Project 5

Integrated Management of Maize Pests and Diseases

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International Institute of Tropical Agriculture

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Preface

In 1999 IITA's research agenda was subdivided into a portfolio of 16 projects (Annex 1), around which these annual reports are prepared. These projects address different aspects of attaining sustainable increases in productivity of dominant farming systems and utilization practices in the various agroecologies of sub-Saharan Africa (SSA). Research and training activities carried out in the 16 projects are being implemented together with national program partners in order to increase the well-being of poor people in SSA through higher levels of food production, better income and nutritional status, and reduced drudgery particularly for women. Additionally, IITA serves as the convening center for the Ecoregional Program for the Humid and Subhumid Tropics of Sub-Saharan Africa (EPHTA) and the Systemwide Program on Integrated Pest Management (SP-IPM).

The institute-wide logframe (Annex 2) shows the expected contribution of each project to the overall institute goal, with the specific project logframe presented in Annex 3.

Highlights from all projects can be found in Annex 4, which thus provides an illustrative overview of IITA's research activities and achievements of the year.

Annex 5 shows the agroecological zones of sub-Saharan Africa in which IITA conducts research.

The project management arrangement for implementing IITA's research agenda is relatively new, and continues to evolve from a divisional/program structure. In earlier years, detailed research outputs and achievements were reported in divisional reports; this is the fourth year that implementation of IITA's research agenda is being presented in individual project reports. To satisfy the continuing needs of disciplinary groups in partner and other interested institutions, portions from the individual project reports will be collated into subject matter reports corresponding to current research divisions—Crop Improvement, Plant Health Management, and Resource and Crop Management.

Project 5
Integrated Management of Maize Pests and Diseases

by V. Adenle, S.O. Ajala, K.F. Cardwell, O. Coulibaly, B.M. Dixon, J.M. Fajemisin, G. Goergen, K. Hell, J.G. Kling, R.H. Markham, W.G. Meikle, A. Menkir, C. Nansen, F. Schulthess (project coordinator) assisted by O. Ayinde, J.O. Bukola, P. Degbey, S. Gounou, S. Odubiyi, S. Olojede, D. Onukwu, A. Tchabi

Project rationale

Maize was introduced to Africa from its native Mesoamerica, in the 16th century. It became the most important cereal crop in East Africa where it is a staple for a large proportion of the population. In West Africa, maize is an important component of the farming systems and the diet of many people and is increasing in importance as it expands into the savanna zones. Yields are reduced by numerous plant pathogens such as maize streak virus, *Cercospora zeae-maydis* (Tehon & Daniels) Shoenaken, *Exserohilum turcicum* (Passerini) Leonard & Suggs, *Puccinia* spp., and the downy mildew fungus (*Peronosclerospora sorghi*). Insect pests such as stem and cob borers (e.g., *Sesamia calamistis* Hampson, *Busseola fusca* (Fuller) (Lep.: Noctuidae), *Eldana saccharina* (Walker), *Mussidia nigrivenella* Ragonot (Lep.: Pyralidae)) have moved on to maize after having evolved on native grasses or cereals such as sorghum and millet, and other host plant species. Other pests such as the stem borer *Chilo partellus* (Swinhoe) (Lep.: Pyralidae) and the larger grain borer *Prostephanus truncatus* (Horn) (Col.: Bostrichidae) have been accidentally introduced from Asia and the Americas. In many areas, maize is replacing indigenous cereal crops such as sorghum and millet, as well as wild habitats. As a result, maize has become the major host of insect pests and diseases.

IITA's first approach to controlling maize pests and diseases has been host plant resistance. Resistance to maize streak virus and the downy mildew fungus, and tolerance to *Striga* has been developed. IITA's maize germplasm also has some resistance to the blight and rust fungi such as *B. maydis*, *E. turcicum*, and *Puccinia* spp. Nevertheless a potential for damaging outbreaks of these pathogens exists given a change in host genotype and environmental conditions. These factors also influence the population dynamics of leafhoppers *Cicadulina* spp., which are vectors of the maize streak virus. Hence, 'habitat management' studies are especially important to understand fluctuations in the populations of organisms relative to climate, cropping intensity, management practices, and genotype. For insect pests such as *S. calamistis* and *E. saccharina* only moderate levels of host plant resistance are likely to be obtained while maintaining a good agronomic background, thus habitat management and biological control are alternatives which are receiving increased attention. IITA germplasm, as well as germplasm obtained from collaborative work with CIMMYT and local West African varieties, are also being evaluated for resistance to postharvest pests such as *P. truncatus* and *Sitophilus zeamais* Motschulsky (Col.: Curculionidae). The effects of varietal resistance on insect ecology have been integrated into an IITA decision-support tool for stored product systems.

Food security and human nutritional status of the target clients of the CGIAR are directly impacted by losses in quantity and quality of the harvested crop. In some cases, the losses to pests and microbes postharvest far outweigh any reasonable hope for increases in productivity through improved germplasm and pre-harvest management. There are reports from Africa of postharvest losses averaging 30% of grain dry weight in maize stored on farm due to *Tribolium castaneum* Herbst (Col., Tenebrionidae), *S. zeamais*, and *Sitotroga cerealella* (Olivier) (Lep., Gelechiidae). *P. truncatus* can cause much higher losses where it occurs. Lepidopterans riding in the cob coming from the field cause additional losses in grain weight.

Compounding the problem of actual grain weight losses, insect-damaged kernels are highly likely to be contaminated with dangerous levels of aflatoxins which are known carcinogens, and are also thought to be immuno-toxic and growth suppressants. A Rotary International (RI) Health, Hunger, and Humanity project has been designed with IITA, governmental organizations (GO), and Rotary Clubs from 5 countries to increase trader and consumer awareness of the deleterious nature of poor grain quality in West Africa. Information campaigns in Bénin, Togo, Ghana, and Burkina Faso will target urban centers with messages about how to recognize and eliminate poor quality grain, and how to recognize symptoms of aflatoxin intoxication in children. Grain quality in these markets will be monitored biannually by the official food quality laboratories of each country. Animal husbandry will be the target of another set of RI campaign messages about how to render safe low quality feeds in order to provide a legitimate alternative market for poor quality grain.

The other important factor in food quality management is government policy. Most governments in West Africa have toxicology monitoring capability and regulatory aflatoxin limits as statutes of law. The problem is lack of prioritization and insufficient funding. Countries with a low tax base and a large social load must have economic prioritization of the state-run programs. Real information about macroeconomic impact of mycotoxins in terms of lost human resource potential and public-health costs is needed to move this issue to the top of policy concerns. This will be the purpose of a medical interface study, funded by BMZ to begin in 1999, which will attempt to assess the immune-suppressive effect of mycotoxins in small children. The government of Holland is helping sponsor the collection of socioeconomic covariant factors to nutrition, thus isolating variables which have confounding effects on health.

