity blowing, the affected stems may break at the points of weakness. If the larvae penetrate the stems prior to peduncle elongation, tissues of the closely packed internodes below the apical meristem are destroyed and the plants may become stunted.

Stemtunnelling occuring at the same time as tne peduncle is elongating may lead to the destruction of vascular bundles and grain filling may be interrupted (21). If stemtunnelling is confined to the pith and the vascular bundles are not damaged grain development will be normal. If stem or peduncle breakage due to damage by stemborers occurs after physiological maturity is attained then the reduction in yield will be minimal. Sometimes pith decay occurs as a result of larval tunnelling activity and the phloem and xylem vessels become damaged with the consequent malformation of grain. Accordingly neat stemtunning confined to the piths of maize stems in the absence of deadhearts, stembreakage and cob rotting may not be correlated with yield loss (36).

YIELD LOSS AND CONTROL

The current information on stemborer infestation levels, injury to crops, and the consequential maize yield loss in eastern, central and southern Africa is inadequate as it fails to build up the necessary foundation for stemborer management in the field. Information available in the region under review is attributed to work in East Africa, Zimbabwe and South Africa conducted by Ingram (1958), Walker (1960, 1965, 1977), Rose (1962) and Van Rensburge et al. (1988). These investigators concentrated on maize yield losses resulting from primary damage (leaf-feeding, deadheart formation and larval biomass per stem) without assessing the extent of injury of secondary damage (larval feeding activity in the stem) in relation to grain yield loss. Apart from information generated by these workers, yield loss estimates have been very subjective rather than being objective. Where attempts to quantify maize yield reduction due to stemborers were made, studies have been confined to research stations without concurrent on-farm activities.

In making decisions on what control measure to take, information on the relation between the rate of stemborer infestation and yield must either be available or generated (45).

The rate of infestation is measured as percentage number of plants attacked, degree of leaf-feeding, number of deadhearts, internodes attacked, stembreakage, eggs, larvae and pupae per maize plant. This quantitative assessment is important in the establishment of economic thresholds of infestation for purposes of mapping out control strategies, conduction of surveys on maize yield losses on the basis of infestation levels, prediction of losses from infestation from infestation intensity and evaluation of maize genotypes for resistance to stemborers in maize breeding activities (7). The concepts of economic injury and economic threshold constitute a good foundation in decision making because they integrate both biology and economics (32,35,25,33,4,28).

Larvae play an important role in the spreading of micro-organisms either directly as carriers or indirectly by boring into maize stems and cobs. This larval feeding activity facilitates the entry of micro-organisms into plants (37). The second generation larvae are often associated with cobrot disease Fusarium moniliforme. According attention ought to be paid to the interaction between stemborers and pathogens like Fusarium in relation to yield loss.

In the region under review there are reports of stemborer infestations ranging from 14% with a yield loss of only 9.8% (6) to 49% infestation with a yield loss of 37% in untreated plots (42). In 1957 Swaine recorded 22% damage plants in untreated lands and harvested 83% more grain from uninfected plants than infected plants. Borrow (9) working on maize genotypes resistant to stemborers reported that yield potentionals vary under pest attack with reduction in yield ranging from 38% to 100%. He found yield to be significantly correlated with leaf damage and even higher correlation with the degree of stemtunnelling. Table 3 shows percentage estimates of stemborer infestations and maize yield loss in countries of estatern, central and southern Africa. This clearly shows no relationship between the degree of stemborer infestation and maize yield loss.

Table 3: Estimates of Stemborer Infestation Levels and Maize Yield Loss

Country	Area	Infestation (%)	Yield Loss (%)
Kenya[1]	Late Maturity Zone: Kisii Kitale	10 - 33	2 - 30
	Coast Maize Composite Zone: South Coast Mtwapa Kilifi	33	25 - 75
	Early Maturity Maize Zone:	Very serious (No estimate)	No estimate
Tanzania[2]	Central	No estimate	44
	Western	No estimate	14
	South	No estimate	48
	Coastal	No estimate	11
Malawi[3]	Northern Region: Mzuzu	5	No estimate
	Central Region: Dedza	20 (9 larvae/ plant)	No estimate
	Zomba	25	No estimate
	Thondwe	48 (4 larvae/ plant	No estimate
	Chikwawa (Shire Valley)	17 (4 larvae/ plant	No estimate
Mozambique[4]	Maputo and Gaza Provinces	70 - 80 (Cobs infested: larvae/plant)	No estimate
Zimbabwe[5]	Natural Region I	40	
	Natural Region II	50	
	Natural Region III	40	10 - 43
	Natural Region IV	30	
	Natural Region V	30	
South Africa[6]	Eastern Transvaal: Malelane Komatipoort	80	50

1 Mailu, Waiyaki and Nyamasyo (1987).
2 Duerden (1953), Swaine (1957), Kabisa and Luhusa (1975).
3 Munthali (1987).
4 Berger (1981).
5 Wally (1967) and Page et al (1985).
6 Revington (1986).

Stemborer infestations on cereal crops cause the most severe damage during the early stages of development unless there is a high degree of peduncle boring for example at a later stage. Results of investigations conducted by Sharma and Sharma in India and the author of this paper in Zimbabwe favour the protection of cereal crops during the early stages of development because it is more beneficial in relation to yield loss reduction than when pesticides are applied at their later stages. Since two or more stemborer generations may occur on the same cereal crop, it is reasonable to assume that first generation larvae are more important than second generation larvae in reducing yield (28). However, second generation larvae are equally important in reducing yield in late planted maize crops and therefore late planting should be avoided as much as possible in order to minimise cob damage attributable to second generation larvae. Larvae are often observed in the funnels of young maize and sorghum crops about a week after hatching or artificial infestation and it is during this period that they are vulnerable to funnel applied pesticides. However, once they have penetrated the stems, control becomes extremely difficult unless a systemic pesticide has been applied at planting. Therefore chemical control measures should be applied either at planting or some time during the early stages of development. In breeding for resistance to stemborer attack, it is important to pay particular attention to the vulnerable early stages of crop development.

Different crop genotypes show variation in their reaction response to stemborer attack (9). The variations in crop genotype response to stemborer attack are reflected in the extent to which crop yields are reduced. Although little or no work on yield loss assessment has been conducted in the region, indications are that with ageing the toughness of leaves and stems of cereal crop increases, crop susceptibility to stemborer attack decreases and yield loss decreases (19,8,16,1,28,30).

CONCLUDING REMARKS

In conclusion, I would like to make the following recommendations in relation to maize yield losses attributable to stemborers:

1. The available information on yield losses in the farmers' fields is based on visual estimates with very few objective estimates in some countries. Therefore, more objective estimates should be made.