Finally, in the event that aflatoxin control becomes a priority policy issue in Africa, research into host plant resistance and biological control solutions is being done with collaboration between the USDA and IITA. With this basic research, the hope is to find single efficacious technologies that would not require complicated changes in crop management systems of small-scale producers, resulting in greater ease of dissemination and adoption of the intervention. Temperate maize germplasm with high levels of *Aspergillus flavus* resistance in the U.S. are being converted to lowland tropically adapted lines. Atoxigenic isolates of *A. flavus* from West Africa have been characterized and are being tested as biocompetitive agents in the field against toxic indigenous populations.

Outputs

5.1. Knowledge of pest and disease systems in pre- and postharvest maize

Background

Countrywide surveys are conducted and farmer questionnaires distributed to determine the extent of losses in maize production due to pests and diseases in the field and in storage, and farmers' perceptions of these losses. Multivariate analyses of the survey data generate hypotheses on the interactions among physical components of the cropping system such as edaphic and crop management factors with biotic components of the system. The hypotheses are being tested in selected benchmark sites, on-farm participatory trials, on-station, or in the lab or greenhouse, using controlled experiments (See 5.3.). The survey protocols are regularly modified to incorporate findings from the controlled experiments. Yield assessment surveys are repeated in areas with critical pest densities and after an intervention technology has been introduced to assess impact on pest or pathogen populations and yield of maize.

Downy mildew disease of maize reached epidemic proportions in the southern half of Nigeria beginning in 1989, and began to spread. New infections began to appear sometimes as far as 100 km away from the nearest infection foci. It had previously been reported to be spread only by airborne conidia, as no alternate host had been located and none had found oospores in the maize infecting strain. In 1993, a program was designed to understand the mode of spread of the pathogen, and to begin practical implementation of a control program. By the end of 1995, the disease had spread into seven states and could be found within 50 km of the international frontier with Benin Republic. In 1998, the disease control campaign appeared to be having effect as the pathogen was not reported to have crossed into previously uninfected areas. In 1999, disease levels continued to decline as efforts continue to move downy mildew resistant maize seed further into the country by pyramid extension efforts in partnership with NGOs.

The larger grain borer was accidentally introduced from its area of origin in Mexico and Central America to East and West Africa in the late seventies and early eighties, respectively. It has been confirmed from many countries in West, East, and Southern Africa. In the affected countries, the larger grain borer has become one of the most important pests of farm-stored maize and cassava, particularly for small-scale farmers. In addition, grain and cassava postharvest losses to *S. zeamais*, the maize weevil, continue to be severe. The general approach of the Stored Product Pest Management project has been to use simulation modeling and GIS to provide a framework for putting together information on the ecology and economics of the pests, and then to examine the framework to develop specific lab and field experiments. On-farm surveys continue to be used to identify possible control options as well as farmer practices that may be ineffective or even dangerous, such as the application of field pesticides to grain stores. Properly arranged on-farm trials to ensure the immediate relevance of our work to farmers in the region, and the results are being used as the basis for courses developed in collaboration with NGOs and NARES. The simulation models themselves, as well as programs useful for developing sampling plans specific to a particular region, are to be included in a decision-support tool for release in 1999.

Ongoing and future activities

5.1.1. Diagnostics and loss assessment studies

by F.S., K.F.C., O.C. - in collaboration with G. Bigirwa, M. Botchey, E. Darkwa, A. Fofana, S. Hauser, S. Weise, C. Nolte, M. Koubé, R. Ndemah, Z. Ngoko*, W. Marasas, M. Sétamou**

(For pest and disease diagnostics in Cameroon see R. Ndemah 1999 and Z. Ngoko et al. under completed studies.)

The distribution of lepidopterous maize stem borers and diseases was assessed in farmers' fields in the southern regions of Ghana during three consecutive years. Maize stem borers encountered during the surveys included, in order of importance, *Eldana saccharina*, *Sesamia botanephaga*, *Sesamia calamistis*, *Busseola fusca*, *Chilo aleniellus* and the cobborers *Mussidia nigrivenella* and *Cryptophlebia leucotreta*. Highest infestations of stem borers were found in the Ashanti region. Seven fungi (*Bipolaris maydis*, *Puccinia polysora*, *Physoderma maydis*, *Stenocarpella macrospora*, *Curvularia* spp. *Marasmiellus paspali*, *Cercospora zea-maydis*), two viruses (maize streak and maize mottle virus) and 'physiological spot' of unknown origin contributed to leaf area destruction of 8–20% depending on season and region. Decreased soil fertility and high plant density favored the spread of *Puccinia polysora*. Physiological spot was negatively related to soil organic matter indicating perhaps that lack of soil organic matter promotes this condition of unknown etiology. The complex of factors responsible for foliar loss varied with season and region. However, maize streak virus *P. polysora*, *B. maydis*, *Curvularia* spp., and nitrogen

deficiency were the most important across regions in all the surveys. Across regions, *B. maydis* and crop density caused 76.48 g per plant yield loss in the early season of 1996 while in the late season, more than twice this quantity was lost to maize streak virus, nitrogen deficiency, crop density, and stem borer tunneling. Cob weight reduction across the benchmark sites was about the same for both seasons in 1998 (45.86 g/plant). Factors that were responsible for losses in the early season included maize streak virus, nitrogen deficiency, crop density, *Marasmiellus paspali*, *Cercospora zea-maydis*, physiological spot and stem lesions but in the late season, the causal factors were maize streak virus, *Stenocarpella macrospora*, *P. polysora*, and *Sesamia* spp.

5.1.2. *M. nigrivenella*: a cob feeding pest of maize in western Africa

by F.S. - in collaboration with M. Sétamou, S. Gounou

Investigations on the ecology of and control options for the maize cob borer, *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae), were conducted in the different agroecological zones of the Republic of Benin, West Africa. Countrywide surveys in maize fields and on-station experiments revealed that the borer is the most abundant and the most damaging pest of pre-harvest maize. The damage of *M. nigrivenella* also continues during the first two months of the storage period. A simple mathematical model, relating *M. nigrivenella* cob infestation levels at harvest and maize yield losses due to the borer was developed. Yield losses caused by *M. nigrivenella* in the field could be determined by calculating the percentage of cobs infested by the borer. Infestation of maize cobs by *M. nigrivenella* was also associated with *Aspergillus flavus* infection and subsequent aflatoxin production in maize grains. The incidence of the borer varied with the agroecological zones. The borer is particularly damaging in the Guinea savannas of central and northern Benin. The evaluation of the host plant range revealed the polyphagous feeding behaviour of *M. nigrivenella*. Moreover, the high abundance of *M. nigrivenella* in the Guinea savannas was most likely due to the overlapping fruiting periods of host plants in these zones.