2. Surveys on stemborer species on the farmers' fields should be conducted using standardised procedures that will permit repeatability and comparison of data across locations.

3. There is need to conduct loss assessment trials at specific location using the following methodologies:

   - Protected and unprotected trials
   - Artificial infestation
   - Paired plant analyses of infected and uninfected plants.

   This should be conducted both at stations and farmers' fields.

4. The relationships between borer infestation and actual yield losses, amount of protection, and cost should be worked out.

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CHAPTER V

PESTICIDES

1. PESTICIDE SAFETY, STORAGE AND DISPOSAL

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CONTENTS

WHAT ARE PESTS?

Insects, weeds and fungi constitute the three classes of pests.

There are about one million species of insects, far more than all other animal and plant species combined. The number alive at any given time is reckoned at around 10^{18} of which 99.9% are quite harmless from a human point of view; some of them are even helpful. It is the other 0.1 per cent which come under the category of pests.

Weeds are also considered as pests, although the pure biologist would probably regard them as plants in their own right. Weeds qualify as pests because they (a) compete for nutrients, water and light, (b) occupy valuable space above or below the ground (c) may be poisonous to man, livestock and crops, (d) harbour and transfer diseases and (e) upset crop economics by making harvesting more difficult and reducing produce quantity and value.

Fungi are responsible for many serious diseases. The alleviation of diseases or suffering of plants should be considered as important as alleviation of human or animal suffering from diseases.

WHY CHEMICAL PEST CONTROL?

The various options available for plant protection range from traditional practices to modern and sophisticated methods. These are: (a) cultural or mechanical methods, (b) biological control, (c) application of pesticides, (d) designed interference and (e) integrated control. Some of these are elaborated in Table 1.

Table 1: Methods of pest control

Mechanical methods

Ploughing, harrowing, flooding, draining, oiling, fire, machines to remove tough weeds, quarantine, notification, eradication.

Biological methods

Use of animals to control weeds (geese for weeds in mint)
Use of one living organism to control another
Highly specific predators
Pathogens (fungi, bacteria, viruses)

Chemical control

Application of synthetic pesticides
Use of natural product extracts

Designed interference

Insect hormones, chemical sterilisation, sex lures, food lures, oviposition lures, electromagnetic energy

Integrated control

Judicious and planned combination of methods, with environmental compatibility

One other method has proved as effective, fast, easy to use and amenable for widespread utilization as chemical pest control. It continues to be the preferred option for pest management. It is estimated that without pesticides, two-thirds of all crops would be lost, depriving millions of people of food.

The present annual rate of consumption of pesticides is equivalent to an application of 0.5 kg for every person in the world. Since the majority of the world population lives in developing countries, relying in most cases on an agricultural economy, the indispensability of agrichemicals needs no emphasis. Agricultural economists have estimated that if pesticides are not used, the cost of production could increase by anywhere between 60 and 200 per cent depending on the nature of the crop.

PESTICIDE CLASS AND TOXIC ACTION

There are in use in the world today approximately 40,000 formulations and products based on about 600 active pesticide ingredients. Though staggering in number, the basic technical materials fall into five broad classes listed in Table 2, with several examples.

Table 2: Pesticide classes and examples

Major pesticide class	Examples
Phosphorus-containing	monocrotophos, tetrachlorvinphos, chlorfenvinphos, diazinon, phosphamidon, parathion, temephos, chlorpyrifos, malathion
Halogen-containing	DDT, ethoxychlor, 2,4-D, 2,4,5-T, endrin, toxaphene, PCP, MCPA, chlordane, heptachlor, endosulfan
Nitrogen-containing	aldicarb, carbaryl, alachlor, captan, monuron diuron, triazine herbicides, diquat, paraquat
Synthetic pyrethroids	permethrin, deltamethrin, cypermethrin fenvalerate
Miscellaneous group	inorganic sulphur compounds, organic tin compounds, antibiotics, copper, phenolic compounds

Being chemical compounds, most pesticides are active or reactive and perform by being toxic or inducing toxicity to the pest. Toxicity is thus a basis for pesticide function. Phosphorus-containing pesticides act by inhibiting a vital body enzyme called cholinesterase. Symptoms of poisoning by this class are headache, nausea, blurred vision, abdominal pain or diarrhoea, and advanced stages may cause coma, convulsions and lung failure. The mode of action of chlorine-containing compounds is still not clearly understood, one of the reasons being their stability and very slow degradation. The metabolites are often fat-soluble and tend to accumulate in the adipose tissues. The mode of action of other classes of pesticides are also not conclusively understood yet. For example, deposits of DDT and (its principal metabolite) DDE are found in body fat of the general population in many countries of the world. The significance of these body deposits is not clear and no serious adverse effects have been associated with this presence.

Pesticides undergo extensive testing and trials before they are cleared for field use. Registration data requirements are, in many countries, very rigid. A large amount of information is available on the acute, subacute and chronic toxicity of pesticides in different species of experimental animals and is useful for reference and guidance in formulating methods of treatment in cases of pesticide poisoning.

NATURE OF HAZARDS FROM PESTICIDES

According to the World Health organisation, there occur, in the developing countries each year, some 375,000 cases of pesticide poisoning, out of which two persons die every 90 minutes.

In discussing the nature of hazards from pesticides, this article excludes hazards associated with the manufacture of basic technical pesticides. Hazards arising in the following stages will be considered here:

- transportation
- formulation at field or user level
- storage
- application
- general handling at farmer level
- disposal of unwanted stocks

The primary requirement for safe handling in all the stages mentioned above is a good and up-to-date knowledge of the physico-chemical and biological properties of the chemical concerned. Dangers arising from misuse or mishandling of pesticides could be physical risks and human or environmental effects. These are summarised and listed in Table 3.

Table 3: Physical, health and environmental risks of pesticides

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Physical risks

Explosion under effects of flame or friction
Exothermic reactions on contact with other substances
Fire by ignition or contact with air

Health risks

Corrosive effects on living tissues
Irrigation or inflammation of skin and mucous membranes
Acute or chronic health impairment by inhalation or skin penetration
Carcinogenic effects
Fatality in serious incidents

Environmental risks

Death of animals near plantations
Toxicity to fish
High residue levels in edible materials
Unsafe environment to living systems

Hazards in movement and storage

Although every country has laws and regulations governing the transportation and storage of pesticides, accidents continue to arise due to violation of regulations, lack of knowledge or plain carelessness.