Life table studies of *M nigrivenella* on natural host plant materials demonstrated the preference of the borer for jackbeans, *Canavalia enseiformis* (L.) DC. (Fabaceae). In order to prevent this new cover crop in West Africa from constituting a potential source of infestation of *M. nigrivenella* for neighboring maize fields, planting of jackbeans should be timed in such way that its fruiting period does not precede that of maize. Larvae of *M. nigrivenella* showed an aggregated distribution on fruits of most wild and cultivated host plant species, except for *Gardenia* spp. (Rubiaceae). Spatial distribution on a particular host plant species was highly correlated to the respective fruit sizes. Sample sizes and time expenditures needed to estimate *M. nigrivenella* populations at a precision level of 25% on the various host plants were determined. The flight activity of *M. nigrivenella* moths was affected both by weather factors and availability of fruits of major host plant species. Delaying the harvest of maize increased the incidence of the borer. Sun drying of cobs at harvest for a week, however, reduced further damage in store. Investigations on the natural enemies revealed only few parasitoid species attacking *M. nigrivenella* and their presence was associated with the different wild host plant species. No natural enemies could be collected from maize and other crops. Parasitoids were found only on wild host plant species with the pupal parasitoid, *Antrocephalus crassipes* Masi (Hymenoptera: Chalcididae) being the most abundant species. Levels of parasitism were rather low. In future, biological control of *M. nigrivenella* should therefore pursue the 'novel-association' or the redistribution approach of natural enemies. Search for efficient natural enemies should concentrate on areas where *M. nigrivenella* doesn't pose a problem to annual crops as in East and Southern Africa.

5.1.3. Study of stem and ear borers × storage pests × mycotoxic fungi interactions

by K.F.C., F.S., J.G.K., B.M.D. - in collaboration with O. Ayinde, A.A. Baba-Moussa, Z. Ngoko*, W.F.O. Marasas, S. Odubiyi*

Several field experiments have shown that higher numbers of all types of insects can be found in cobs that were infected with *F. moniliforme*. Many insect species including the lepidopteran *E. saccharina* and *M. nigrivenella*, and known storage pests such as *S. zeamais*, *Carpophilus* spp. and *Cathartus* spp. have been found in higher numbers when the fungus is present. Work in 1997 and 1998 has revealed that stem borer numbers were also higher on plants with endophytic *F. moniliforme* than on plants without. Greenhouse and lab experiments showed that significantly more eggs were laid on plants inoculated with *F. moniliforme*, *E. saccharina*, and *M. nigrivenella* than on fungus-free plants, and survival of immatures was higher. Similarly, olfactometer studies revealed that both *S. zeamais* and *Carpophilus dimidiatus* are strongly attracted to grain infected with fusarium. By contrast, development time on infected plants was significantly shorter and longer for *S. zeamais* and *C. dimidiatus*, respectively. It is concluded that keeping the plant fungus free would also partly solve the insect problem in the field and store.

5.1.4. Improvement of maize quality through the reduction of aflatoxin contamination

by KFC, KH, AH - in collaboration with Koube, Marius ?, Egal, Ayin

At the beginning of 1999, a special project on the 'Improvement of maize quality through the reduction of aflatoxin contamination' received funding from BMZ/GTZ. A planning workshop was convened to assemble researchers working on the problem in Benin and Togo with resource persons. The results of this workshop were a project activity plan for the three research areas involved in the project: e.g., socioeconomic, medical, and agronomic. The agronomic activities are the participatory evaluation of management practices to reduce aflatoxin contamination in stored grains. Some of the management practices studied are timing of harvest, drying, influence of storage structure and insect control in 6 villages in 2 agroecological zones in Benin and Togo. On-station trials look at the influence of insect control methods on toxin levels. These technologies are being evaluated separately with the aim of developing technology packages that effectively reduce toxin load. Applied research is looking at the effect of variety on aflatoxin, biological control options, and influence of N-source.

The socioeconomic actions are household level surveys in 12 villages in Benin and Togo to get basic socioeconomic data on the 50 households in each village involved in this study, e.g., income, expenses, etc., and the cost-benefit analysis of technology packages to reduce aflatoxin contamination.

The medical team will look in the first phase at the effect of aflatoxin exposure in 50 infants (0–3 years) in each of 16 villages in Benin and Togo. In a second phase, a more intensive study will look at differences in vaccine response and growth of children and the relationship with aflatoxin contamination in low and high toxin areas.

Up till the end of 1999, the 16 villages participating in this study in Benin and Togo have been selected and characterized. The participatory tests have started and the protocols for the medical and socioeconomic village-based activities have been prepared.

5.1.5. Biology and ecology of *P. truncatus* outside grain stores

by C.N., W.G.M. - in collaboration with A. Tchabi, T. Adouhoun, S. Awande, R. Kleespies

Analytical tools for analysis of *P. truncatus* flight activity have been identified and were used to link abundance of trap catches with vegetational variables. Changes over time in *P.*

truncatus flight activity were compared for traps near grain stores and in a forest environment, and trap catches showed quite similar changes over time in the two environments. For this reason it is believed that, although the magnitude of trap catches is probably determined by the environment in a restricted range from the trap site, the overall changes over time are determined by weather-driven changes influencing traps on a larger spatial scale. Spatial distribution analyses of pheromone trap catches are being conducted to examine the spatial association of *P. truncatus* and its natural enemy.

Intensive field sampling of woody substrates, shown from laboratory experiments to be susceptible to *P. truncatus*, failed to document these as potential substrates to *P. truncatus in* the forest environment. Screening of potential non-wood substrates (roots and seeds) for *P. truncatus* in the forest was conducted as a subsequent phase to previous screening of woody substrates. The importance of substrate quality (woody substrates compared with maize) on male produced pheromone was studied by quantitative (field studies) and qualitative (extractions and gas chromatography of pheromone in laboratory experiments) comparisons of attraction.

5.1.6. *Modeling of storage pest population dynamics and grain losses*

by W.G.M., R.H.M. C.N. - in collaboration with N. Holst

The first draft of an "electronic book", in the form of a CD ROM and downloadable from the Internet, was assembled jointly by workers at IITA and the Danish Institute of Agricultural Sciences. The book contains chapters on simulation modeling of stored product pest population dynamics, and grain store sampling plans, as well as a brief history of larger grain borer research. The simulation models are linked to each other, via functional response, to a "systems" model of the grain store environment. Executable files of simulation models for *P. truncatus*, *S. zeamais*, and the predator *Teretrius nigrescens*, and of programs for constructing sampling plans, are included, along with all the C++ coding and the datasets used to validate the models.

Iterative statistical techniques involving 43 datasets of experimental stores in different locations (Benin and Nigeria) and from different years were used to estimate the daily per capita rate of maize damage for *P. truncatus* and *S. zeamais*, and the results accepted for publication. Different models, one linear and one nonlinear, were examined. The nonlinear model, based on the prey/predator functional response, was found to have a much better fit, although it requires more parameters. The per capita rates are used to link the pest models to the grain store environment described above, and to link model output with economic analyses.

The field experiment to monitor store conditions, insect density, and fungal infection and aflatoxin contamination in 9 rural maize stores in southern Benin, was completed. Several stores suffered high infection rates by fungi as well as high densities of *S. zeamais*. However, the most common fungi were *Fusarium* spp.; the rates of infection by *Aspergillus* spp. were comparatively low and aflatoxins were found in some but not all samples. Statistical analysis of the data has not been completed.

5.1.7 Economic analysis of stored products

by W.G.M., C.N., R.H.M. - in collaboration with N. Holst

A database of maize prices was used to create a monthly map of average prices across Benin. The coordinates of the data from 20 markets were obtained, values were interpolated across all of Benin, and maps generated using the real and interpolated values. The maps show two peaks in prices, one in the south centered around Cotonou and occurring from March to June, and another one, centered around Natitingou in northern Benin, and

occurring from June through August. These price maps will be linked to insect growth maps to estimate the potential value of IPM strategies. Data will be obtained for cassava.

5.2. Disease and insect resistant germplasm (pre- and postharvest)

Background

The front line defense of choice for most pest and disease control is host plant resistance. The wide genetic variability that exists in most domesticated plant species offers one of the most powerful tools used in agriculture. Many plant diseases and some insect pests are characterized by an intimate host-parasite relationship, which involves specific mutual recognition genes. These intimate relationships have the greatest potential for host resistance development through classical breeding methods, yet these relationships are also the most susceptible to catastrophic resistance failure. Breeders, entomologists, and pathologists must be constantly aware of what kind of pressure is being exerted on the pathogen/pest population as the breeding strategy unfolds.

Concurrent with upgrading of the levels of resistance to stem borers and maize downy mildew, extraction of inbred lines continues for both of these biotic constraints. A multiple-trait selection approach is employed whereby only lines showing highly reduced levels of leaf feeding and stem tunneling are advanced to the next generation.

Currently, breeding efforts are continuing to develop resistance to the African complex of stem boring Lepidopterans, the grey leaf spot disease (*Cercospora zea-maydis*), the grain mold fungi *Aspergillus flavus* and *Fusarium verticillioides* (ex *F. moniliforme*), and the larger grain borer, *P. truncatus*, among others. In these cases, host plant resistance is usually not the only line of defense that needs to be employed to achieve acceptable control. The research program must be well coordinated to create control packages such that the component technologies complement each other. Nevertheless, whether or not it is likely to obtain high levels of resistance, breeders and plant projectionists must ensure that susceptibility is not being inadvertently introduced into germplasm that is being developed for other characteristics. Thus screening trials for pathogens and pests must be a constant collateral activity.

Ongoing and future activities

5.2.1. Mass rearing of stem borers and development of field increase systems with NARES

by F.S. - in collaboration with S. Odubiyi, S. Gounou

Mass rearing of *S. calamistis* and *E. saccharina* is a routine activity of the IITA-Ibadan laboratories. Approximately 10 million eggs of the 2 species are produced every year. These are used for field infestations of breeding trials and for biological studies. In 1997, insect production at the IITA-Ibadan lab was drastically reduced to maintenance level due to financial constraints.

Besides those for *S. calamistis* and *E. saccharina*, IITA-Benin established small lab colonies of *B. fusca*, *M. nigrivenella*, and *S. poephaga*. These insects are also used for testing their suitability for indigenous and exotic natural enemies' species and strains, and for mass rearing natural enemies including entomophagous organisms.

The major constraint in NARES HPR programs is to achieve uniform field infestations. Since rearing of stem borers on artificial diet is too expensive to be afforded by NARES, other field increase methods have to be sought such as the use of diapausing larvae for egg production (e.g., for *B. fusca*) or the synchronizing of planting time with peak adult flight in areas with reliably high naturally occurring infestations. These methods are being devel-

oped and tested in Cameroon in collaboration with IRAD within the framework of an IFAD-funded project on plant health of maize. First results show that sequential planting of spreader rows yielded uniform *B. fusca* infestation in the third maize plantation. In 1999 additional trials were carried out by NARES in Ghana and Cameroon financially and technically backstopped by the CIMMYT/IITA project on breeding for stress resistant maize in Africa (AMS).

5.2.2. Improve stem borer resistant populations/lines

by SOA and FS

A total of 706 S1 progenies from four maize populations (ICZ5BC2A, ICZ5BC2B, TZBR Syn WC1, and TZBR Syn YC1) with resistance to *Sesamia* or *Eldana* stem borer were evaluated at three locations, one of which was under artificial infestation with *Sesamia* or *Eldana*. S2 lines from selected S1 progenies were recombined in the irrigation season of 1999–2000 to form new cycles of the populations. Furthermore, 192 S1 lines from a newly formed stem borer resistant population (TZBR Eldana 4 C0) were evaluated in three locations one of which was under artificial infestation with *Eldana saccharina*. TZBR Eldana 4 were formed by introgressing adapted germplasm into TZBR Eldana 1. Results obtained from the evaluations indicated that enough variability exists for effective selection to be practiced. S2 lines from selected S1 progenies were recombined in the irrigation season to form the cycle 1 of this new population.

Table 1. Means, ranges, and coefficient of variability (CV) of traits used in an index to select for a new adapted stem borer (*Eldana saccharina*) resistant population, BR *Eldana* 4 C0, evaluated at three environments in Nigeria

Variable	Average	Min	Max	Range	CV
*Cob damage rat.	4	2	7	5	24
Cob damage count	6	0	18	18	59
Stalk breakage (count)	2	0	10	10	84
Silk (days)	59	46	72	26	7
Plant height (cm)	197	91	292	201	11
*Ear aspect rat.	3	1	6	5	29
Yield infested (kg/ha)	2703	87	8343	8343	46
Yield uninfested (kg/ha)	2996	379	8623	8244	42

*Ratings on a 1–9 scale.