1. Toxic leaks and spills may arise from defective containers or from puncturing, tearing or breaking of containers. Such spills may cause acute toxicity to people involved in transportation or in warehouses. More problems may arise if the spill of one type of pesticide contaminates other types, leading to fires, emission of fumes or even explosive reactions, apart from contamination of surrounding areas. To avoid these hazards, pesticide containers should be closely and regularly inspected. Containers showing signs of leakage should be isolated and not transported. Loading of containers should be such that they are secure and would not get displaced or damaged. For example, sharp tools or objects which could fall or hit pesticide containers should be isolated.

   Under no circumstances should pesticides be placed or transported along with food, fruits or other materials intended for human or animal consumption. Personnel (handlers and supervisors) should receive training and updating of knowledge which should include first aid and rescue procedures. The use of protective apparel and gadgets (gas masks, goggles, face shields, gloves, boots, etc.) should be enforced.

2. Fire is a major potential hazard when dealing with liquid pesticide formulations which contain organic solvents with low flash points.

Warning statements such as the following used in USA are suggested:

- flash points at or below 20°F (-6.7°C): danger - extremely flammable! Keep away from fire, sparks and heated surfaces.

- Flash points between 20°F and 80°F (-6.7 to 26.7°C): warning - flammable! Keep away from heat and open flame.

- flash points between 80°F and 150°F (26.7 to 65.6°C): do not use or store near heat or open flame.

Proper warnings on the label and compliance can go a long way in averting fire hazards.

When pesticides catch fire, serious danger may arise through dispersion of fire to other inflammable materials, release of toxic vapours and even explosion (e.g. aerosol cans). Even run-off water from pesticide fire-fighting could be toxic and care should be taken to prevent contamination of fresh water systems.

Handling pesticide fires is an extremely difficult and risky operation. Personnel assigned to these operations must themselves be protected and informed appropriately.

Decontamination of affected and suspected areas (as also tools and equipment employed) also needs careful supervision.

3. Heavy rains or floods may also pose a serious problem during transportation and in storage of pesticides, ranging from soaking to being swept away or destroyed. In such events contamination of water and ground is a serious possibility. Coordinated action by the authorities and the public who are likely to be affected is a very important need in such situations.

4. Defects in design, construction or maintenance of pesticide storage areas or sheds are often the cause of accidents involving large inventories. Financial losses apart, fire or spills would leave lasting effects on human health and environment. It is, therefore, very important that pesticide storage areas are carefully selected (with regard to wind direction, ventilation), constructed (material of construction, segregation according to properties and likely risks) and maintained (temperature control, exhaust efficiency, personnel safety and emergency preparedness).

Care and control of storage areas

For convenience and ready reference, the following guidelines are suggested.

1. Pesticides should only be stored in original, approved and labelled containers. They should never be transferred to old bottles or drums in which they could be mistaken.

2. Pesticides should be stored as far away as possible from food stocks, animal movement or human interference.

3. Storage areas should be secure, and pilfer-proof.

4. Inventory maintenance, inspection and monitoring are important.

5. Fire fighting, protective clothing and decontamination equipment should be available and operational at all times.

6. Local authorities (public health, environmental protection, fire service and police) should regularly inspect the areas for compliance with regulations.

7. Safety literature in local languages should be freely available and displayed appropriately.

Care in field use and application

Apart from the risks and safety aspects discussed in the foregoing paragraphs, people who need to handle pesticides in the field should be specifically careful in dealing with them. There may be need to mix before application in some cases. Common formulations of pesticides applied are: wettable powder, dust, emulsifiable concentrate, soluble powder, granules, fumigants and seed dressings.

Persons directly handling the jobs of mixing, loading and applying pesticides tend to be contaminated by skin contact, mouth ingestion (eating, smoking) and breathing. There is likelihood of acute poisoning if the concerned persons do not exercise the prescribed safety procedures. Manufacturers of pesticides and their formulations and regulatory authorities have a responsibility to make available all the relevant safety and handling information, but the persons who are ultimately concerned with their application have an even greater responsibility. At least three important factors arise:

- care in the choice of pesticide to be used
- care in selecting the right application method and equipment
- thorough knowledge and faithful compliance of instructions, based on respect for the properties of the chemical substances involved.

Disposal of unwanted stocks and containers

In the pesticide life cycle, from manufacture to end use, the need may arise to dispose of the following:

- empty containers after use
- surplus stocks not likely to be used
- obsolete or time-barred stocks
- spoiled materials arising from spills, leakage or flooding

In spite of impressive progress in the chemistry, technology and application of pesticides, there are still no satisfactory answers to the question of disposal of unwanted pesticides and their containers. The problem is less severe at commercial manufacturing facilities because of first-hand knowledge and access to needed resources. It is simply impossible, in the present conditions, to collect and return empty containers to the manufacturer or to re-use them. The following options are to be considered depending upon the type, quantity or state of the material for disposal.

- Large metal drums may be purchased and processed by firms suitably equipped to do so.

- Compliance with local regulations on the safe destruction of containers. Containers made of combustible materials can be incinerated at carefully selected locations.

- For disposing of sizeable quantities of unwanted pesticides, none of the available methods is totally acceptable from health and environmental points of view. However, subject to appropriate pre-treatment, the following modes can be employed: (a) incineration, (b) burial in identified land sites, (c) discharging into ocean, (d) lagooning for solar and soil decomposition. It is a good practice to consult experts, preferably the manufacturers of the product, in this regard.

- At farmer and household level, complications may arise by improper attention to storage and handling of pesticide residues and containers. Children, illiterate persons and animals are prone to be affected if sufficient care is not exercised. Where quantities involved are not large, empty containers can be thoroughly rinsed and cleaned with water and drained away, or buried in deep soil pits (under at least 60 cm of top soil). Purchase and stocking of unnecessarily large quantities should be avoided. Pesticides manufactured and distributed by reputable firms generally carry sufficient instructions and guidance in local languages which, if properly and faithfully followed, should make pesticide handling, storage and application, a normal, fearless and effective proposition.

It is important to note that many pesticide formulations which are commercially distributed are sensitive to temperature rise. They may undergo deterioration or degradation, resulting in reduction or loss of activity. A degraded pesticide may have more toxicity than the original material. These aspects should be kept in mind when storing pesticides at farmer or household level.

2. PESTICIDE MANAGEMENT IN RELATION TO USER SAFETY

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CONTENTS

INTRODUCTION

Since the introduction of DDT to control insect pests in the 1940s, man's use of chemicals to control the pests attacking his crops, livestock and health has increased. Many millions of tonnes of formulated pesticides are used each year to control a wide range of pests in agriculture and public health, and pesticide use is increasing (2). At least 30 per cent of the world's potential crop production is lost each year to pests, diseases and the effects of weather. Losses would very probably double if existing pesticide uses were discontinued. World sales of pesticides amounted to some $16,500 million in 1986, with developed country markets accounting for about 75% of total sales. Markets in industrialised countries are now generally regarded as static, with little potential for expansion. The developing countries, conversely, are regarded as having a dynamic and expanding market, and pesticide use is increasing rapidly. Despite increasing emphasis on integrated pest management and non-chemical methods of pest control, pesticides will remain the principal and, in many instances, the preferred means by which pests and diseases are controlled for some time to come.

Increasing use of pesticides leads to increasing risks to the user and the environment. Bull (7) highlights some of the documented problems throughout the developing world. Much emphasis is placed on controlling the pest organism, whilst safety to the user and the environment often becomes of secondary importance. In particular, misuse of pesticides through lack of training, lack of awareness and inadequate facilities and equipment may represent a serious potential hazard. The WHO recently estimated that throughout the world up to one million people may suffer symptoms of unintentional pesticide poisoning each year and, of these, as many as 2% may die as a result (35). To put these figures into context, WHO estimates that pesticides are responsible for less than 4% of all poisoning accidents throughout the world. The majority of these cases occur in developing countries. In these countries, poor controls on pesticide use and mishandling and misuse of pesticides due to lack of awareness of hazards may lead to contamination of the user and unacceptable or hazardous residue levels in produce and water supplies. The likelihood of pesticide poisoning occuring depends not only on the inherent toxicity of the product but also on how that product is used (7). Pesticide hazard is therefore a function of the toxicity of the pesticide and the potential for exposure to that pesticide(25, 28), and can be expressed, in simple terms, as:

HAZARD = TOXICITY x EXPOSURE

Toxicity is a fixed attribute for each individual pesticide. Exposure will vary according to the handling and use patterns, and depends on the degree and duration of contamination. Pesticides have a wide range of mammalian toxicities, from extremely toxic, such as parathion or methyl parathion, to only slightly toxic, or even those which are unlikely to present an acute hazard in normal use, in accordance with label instructions, such as cypermethrin, methoxychlor or tetrachlorvinphos. Some of the more commonly used pesticides and their hazard classifications are given in Table 1.

Table 1: Comparative mammalian toxicities and maximum acceptable daily intake of some commonly used pesticides

Pesticide	Toxicity[a, b] (mg/kg body weight) oral LD_{50}	dermal LD_{50}	Maximum ADI[c] (mg/kg body weight)
Insecticides			
aldrin	67	98	0.0001
carbaryl	300	>4,000	0.01
carbofuran	8	2,550	0.01
chlorfenvinphos	10	31	0.002
cypermethrin	>4,000	>2,400	0.05
DDT	113	2,510	0.02
deltamethrin	>2,200	>2,000	0.01
diazinon	300	>2,150	0.002
dimethoate	150	600	0.002
endosulfan	80	359	0.008*
fenitrothion	503	890	0.003*
malathion	1,200	4,100	0.02
methomyl	17	>1,500	
monocrotophos	14	336	0.0006
pirimiphos-methyl	2,018	>2,000	0.01
tetradifon	5,000	>10,000	
Fungicides			
benomyl	>9,590	10,000	0.02
binapacryl	150	750	0.0025
chlorothalonil	>10,000	>10,000	0.005*
triadimefon	363	1,000	0.01*
Herbicides			
2, 4-D	375		0.3
dalapon	9,330		
glyphosate	4,320	>5,000	
paraquat	150	236	0.001*

a Various sources
b LD_{50} values are for rats (or rabbits where rat data unavailable)
c Joint FAO/WHO recommended ADIs
* = are temporary values

It is important that the fact of differing toxicities is recognised by all pesticide users so that they act accordingly and take proper safety precautions, particularly when handling the more toxic products.

Problems of human safety in relation to pesticide use have been addressed in a number of review articles and books. There are many references to safety in Hayes' (7) review of pesticide toxicology. The same author has reviewed in detail much of the work on pesticide studies in man (18). Ecobichon and Joy (12) have reviewed in detail the neurotoxic effects of pesticides in mammals, and methods of studying the clinical toxicology of agrochemicals is covered in some detail by Wagner (34), with reference to some individual pesticides and their effects on man. Other authors have reviewed work on human exposure to insecticides (26), occupational exposure to pesticides (14,19,33) and pesticides and human health (13,15). Many researchers have addressed the problem of occupational exposure to pesticides in specific studies of pesticide usage (6,21,22,29,30).

PESTICIDE USAGE

There are many documented instances of accidental poisoning due to misuse, abuse or ignorance in handling and application of pesticides (4,5,8,23,27). The main influences on human safety in pesticide usage in the field are:

- choice of pesticide (inherent toxicity and volatility)
- choice of formulation (type/concentration may affect hazard category)
- method of application.

Workers' own attitudes and experiences can affect human safety; a 200-fold variation in dermal exposure among workers using parathion on tree crops has been documented(36).

Dermal contamination is generally the most likely route of pesticide entry into the body under field conditions (26). Routes of entry and factors affecting pesticide penetration into the body are discussed by Dedek (11) and dermal absorption of pesticides has been reviewed in detail by Bainova (3). Many instances of pesticide poisoning amongst field workers applying pesticides have been documented (20,26,31), and the effects of pesticide residues on those workers entering treated crops within the recommended safety period (20,26,31).

Farmers' perceptions of pests and pesticide usage have been reviewed by a number of workers (1,9,10,32). Abrahamse (1), in a survey of pest control practices in some parts of Zambia, highlights the variability of practices and perceptions, dependent on whether or not farmers were "progressive" in outlook. Cox (10) has surveyed pesticide use patterns and economics of pesticide use in Tanzania, as well as assessing farmers' abilities to forecast return (increased yield) on investment (pesticide application). Variation in pesticide use practices is often an adaptive response to the differences in the expected yield increase of the crop and hence return on investment. User recommendations, although known, are often modified in the light of farmer experience.

Problems relating to safety may be encountered at any stage of the 'life history' of a pesticide, from manufacture and formulation, through storage, distribution and marketing to end use and disposal of the wastes and empty containers. Staff of the Overseas Development Natural Resources Institute (ODNRI) have been carrying out some research into pesticide use and human safety with the aim of trying to quantify the hazard to pesticide users. This research attempts to identify the main operational hazards to users of pesticides (the term 'users' includes all those who come into contact with pesticides in their normal work; for example manufacturing workers, storekeepers, distributors, farmers and field workers) and to investigate the ways in which various types of hazard may be minimised, given the practical constraints under which users, particularly in developing countries, often have to operate. Research techniques are based on the use of structured evaluation, by checklist or questionnaire, of pesticide safety practices in different countries, together with physico-chemical field contamination trials to determine the distribution and magnitude of the contamination of pesticide applicators under normal spraying conditions.