A 10-parent diallel of germplasm with resistance to *Sesamia calamistis* and/or *Eldana saccharina* was completed under artificial infestation with *Sesamia* and/or *Eldana* and at a hot spot location in Southeast Nigeria. Results (Table 2) from the evaluation and from knowledge of the germplasm permitted the assignment of four and five populations, respectively, to form two broad reciprocal populations (TZBR Comp 1 and TZBR Comp 2) with some levels of resistance to both *Sesamia* and *Eldana*. The tenth population, AK9443DMRSR, although a very good general combiner, did not really fall into a particular group, but was included in the formation of TZBR Comp 1 because of its high specific combining ability with two populations that were assigned to TZBR Comp 2.

A study to estimate the progress from selection for stem borer resistance was conducted under artificial selection with *Sesamia* and/or *Eldana* and also under natural infestation at a hot spot location—Egbema in southeast Nigeria. Results obtained, for example, from two of the populations (TZDR Eldana 3 and TZBR Sesamia 3) evaluated at Egbema are presented in Table 3. This result suggests that in general, grain yield increased with newer

cycles but plant aspect, a measure of the physical appeal of the genotype and cob damage due to stem borer infestation were rather constant. In effect, the selection index used in identifying superior genotypes with reduced levels of damage and good grain yield has resulted in an increase in tolerance rather than antibiosis. Tolerance as a mechanism of resistance is being promoted in the region because of its desirability in sustainable pest management programs.

Table 2. GCA (on-diagonal, underlined) and SCA effect (off-diagonal) for grain yield from a 10-parent diallel of stem borer resistant populations evaluated in 10 environments of Nigeria from 1998 to 1999

Crosses	1	2	3	4	5	6	7	8	9	10
1*	-75.7	322.2	-258.5	147.1	-183.3	-2.9	92.6	-16.6	18.3	-119.0
2		49.7	60.4	-185.8	208.3	-42.9	-130.1	-72.5	-101.7	58.6
3			-130.8	-33.7	-85.8	-190.3	-28.9	35.9	246.0	254.4
4				47.1	-25.1	307.7	3.0	-323.5	9.5	100.9
5					-144.3	85.0	141.8	6.6	-33.0	-114.3
6						-99.3	145.8	102.7	-222.9	-183.0
7							-112.2	35.0	-43.6	-215.9
8								259.4	12.0	199.8
9									113.3	115.4
10										92.8

*1 = TZBR Eld. 1; 2 = TZBR Eld. 3; 3 = TZBR Ses. 1; 4 = TZBR Ses. 3; 5 = TZBR Syn W; 6 = TZBR Syn Y; 7 = ATP; 8 = Ak 9443 DMRSR; 9 = DMR-LSRW; 10 = Suwan-1 S.

5.2.3. Improve levels of resistance to downy mildew in maize

by SOA

A study to estimate progress from selection to downy mildew attack in maize was conducted in 1999 at Akure, Nigeria. Result obtained (Table 4) showed that in general, grain yield of the genotypes increased with a concurrent reduction in downy mildew incidence with each cycle of selection. This study and similar studies from previous years also revealed S1 selection to be an effective procedure in decreasing downy mildew infection in maize with 4 and 5 cycles of selection being highly effective in reducing downy mildew infection to almost nonsignificant levels.

Table 3. Comparison of selection cycles from stem borer resistant maize populations evaluated at Egbema, Nigeria—Late Season 1999

Genotype	Grain yield (kg/ha)	Plant aspect rating (1–9)	Cob damage rating (1–9)
TZBR *Eldana* 3			
C0	3981.7	4	4
C1	4370.7	3	5
C2	4437.2	3	4
TZBR *Sesamia* 3			
C0	2279.0	5	6
C1	2459.9	5	5
C2	3092.9	4	5
Mean 3123	4	5	
SED	629.2	0.5	0.8
r-squared	0.7	0.5	0.9
CV	28.5	67.1	23.0

5.2.4. Evaluation of maize inbred lines derived from adapted x exotic backcrosses for resistance to downy mildew

by A.M., K.F.C.

Seven-day-old seedlings of 48 maize inbred lines derived from backcross populations between downy mildew resistant and adapted inbred lines, namely KU1414 SR and KU1403, and introduced inbred lines were inoculated with downy mildew suspensions of 1.0×10^5 to 1.2×10^5 conidia ml^{-1}. Inoculated plants were transferred to the screen house and the number of infected plants was counted two weeks later. Significant differences among inbred lines were detected for percent downy mildew infection (Table 1). The disease pressure was so severe that even the inbred line with known resistance to downy mildew, KU1414-SR, showed 100% disease incidence. However, three inbred lines derived from backcross populations of KU1414-SR did not show any downy mildew infection (zero infection). The donor parents of two of the three inbred lines were introductions (FLA2AT98, and FLA2AT116-1). These lines can serve as new sources of resistance to enhance durability of resistance to downy mildew in adapted varieties and hybrids.

Table 4. Comparison of selection cycles from downy mildew resistant maize populations evaluated at Akure, Nigeria—Early Season 1999

Genotype	Grain yield (kg/ha)	DM incidence (%)
TZL Comp4 DMRSR C11	2924.0	38
Ak 95 TZL Comp 4 DMRSR	4088.4	10
Acr.90 DMRLSR-W	3595.5	13
Ak. 93 DMRLSR-W	3017.9	2
Acr. 96 DMRLSR-W	4154.3	4
Ak. 95 DMRESR-W	2543.0	7
Acr. 89 DMRESR-W	1739.3	7
Mean	2448.1	26.7
SED	518.7	6.0
r-squared	0.7	0.9
CV	30.0	31.9

5.2.5. Evaluating postharvest resistance to maize pests

by W.G.M, R.H.M. - in collaboration with D. Bergvinson, B. Maziya-Dixon

The variety which showed the most resistance to *P. truncatus* development and survivorship in laboratory tests was multiplied in the field, with samples sent to Ibadan for testing against pathogens, and to local farmers, to evaluate their impressions. The variety, which has a very short cycle (less than 90 days), was severely attacked by several diseases in Nigeria, and would not be acceptable in its present form in the African moist savanna. However, farmers in Benin, who did not experience many disease problems this year, appreciated the short cycle and found the maize acceptable in terms of color, hardness, and taste. However, it remains to be seen whether the resistance characteristics observed in the lab provide economic benefits. Results from previous field trials and simulation modeling have shown that even relatively strong resistance may only provide temporary protection in field situations. In any case, performance in postharvest situations is only one factor of many (for example, field resistance to pests, diseases, and drought) that farmers consider in their choice of variety, so varietal resistance is best considered as part of an overall strategy against stored product pests, rather than a stand-alone technology.