PESTICIDE STORAGE

It is estimated that less than 0.2% of all the pesticides manufactured for agricultural purposes in industrialised countries is wasted before use. In developing countries, perhaps as much as 10% may be wasted before application due to poor transport and storage facilities. Observations in many countries, including Somalia, Pakistan, Mauritius, Burma and Indonesia (16) have indicated the likely problems that may occur in pesticide stores. Such problems include the siting of stores too near to other premises such as private dwellings or shops. Several instances were found of stores being sited near to fuel pumps, and in one or two instances pesticide stores have also been found to be selling fuel supplies such as kerosene or gas cylinders. Stores are rarely purpose-built and quite frequently are too small for the quantity of pesticide stock carried. Ideally, there should be some means by which spilt pesticide can be retained or prevented from contaminating the surroundings, but this is rarely found in any but the largest stores.

Mixed storage of pesticides with seeds and fertilizers is a fairly frequent occurrence, and occasionally food or drink may also be stored - a potentially very hazardous situation. It is common to find the storekeeper's office or desk inside the store, and many stores could improve general housekeeping standards. These can be hazardous situations because pesticides could contaminate fertilizer and seed stocks and have phytotoxic effects in some circumstances. Additionally, farmers and field workers using seed stocks contaminated with pesticide are unlikely to be aware of the fact, and may themselves become contaminated. Bad housekeeping leads to accumulation of out-of-date stocks and therefore wastage of costly products. Also, inefficient storage systems may lead to damaged containers, contamination of packages and pesticide spills. Fumes from vaporising pesticide spills may cause low-level chronic poisoning of store keepers, particularly if the office or desk is within the store.

FARMERS AND FIELD WORKERS

Surveys of farmers and field workers have shown that when handling the concentrate, mixing spray solutions, and when spraying, some safety instructions are obeyed. However, in some instances, incorrect concentrations of spray solutions are used. Farmers sometimes have a tendency to increase doses on the assumption that the greater the concentration the better will be the control achieved. This, of course, is wasteful of pesticide and could also encourage the development of resistance in the target pest, as well as adversely affecting the environment.

Standards of maintenance of application equipment can be variable, and cost and availability of spare parts for repairs will influence maintenance procedures. In recent visits to Asia, a total of 66 farmers and farm workers were surveyed by questionnaire. Results indicated that many farmers were unaware of some of the dangers of pesticide contamination; many tended to overdose when spraying, particularly on vegetable crops, with consequent risk of unacceptable residues on market produce; equipment was poorly maintained, with consequent effect on the amount of pesticide contamination received during spraying operations; some farmers failed to follow even the most basic rules of safety when handling and using pesticides; on a number of occasions, pesticides were improperly stored, sometimes in the general living quarters within easy reach of small children. In general, farmers and farm workers are aware that pesticides can be harmful to man, and most recognise the oral and inhalation routes of pesticide entry into the body. However, only about 30-40% of farmers appear to be aware of the dermal route of entry. This has serious implications for the safety of pesticide applicators. Research by Maibach et al.(25) with parathion has shown that pesticides can penetrate the skin of different parts of the body at different rates, penetration through the skin of the forearm being the slowest, and penetration through the genital area being some twelve times faster than this. In general, skin that is thin, or with blood vessels close to the surface, or which is cut or abraded will allow rapid pesticide penetration.

Adequate and suitable protective clothing is rarely available and first aid facilities to treat any pesticide poisoning may often be some distance away. In surveys carried out in the Philippines and Thailand, over 50% of the Filipino farmers had suffered symptoms of pesticide poisoning; in Thailand the figure was lower, at 36% of the sample. However, the Thailand National Environment Board has initiated its own, much larger, survey of farmers and preliminary results indicate that the percentage could be considerably higher, as much as 70%. In a recent visit to the Philippines, a very brief survey of rice and mango farmers in a small area indicated that levels of pesticide poisoning incidence could be as high as 80% for rice farmers and between 30 and 40% for mango farmers. ODNRI is now undertaking a much larger scale survey of the incidence of pesticide poisoning amongst rice, vegetable and mango farmers in the Philippines.

Farmers and field workers tended not to observe a recommended safety interval after spraying and before re-entering the crop. However, in the Sudan, an arbitrary safety interval of 24 hours was sometimes quoted. A very small survey in Tanzania indicated that this is a more widespread practice, 24 hours being the usual safety period quoted. In some countries in South East Asia, farmers have been known to spray the crops in the early morning and then, on hearing of good market prices, to harvest and market produce later in the day.

OCCUPATIONAL EXPOSURE TRIALS

In field trials in the Philippines and Thailand, non-toxic model pesticides with tracer dyes were used to determine the extent of contamination of farmers during spraying operations. Suits of light-weight protective material were used as targets to collect spray deposits for quantitative analysis. Trials were done in rice, mango and vegetable crops. Results indicated difference in patterns of contamination on the different crops. This is, in part, due to differences in crop height and to the technique of application (mango farmers, for example, often climb inside trees to spray the upper canopy). Whole body contamination levels also varied between crops and crop heights.

This research into pesticide contamination amongst pesticide applicators in rice, vegetable and tree crops has shown that gross contamination levels can be very high and concentrated on particular areas of the body, such as the lower trunk in rice sprayers, and on the upper body and head of tree crop sprayers.

The safety implications for workers applying pesticides in tropical conditions, where minimal protective clothing, if any, is worn, should be given careful consideration, and particularly where the more hazardous pesticides and formulations are used.

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CHAPTER VI

HOW TO LEARN FROM FARMERS

HOW TO LEARN FROM FARMERS

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CONTENTS

"Though this be madness, yet there is method in't"
Shakespeare: Hamlet, Act II, Scene 2

INTRODUCTION

Why do we want to learn from farmers? The short answer is that over the last decade or two research has been unable to provide extension services and therefore farmers, with technology that works reliably at grass roots levels of application. Despite this farmers have continued to produce, and in some instances to solve problems that have baffled research.

Chambers, D.R. and Jiggins, J. (2) have noted that the reductionist approach to research works well on farms and large estates where the number of variables controlled by the farmer is kept to manageable proportions partly through being resource rich and partly through having relatively simplified farming systems with but few enterprises. Where the resource poor are concerned, the researcher is faced with a much more diverse and closely woven system which presents both complex and dynamic difficulties. Not only is the system closely interlinked at several levels, but it is shifting and responding to multiple and frequent changes in the surrounding agricultural, economic and social environment. Making reliably accurate recommendations is complicated by the need to obtain reliable results from a system which is ever changing.