Table 1. Mean percent downy mildew incidence of three resistant and three susceptible inbred lines selected from a trial inoculated with spore suspension in the screen house in 1999

Selected lines	Percent downy mildew infection	
	Screen house	Field
(KU1414SR/SRx1368STR)-1-1-B	0	16
KU1414xFLA2AT98-1xKU1414-4-2 BAG	0	0
KU1414xFLA2AT116-1xKU1414-2-1 BAG	0	11
KU1414SR	100	2
1368STR	100	51
TZMI102	100	74
ACR90 POOL 16 DT (Susceptible check)	100	90
Mean	86	38
SE	26	18
CV (%)	30	47
Probability of F	0.002	0.000

5.2.6. Development of germplasm with resistance to *Aspergillus flavus*

by A.M., K.F.C. - in collaboration with R.L. Brown, D.G. White

Aspergillus ear and kernel rot of maize is caused by *Aspergillus flavus* Link:Fr. This disease and its associated production of aflatoxin in maize grain is severe in areas with drought conditions. Aflatoxins, which are toxic secondary metabolites, are potent carcinogens to humans and domestic animals, because they frequently contaminate the maize grain. Host plant resistance can make major contributions to the control of aflatoxin contamination in maize. In our effort to develop cultivars resistant to *A. flavus*, we introduced a breeding population and nine inbred lines exhibiting resistance to aflatoxin contamination in field and laboratory studies in the US. Backcross populations involving these genetic materials as donors of resistance to *A. flavus* were developed in 1999. Several S1 lines were extracted from three backcross populations for further inbreeding. As part of a collaborative research work with USDA, 76 IITA inbred lines were evaluated for resistance to aflatoxin accumulation, using a laboratory kernel-screening assay. At least 18 inbred lines had aflatoxin levels as low as or lower than the most promising resistant genotypes identified by USDA. These lines also showed protein profiles that were not found among inbred lines developed in the US. Six potentially resistant and 4 susceptible inbred lines from the KSA, were selected for further investigation. Using an *A. flavus* genetic transformant containing a GUS reporter gene linked to a β-tubulin gene promoter in conjunction with the KSA, fungal growth and aflatoxins were both quantified and then compared in the selected lines. Generally, kernels of inbreds supporting lower levels of aflatoxins supported lower fungal growth and vice versa. Exceptions to this were inbred #1368 which accumulated moderately low levels of aflatoxin B_1, yet high levels of fungal growth, and inbred #15 with high aflatoxin levels and low fungal growth. Further studies of inbred lines 15 and 1368 may provide information leading to the identification of traits that directly affect the biosynthesis of aflatoxins. Traits previously identified appear to limit aflatoxin production indirectly through fungal growth inhibition.

5.2.7. Breeding for host plant resistance to *Cercospora zeamays*, causal agent of grey leaf spot of maize

by A.M., J.F., K.F.C. - in collaboration with G. Bigirwa, Z. Ngoko

In recent years, grey leaf spot has become the most devastating disease of maize in Eastern and Southern Africa. This disease has also been reported in Cameroon. Consequently, we initiated screening of our elite inbred lines in collaboration with scientist in the national programs to identify lines with good levels of resistance to this disease. Resistant lines will be useful to incorporate in our germplasm base in the event of an outbreak of grey leaf

spot in West and Central Africa. A total of 64 elite midaltitude inbred lines were planted in Uganda and Cameroon for screening against grey leaf spot. The data has not been received from our collaborators for analysis and inclusion in this report.

5.2.8. Evaluation of interaction between maize genotype, *Fusarium*, and stem borers

by S.A., F.S., K.F.C.

Old and new cycles of selection of 8 IITA maize genotypes were subjected to a 2 x 2 factorial experiment design with plants inoculated and non-inoculated with *Fusarium verticillioides* and *Eldana saccharina*. The hypothesis is that genotypes that have some resistance to stem borers, may also be resistant to *F. verticillioides*. From this experiment, it will also be possible to tell if, within the same genotype, cycles of selection toward greater stem borer resistance are also having an effect on the amount of pathogenicity and asymptomatic endophycity of *F. verticillioides* in the maize stem.

5.3. Biological control and habitat/store management options

Background

Biological control and habitat management provide the options of choice, when levels of host plant resistance are inadequate to protect the crop against pest or disease pressure, since the strategies are usually highly compatible, or even synergistic, with genetic resistance. Indeed, biological control, especially for an introduced pest species like the larger grain borer, can often be implemented much more rapidly than adequate levels of plant resistance can be developed by breeding; thus, in some circumstances, biological control becomes the option of first choice. In the case of maize pests and diseases in Africa, we are faced with organisms of a variety of origins, including co-evolved species, introduced recently or long ago from the same area of origin as the crop, African species which have moved from other wild or cultivated cereals, some African species originating from botanically unrelated host plants, and a few species of quite different geographical origin. Before biological control or habitat management options can be developed, it is vitally important to diagnose the source of the pest or disease problem correctly. Especially for biological control of stem borers, collaboration or informal networking with taxonomists and with entomologists working in other regions and crop systems has played a key role in suggesting innovative ways to tackle this long-intractable pest problem.

Habitat management has, in principle, great potential as a strategy to reduce pest populations, either directly (for instance by killing pests surviving between cropping seasons in crop residues or on alternative host plants) or indirectly, by encouraging the action of natural enemies. However, in practice, the usefulness of this approach is constrained not just by our incomplete knowledge of the interspecific relationships involved (which can be addressed by research) but by the difficulty of changing the management of field margins and fallow areas, which normally receive little attention, especially in situations where the availability of labor is often strictly limited. The feasibility of any potentially useful options must be evaluated very carefully through participatory research and extension exercises.

Bio-competitive niche management is a new approach for reducing the presence of several deleterious fungi associated with maize. There are current working examples of effective displacement of an undesirable target species with either an introduced or enhanced indigenous species that is more acceptable. Examples include hyperparasitic fungi such as *Trichoderma* spp. that can invade the niche of other fungi, such as endophytic *Fusaria* spp. or rhizophytic *Rhizoctonia* spp.; and toxigenic *Aspergillus flavus* strain displacement by non-toxigenic strains of the same species.

Ongoing and future activities

5.3.1. Identification of promising redistribution candidates

by F.S. - in collaboration with W. Overholt, D. Conlong, R. Ndemah, G. Thottappilly

Surveys and on-station trials in various West and East African countries indicate that in many ecologies most indigenous parasitic natural enemies of cereal stem borers are not reliable and important natural control factors. In West Africa and under certain ecological conditions, exceptions are the *Sesamia* egg parasitoids, *T. busseolae* and *T. isis*, which reach peak parasitization rates of over 90% before and during the second cropping season when the crop is both most attractive to ovipositing moths and susceptible to stem boring larvae, thereby significantly reducing yield loss. Likewise, recent on-farm studies in the forest zone of Cameroon have shown that *Telenomus* spp. egg parasitism is the main factor responsible for reduced *B. fusca* attacks on second season maize. Whereas *T. busseolae* has been reported to exist across Africa, *T. isis* has not yet been found in the eastern African region. The same study also showed higher diversity of beneficials on the wild host *Pennisetum purpureum* as compared to maize. Some of the species common in the Cameroon such as the tachinid *Actia? antiqua* and species of the *Tetrastichus atriclavus* complex, were never recovered from any other West African country, and Actia does not exist in South Africa indicating opportunities for the redistribution BC approach. *C. sesamiae*, a common larval parasitoid of *S. calamistis* and *B. fusca* in East and Southern Africa, is exceedingly rare in western Africa. In Cameroon, a few specimens only were obtained from *P. purpureum*. Strains of *C. seasmiae* from the Kenyan coast and Kitale provided by ICIPE were released in Benin and Nigeria but so far the coastal strain only established in southern Benin. In both countries, the release cages disappear/get stolen as fast as they are set up and the fate of the parasitoids released is mostly unknown. In 2000, releases will therefore only be made on research stations.

Collaboration with the South African Sugar Experiment Station (SASEX), Durban, continued in 1999. Several consignments of Sturmiopsis parasitica, a tachinid pupal parasitoid attacking *S. calamistis* and *E. saccharina*, were sent to South Africa, and finally released in sugar cane fields.

In 1999, further consignments of *S. calamistis* pupae parasitized by *Pediobius furvus* were shipped to Brazil to be tested on the sugar cane borer *Diatraea saccharalis*. However, no lab colony could be established yet, for unknown reasons.

5.3.2. Testing the suitability of West African stem borer species for exotic and indigenous natural enemies

by F. S. - in collaboration with S.D. Imeldas, K. Agboka

Suitability tests were continued using five stem borer species—*Sesamia calamistis*, *S. poephaga*, *S. botanephaga*, *Busseola fusca*, and *Eldana saccharina*- and a coastal and Kitale strain of *Cotesia sesamiae*, and the exotic *C. flavipes* and *C. chilonis*, all provided by ICIPE, Kenya. Acceptability varied significantly with stem borer species and parasitoid, and tended to be lowest with *E. saccharina* followed by *B. fusca*. *E. saccharina* was not suitable to any of the parasitoids, whereas *B. fusca* was unsuitable for *C. chilonis*, *C. flavipes* and the coastal strain of *C. sesamiae*, and *C. flavipes* did not produce any offspring on *S. botanephaga*. For all species, highest proportion of female parasitoids were produced on *S. calamistis*, except for the Kitale strain for which *B. fusca* was the most suitable host. It is recommended to use the coastal strain of *C. sesamiae* in areas with multiple Sesamia species (Ghana) and the Kitale strain in areas where *B. fusca* is the predominant species (Cameroon with special reference to the Western Highlands). As already shown in Benin, and earlier work in Ghana and Côte d'Ivoire, the exotic *C. flavipes* and *C. chilonis* have

little chance to get established because of low host specificity and suitability of some common host species.

The suitability of eggs of *Sesamia calamistis*, *S. botanephaga*, and *Busseola fusca* for the noctuid egg parasitoids *T. busseolae* and *T. isis* was tested in lab experiments. The parasitoids accepted and developed in all three host species. Generally, *T. busseolae* parasitized more eggs (52.0%) than *T. isis* (29.7%). For *T. isis* only, significant differences in parasitism between host species was found, with the highest rate of 40% on *S. calamistis* and 29.7% and 26.5%, respectively, on *B. fusca* and *S. botanephaga*. For both species, emergence was highest on *B. fusca* and lowest on *S. botanephaga*. The sex ratio was not influenced by the host species but sex ratio of *T. isis* was always higher than that of *T. busseolae*.

5.3.3. The effect of various soil nutrients on development and survival of stem borers

*by F.S., S.A. - in collaboration with S. Hauser, S. Weise, R. Ndemah**

Survey work, and lab and field trials conducted in Benin showed that increasing soil nitrogen favors both plant growth and survival and fecundity of stem borers, but had no effect on ear borers such as *M. nigrivenella* and *C. leucotreta*. Silica had a negative effect on survival on young *S. calamistis* larvae. However, differences between treatments were small, probably due to the low silica content of maize as compared with wild grasses and rice. Surveys carried out in southern Benin in 1993, showed negative relationships between *S. calamistis* densities and some soil nutrients. Life table studies of borers on plants subjected to various doses of K showed that for *S. calamistis* fecundity decreased linearly with K, whereas for *E. saccharina* only very low and very high dosages had a negative effect. Similarly, work in the forest benchmark sites in Cameroon yielded negative and positive relationship between K and Mg, respectively, and *B. fusca* densities at harvest. It is theorized that under insular conditions as occurring in forest fields, K could have a long-term negative effect on *B. fusca* populations via reduced fitness.

5.3.4. HPR × soil nutrient interactions

by S.O.A. and F.S.

The nutrient status of the soil affects to a large extent the resistance or susceptibility of genotypes to stresses. Preliminary results obtained from a study conducted on the interaction of stem borer resistant or susceptible maize varieties with nitrogen and potassium fertilizer levels showed that grain yield and stem tunneling of the entries due to *Sesamia* infestation increased with nitrogen levels. Potassium had a negative effect on stem tunneling. Both the resistant and the susceptible entries gave their best grain yields at 120 kg N and 30-kg K.

5.3.5. The role of wild hosts as a refuge of natural enemies in the stem borer ecosystem

*by F.S. - in collaboration with S. Gounou, R. Ndemah**

Since maize is not available all year round, biological control by larval and pupal parasitoids takes place in the wild habitat. Thus, they are a refuge for natural enemies during the between and the off-season for maize and thereby stabilize the system. For example, results from trials in Cameroon showed higher diversity of parasitoids on the wild host *Pennisetum purpureum* than on maize. In addition, results from surveys in various countries and from lab studies indicated that many grass species act as trap plants causing immature mortalities of close to 100%.