Peters, T.J. and Waterman, R.H. (12) in "In Search Of Excellence, Lessons From America's Best Run Companies", stated that key managerial processes are extremely complex ... drawing on the vaguest of information and using the least articulated of mental processes. These processes appear to be more relational and holistic than ordered and sequential and more intuitive than intellectual. They conclude that it is probably only the intuitive leap which allows us to solve problems in such complex systems at those in which land by which we live. While it would be dangerous to draw too close an analogy between a large corporation and small farmers in terms of the complexity of their systems, it does not seem inappropriate to take cognisance of the remarks by Peters and Waterman when considering future directions for research into the problems of the small farmers.

A major and widely fluctuating variable, particularly in the semiarid tropics, is the climate with which farmers have to contend which greatly adds to the risk element for farmers, extension staff and researchers alike. Researchers also have to contend with the paucity of the feedback obtained through extension. Rhoades, R.E. (14) notes that technologies introduced to farmers have been considered as inherently good and that, if they have been around long enough and thoroughly communicated, farmers should adopt them. Diffusion of innovations literature assumes that the offered technologies are superior to those presently in use and that factors such as the age, class, literacy, family size, etc. determine the rate of adoption.

Rhoades continues to state that there is an assumption that there is a stockpile of technology on the shelf waiting to be transferred. Even the much vaunted farming systems research made this assumption and just set out to fit the pieces of the technology into the jigsaw of the farming system.

Since time immemorial rural populations have been characterised as simple, conservative and tradition-bound. This paper will argue that farmers are a source of remarkable achievements and innovations which should be capitalised upon both by research and extension services.

PAST EFFORTS OF FARMERS

In his excellent review, Rhoades, R.E. (14) suggests that farming as an activity stretches back for 10,000 years and that throughout this time, the farmer has been a proactive participant consciously observing, selecting, experimenting and manipulating the farming system as it related to plants, animals, tools and the agroecological environment.

He argues that, long before the existence of modern science, farmers had an 'evolutionary' effect on plants, animals and land and that, furthermore, their improvements embraced processing and storage as well as production aspects of any enterprise simultaneously.

I, personally, had the pleasure some thirty years ago of observing such an improved and integrated farming system in the Gwoza hills in what was then British North Cameroons, now a part of Nigeria. The farmers in this region had, over time, evolved a system which included the terracing of steep slopes, composting all varieties of waste and rotating crops through having a male and female year for crops. A ceremonial ox was fattened in a small house especially constructed to restrict the animal's movements to standing or lying with an input and output hatch at either end for food or faeces. Thus, the energy used by the animal was minimised, enhancing food utilisation, and manure could be captured for application to the land. In addition a system of food storage was practised and there was a form of clan organisation similar to that found in Scotland. While this complex set of agricultural systems existed before the advent of extension or research, with little scope for their subsequent improvement, the people on the lower plains did not use them, and tended to be generally wasteful of resources.

Let us now consider the resource rich end of the spectrum - the flue cured tobacco growers of Zimbabwe who have been responsible for a number of innovations. The work study handbook produced by the growers association (1961) cited some examples of these for instance the Ballance and Kurt reaping machines. In the curing phase, farmers helped to develop the tunnel method as well as methods of reducing costs and using available resources effectively.

To conclude this section let us recharacterise successful farmers as:

experimenters, risk takers, innovators,
intensifiers and diversifiers,
colonisers and pioneers,
addicted to information.
practitioners and developers of common sense,
socially and economically rational, in agreement with R.E. Rhoades.

INFORMATION FARMERS USE BEFORE ADOPTING A PRACTICE

If study could define the information which farmers actually use in deciding to adopt or reject a technology it would greatly assist extension and research in the promotion of innovations.

It is my contention that any advice must cover the following information bases:

- biological
- farm production economics
- risk
- work and ergonomics
- social and economic systems.

Farm systems involve all these factors in a holistic way, acting and interacting continually. Thus, a successful extension officer must endeavour to empathise with farmers to the extent that he also takes all these factors automatically into account in giving advice and in feeding information back to research colleagues.

Let us briefly consider each factor in turn.

Biological

Agricultural research covers many forms of sciences - tillage, chemistry, pedology, irrigation, pesticides, nutrition, breeding, and vaccines to name a few - and must produce results that are, to be generally scientifically acceptable, of a coefficient of variance of 25 or less (for crop trials) and which report the standard error and mean of each treatment, as well as stating if the results are significant or not in terms of a positive cost benefit contribution to enterprise productivity. With this information on hand the farmer is now able to consider economics.

Farm production economics

Research and extension practioners could well, at this stage refer to some text such as, 'From Agronomic Data to Farmer Recommendations, an Economic Training Manual' (R.P. Perrin and J.R. Anderson, CIMMYT) which would enable them to predict monetary outcomes of practice adoption. Meanwhile the experienced farmer has already calculated the monetary and several other effects and decided to adopt or not to adopt intuitively, while the advisers are still reaching for the text. If we assume that the economic analysis says adopt, the next question is one of risk.

Risk

Risk touches a whole spectrum of factors which impinge on farming systems. For my purposes today we will only consider weather, and rainfall within weather, as it affects the farmer. Plainly farmers will not be interested in a research result if it requires rainfall conditions that occur only once in thirty years. Indeed they will very likely not be interested if it requires conditions which he is not reasonably certain of enjoying in nine years out of ten. Research and extension workers may be surprised to know that farmers have already arrived at their decisions on the basis of risk. Consider the Chivi area of Masvingo Province in Zimbabwe. There a research team headed by Dr C Jackson discovered that the ratio of area planted to crops of maize and millet varied in respect to the previous season's rainfall.

If there had been a good year previously the area planted to more water demanding and higher risk maize increased. The reason for this was found to be that farmers with stores full enough of grain to guarantee subsistence for a season could gamble on planting maize which is more risky, but higher yielding in good years, than millet.

Science would address this problem through looking at the probability function of season length (Hussein J. 1987) and would come up with the answer 27% for a crop requiring a season length of 120 days at Chivi. However we could postulate that the more apposite question is to enquire the probability of the farmer getting a successful maize crop at least once in three successive years? The intuitive farmer already has the answer, science tells us the probability of at least one year in three providing a suitable season is $(1-(.73)^3) = .61$. Loan managers of banks would do well to take note of such a seemingly crude approximation and to use it judiciously. A means of evaluating crop experiments for this form of risk is contained in the appendix.

Work and ergonomics

This subject includes any available means of easing the work, how the nature of the work affects the product and the limits to which human capability can undertake the required work. The use of a "Push hoe" having a wheel and a handle to act as a lever may serve as an example of how, in certain circumstances, the productivity of labour can be enhanced through use of simple, practical, mechanical aid. However, the circumstances, the soil type, the spacing of the crop and the nature of the weeds, must all suit.

There would also appear to be scope for using operations research and work study in the development of low technology to enhance the productivity of cropping. It must be remembered that the ease with which work is perceived and the apparent rewards from it are important motivators to getting it done. Recall here Turkish or oriental tobacco which is high yielding but requires a great deal of work of a very finnicky and time-extensive nature which makes it unattractive to the peasant farmer. Recall also the Hawthorn effect where the demonstration of interest by management through changing the work environment, both positively and negatively, yielded successive increments in productivity! There is an important perceptual difference between farmers and researchers, the former being interested in the return per man day while the latter are interested in return per area planted, or per dollar invested. As a result of this, while a researcher will consider an improvement of 10% per hectare worthwhile (and so would the farmer growing 200ha), to the farmer growing less than 1ha the labour needed to obtain the increased yield is not worth the return, especially if it increases his risk of losing the entire crop or requires him to increase his investments in its production.

Work usually impinges on the likelihood of adoption of a new practice through the timing of its requirements, which is especially important in the tightly woven farm systems of peasant farmers. It must be recalled that while the marginal returns to labour vary there is unlikely to be labour yielding zero marginal return at any point during the year and there is thereby, almost always, some opportunity cost to be borne. Thus interventions which can save labour without requiring additional capital investment are most likely to be adopted. Work study and operations research can yield such gains merely by reorganising the way in which work is done to reduce the labour required for its performance.

Socioeconomics

The fifth and last area of information which needs to be considered in proposing innovations is socioeconomics which are, here, concerned with markets, their location, accessibility and the infrastructure within which a farmer needs to be able to work effectively. We must also consider the alternative opportunities such as jobs in urban areas which result, on the one hand in less reliance on farming for subsistence, but on the other hand, results in more agricultural operations falling to the lot of women, in addition to their already existent household work. This trend of men working in towns can also cause delays and disruptions in farming operations if the decision-making function remains with the men who are only infrequently present on the farms. More directly, the money which men earn in towns may be a prerequisite to the procurement of farming inputs and may only be available when they are at home. For many this is often at Christmas which is, on the one hand late in the season and, on the other hand is not a socially usual time to be ploughing and planting. Reynolds N. (13) made an interesting study of the circulation of financial resources as a means of diagnosing poverty patterns in a typical Natural Region IV communal land area of Zimbabwe which others may well find instructive.

HOW FARMERS AUGMENT THEIR EXISTING KNOWLEDGE

Having looked at the types of information which farmers use in deciding to adopt or reject an innovation, it is now instructive to consider how they obtain the information.

Three sources will be considered: observation trials, watching over the fence, and the cocktail party method.

Farmer observational trials

We have already seen how farmers deliberately vary the treatment of different rows of crops from which they derive their preferred practices. What we know little about is how they decide which options to adopt. What is likely is that farmers using their methods can only see improvements when they exhibit returns of between 30 and 50% over the alternatives.

This means that they will select improvements that will give improvement with a margin for error and variation which will still be positive in their yield results. Such apparently crude measures offend the sensibilities of scientific researchers who have been at pains to apply the skills of their trade, particularly the powerful statistical tools largely introduced by Fisher in the 1930's which allow the identification of much smaller changes with confidence. The harsh truth is that farmers are only interested in innovations which yield between 40 and 50% on the additional investment which they require. Such returns can be obtained under the less variable conditions of research stations or monocropping commercial farms from innovations with lower yield responses. To obtain such returns on a peasant farm the yield responses need to be from 15-20% as minima. Use of some simpler analytical tools such as Fisher or Cochran tests and the sign test may be adequately robust to allow extension staff to utilise farmers trials to good effect.

Looking over the fence

It has long been known that prospective purchasers of farms are well advised to pursue judicious enquiries in the nearest hostelry over a series of visits. A similar approach can be used over the farm fence with your neighbours, not necessarily those in direct proximity, but certainly the nearest who is successful in the enterprises you are following, or anticipating to follow. Where extension coverage is sparse, farmers adapt and learn from each other. An experienced extension officer will both learn from farmers and set farmers learning amongst themselves to enhance his effectiveness. A multivariate analysis system using this approach is described by Johnson, P.H.S. (7,8).

The cocktail party method

The apparent value of a cocktail party is to meet people and to discuss trivia. However, C. Northcote Parkinson in his Parkinson's law, and experienced diplomats, would disagree. They have analysed the machinations and peregrinations of such events and demonstrate how they can be effectively used as means to pursue topics to great advantage, rapidly and cost effectively.

In the agricultural extension milieu similar advantages can be obtained through discussion groups. These are usually sponsored by an interested party which sets the theme, which must obviously be topical and significant to attract participants. Once the formal business is concluded the event then metamorphoses into a close analogy of a cocktail party. Now the farmer and the extension agent can really get down to business. The farmer can verify or enlarge on the information presented and the extension officer can justify and exemplify his advice. What is happening is a process of adjusting the advice to obtain a workable fit for the individual farmers. Many workers have fallen foul of the tendency to consider farmers, and particularly peasant farmers, as homogeneous. They are most certainly not. A discussion group, followed by a 'cocktail party' enables the extension worker to prime the participants to a suitable starting position and then to cut and fit the advice to tailor it to the specific requirements. Farmers can do this for one another and will continue to cut and fit as circumstances change during the life of the crop or other enterprises. There are skills to be learned by extension staff in priming and then facilitating such activities and their consequences. It is unusual for farmers to organise such a meeting themselves, perhaps for fear of being overtly seen as trying to direct their peer group.

LEARNING FROM FARMERS

Now that we know something of the information needs of farmers and something about how farmers set about filling those needs, we have the basis on which to design some tactics through which to learn from farmers. Maxwell (10) describes a case study method of understanding farm systems, which, if it is subject to critical review using the frame-work for on farm interviews devised by Carruthers (1), can be of use. Carruthers admits that his critical review procedure is merely a "thinly disguised mechanism for marginal analysis". Our Agritex Crop Production Branch has reduced this to an extension aide in the form of a plastic aide-memoire of pocket size fastened with a split ring to make it more accessible to extension staff. Regular use of the questions and approaches therein should facilitate their internalisation.

The case study method quickly generates information and data on management strategies which can be recalled and used as comparison and contrast at later times. There are analogies possible here between agricultural case studies and those used in the medical and legal professions whereby similarities and variances are checked off against previous precedents as a guide to future action. The medical analogy is probably closer to the agriculture as diagnosis and prescription are needed quickly before the patient (crop or stock) expires. Thus, while formal written case studies may well have utility in getting new staff in the swing of such work, it must quickly be converted to an automatic, almost anecdotal approach, whereby complex systems can be quickly and reliably diagnosed.

CIMMYT (9) characterises diagnostic analysis as comprising of the following:

Identifying the best technical opportunities for improving production in specific localities;
Assessing the utility and acceptability of research results;

Four phases of the process are then defined:

Describing the system of agriculture;
Defining the target group or recommendation domain;
Defining priority problem areas for each target group;
Elucidating the causes of defined problems from an holistic view.

CIMMYT then propose three tools for use in this process:

Informal surveys;
Diagramming causal relationships for problems;
Screening alternative recommendations for utility.

This approach was discussed and recommended from a workshop on cropping in the semi-arid areas of Zimbabwe in 1987 and has, subsequently, been included in a hand-book designed to assist extension in advising farmers in the semi-arid areas.

DISCUSSION

The view is often propounded that we could solve all agricultural problems if research were to be expanded and if extension were to grow to adequate size to be able to disseminate the research results to farmers. It is my belief that a great many of the problems faced by some farmers have been solved by other farmers and that catalysis of those results by extension (and their confirmation or denial by research) is an important missing element to the farmer, extension, research system.

How often has research set off to find answers to problems which are considerably less than immediate in their importance to farmers? More importantly why has this occurred? The answer lies in the failure to close the extension, research, farmer cycle. Research is unguided (if not misguided) because extension is not analysing the information needs of farmers adequately. This has led research organisations to start trying to short circuit the system by doing farm systems research on farm trials with (despite millions of dollars which have been poured into such efforts) mixed results.

Can extension improve its performance in assessing research needs and can farmers practices', in all their variety, assist this? By sheer weight of numbers (there are many times the number of farmers than the numbers of researchers and extension staff) farmers are likely to be more innovating with their farm systems. Extension, considering the arguments which I started out with about the serendipitious, intuitive, leaps which are necessary to understand and improve on complex systems, should be able to pick out some juicy tit bits just in the course of their usual peregrinations around the countryside.

Without this approach it is difficult to see how large numbers of on farm trials will supply anything like the information required to be extended. The large Standard Error (S.E.) normally associated with such trials, together with the high frequency of drought, adds to the difficulty of interpretation of such trials. The method of analysing these trials as proposed by Hildebrand, (1984), although quoted by economists as a solution to such problems, is not widely accepted by agronomists. The biometricians' answer would be to increase still further the number of trials, however it should be borne in mind that the S.E. will only be reduced by the factor of 1/n. This in effect does not solve the problem either, bearing in mind that trials from reasonably homogeneous areas can only be compared. This problem is further compounded by the high failure rate of such trials, a figure of 50% is not uncommon. What span of years will need to elapse before tangible results can be obtained from this system?

More importantly what steps can be taken to improve the efficiency of extension (and research) staff in making the intuitive leaps and fostering the serendipity? Farm systems research and on farm trials are mechanistic and cumbersome means which bureaucracies have tried to develop to meet this need. Now, we all know the saying that the camel is a horse designed by a committee.! Neither mechanistic or bureaucratic solutions suit a non bureaucratic system - the farm. Both extension and research staff need to adjust their methods of thought, observation and analysis away from rigid reductionism towards greater development of their inductive capacity. This view may be considered fantastic or even madness but, "there is method in't."

CONCLUSION

In the body of this paper I have endeavoured to review the learning systems of farmers and the way and means whereby research and extension have endeavoured to match their work to the needs of farmers.

I have postulated that extension and research are well advised to continue learning with (as well as from) farmers but that the means by which they undertake this learning needs to be improved.

The essential and inescapable conclusion which I made is that extension and research staff need, like farmers already are, to become self actualising, proactive learners.

Approaches such as farm systems research and the CIMMYT method are useful ways for officers to learn these approaches but they must become internalised and automatic to be capable of leading to the intuitive leaps with good advice that research requires.

To achieve this, a change is needed in preservice and inservice training, (at whatever level) to direct it away from pedagogy and towards self-learning. I am pleased to be able to report that the majority of inservice training in Agritex has already been converted to a Criterion Referenced Instruction basis, with good results once the trainees learn to cope with self-learning and can be weaned from the bottle of pedagogy. If such systems became the norm in the Colleges, Institutes and Universities where staff obtain their preservice training as well, then we could look to a considerable improvement in extension and research performance.

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APPENDIX

Evaluation (Risk) of Research Results from Research Stations for Extension Purposes

The following step by step procedure is a crude method of assessing "Climatic Risk" to be used with an economic evaluation.

1. Use only those results which have a C.V. of 25 or less.

2. Carry out an economic analysis as detailed in CIMMYT information bulletin 27 (An Economic Training Manual by R.K. Perrin -- J.R. Anderson).

3. Use the publication: "Agroclimatological analysis of growing season in Natural regions III, IV, V of Zimbabwe" by J Hussein. This publication contains, for selected meteorological stations, frequency distributions for the start, end, and length of the growing season. Determine the nearest station to which you can apply the data. If research station is in natural region I or II calculate the start, end, and length of the growing season as described in the publication.

4. Determine the length of the growing season for the year of the trial.

5. Carry out a significance test in the normal way of using,

   $$\frac{\text{"Length of growing season" - mean}}{\text{Standard deviation}}$$

6. Your results from 5 should give you a **measure of reliability**, which can be used for extension purposes. Any number over 2 standard deviations should be used with caution, particularly the negative which has little application. As an example: a marginal net benefit of "X$" was obtained using factor "Y". This result is estimated to have an occurrence of not less than 25 out of 30 years, which involves a low risk.

Crop Protection for Small-Scale Farms in E & C Africa—a Review

Small scale farming families account for the large majority of population in most countries of E & C Africa. Agricultural production is carried out overwhelmingly on small scale farms where labour is scarce and inputs such as pesticides and machinery are not affordable. Extensive yield losses are inflicted upon food crops on small farms by insects, weeds, nematodes and diseases. Improvement of crop protection practices is therefore seen as an important means of raising yields.

Senior scientists from the Commonwealth countries of Uganda, Kenya, Tanzania, Malawi and Zimbabwe have identified key issues in crop protection for small scale farms on which they are focusing their attention. These issues are reviewed and discussed in this volume and include: the use of inter-cropping; yield losses caused by maize stalk borer; efficient control of weeds; pesticide safety and management; learning from farmers' practices.

This volume represents the collection of review papers presented at the Commonwealth Science Council's Crop Protection meeting in Harare, Zimbabwe, in March 1988.

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