Trap plant trials were carried out in 1998 and 1999, using *Pennisetum polystachion* only, and *P. polystachion*, *Panicum maximum*, and *Sorghum arundinaceum*, respectively, as border rows. Data from both trials consistently showed that pest incidence (both *S. calamistis*

and *E. saccharina*), borer densities, and damage levels were significantly higher in pure stands of maize, although no significant differences in egg batch numbers were found between treatments. This was probably due to higher egg parasitism on grasses as compared to maize. Larval parasitoids such as *Cotesia sesamiae*, *Sturmiopsis parasitica*, and *Decampsina* sp. were recorded in the course of both experiments, with significantly higher parasitism on grasses. As for pests, proportion of plants showing *Fusarium moniliforme* disease symptoms was significantly higher in pure maize stands. However, all maize plots surrounded by grasses had considerably higher rodent damage, and as a net result, yields were one-third to one-fourth of that of pure maize fields. It is concluded, that the present planting arrangement, besides not being adoptable, is not an economically feasible option to control stem borers.

5.3.6. Microbial control of stem borers

by K.F.C., F.S. - in collaboration with, A. Cherry, S. Odubiyi, J.O. Bukola

Stem borer populations crash long before the onset of the dry season. It has been suspected that this may be partly due to diseases that become important at high aggregation of the pests. A project on microbial control of stem borers funded by ODA started in 1996. For further details see Project 3: Biological control of pests in the farming systems.

The feasibility of using *Beauveria bassiana* to control *S. calamistis* and *E. saccharina* is investigated, with special reference to endophytic strains. *B. bassiana* isolates inoculated into the whorl of 30-day-old maize plants were recovered easily from the leaf tissue 30 days later. The fungus was seen to be growing in intercellular spaces and on the leaf surface. Field inoculations of maize stems also yielded recovery of *B. bassiana* above and below the insertion point giving the best indication yet that the fungus is capable of living and spreading endophytically within the plant. The plants with and without *B. bassiana* were also exposed to *Eldana saccharina*. Data on reduction in tunneling is being compiled.

5.3.7. Development and testing of pathogen application techniques against storage pests

by W.G.M., R.H.M. - in collaboration with A. Cherry

Data collected from lab and field experiments, conducted in 1997 to 1998 and involving the development of a biopesticide for grain stores, is being analyzed using simulation modeling. While the strain of *Beauveria bassiana* used in the field trial was found to be highly virulent against *P. truncatus* in the lab, application in a field situation failed to control the pest. By incorporating the observed values on the virulence and persistence of the entomopathogens into a simulation model of *P. truncatus*, role of the timing of the application and the target stage of the pest (e.g., larval or adult stage) will be examined. The results will also be used to indicate the characteristics to look for in candidate fungal strains and in carriers and application techniques for stored products.

5.3.8. *T. nigrescens* release and monitoring

by W.G.M, R.H.M., C.N. - in collaboration with D. Bergvinson, J. Hirabayashi, G. Hill, F. Nang'ayo

T. nigrescens individuals, collected by workers at CIMMYT, were sent for quarantine to CABI in the UK. No pathogens or parasitoids were found in any of the collected beetles. When the progeny of those beetles were sent to PHMD for lab tests on their tolerance of cool temperatures, initial results show that the new *T. nigrescens* have similar temperature requirements as those found in southern Benin, suggesting that the poor performance of *T. nigrescens* at midaltitude sites in East Africa is not due merely to cold sensitivity of the strain of *T. nigrescens* released in East Africa, but probably to a complex of other factors.

5.3.9. Soils characterizations for atoxigenic strains of the soil inhabiting *A. flavus*

*by K.F.C. - in collaboration with P.J. Cotty, L. Ayinde, T. Hoffstadt**

Populations of *A. flavus* in agricultural field soils are composed of strains that exhibit a gradient of aflatoxin producing ability. Studies in the USA have shown that toxigenicity of a strain is not related to the ability of the strain to invade and colonize host tissue. In field experiments in the US, atoxigenic strains of *A. flavus* have been found to interfere with and displace toxigenic strains and thus reduce pre-harvest aflatoxin contamination of maize. This is currently being tested on a semi-commercial scale in the US as a potential control for contamination of cotton, groundnut, and maize.

A number of atoxigenic isolates have been identified from Benin, for which NIT mutants have been generated, and characterized as to vegetative compatibility group (VCG). The prevalence of these VCGs in the soils of Benin will be studied over the next few years.

A toxic and an atoxigenic isolate of *A. flavus* were tested in the field on maize ears to assess the possibility of biocompetition between them. Ear silks were inoculated with one or the other strain, and then both strains one after another to determine if toxin production could be precluded by the atoxigenic strain. The atoxigenic isolate alone produced no toxin in the ear. The mixture of atoxigenic and toxigenic significantly reduced toxin production in the ear when the atoxigenic strain was applied after the toxigenic. The trial is being repeated in 1999.

5.3.10. Biological control of *F. moniliforme* with endophytic hyperparasites

by K.F.C. - in collaboration with A.C. Odebode and A.A. Shobowole

Fifty-two fungi including the pathogen (*F. moniliforme*) were isolated from different parts of the maize plant and its rhizosphere using acidified potato dextrose agar (APDA) (July–Sept. 1997). One after the other, each of the fungi was tried as a potential antagonist against the pathogen by pairing in vitro, using three methods of pairing, each of which was done in triplicate (Oct 1997–May 1998). Fourteen of the potential antagonists (ten *Trichoderma* spp., three *Mucor* spp. and one *Rhizopus* sp.) were successful against the pathogen. Analysis showed *Trichoderma longibrachiatum*, *T. harzianum* (str.3), and *T. polysporum* as the best of all the potential antagonists, and inoculation of the antagonist before the pathogen (AGb4P) as the best pairing method. The fourteen successful antagonists were taken to the screen house and to the field and were either paired with the pathogen (*F. moniliforme*) or inoculated singly into maize stalks. Data on length of pith rot, location of recovery of the antagonist and the pathogen from the stem, and yield were taken. Data analysis is continuing.

5.4. Tools and tested packages for IPM of maize pests and diseases

Background

In the high-input cropping systems for which IPM strategies were originally conceived, reduction of excessive pesticide use, and the compatibility of pesticide use with other IPM options, was often the key issue to be resolved in practical development and testing. However, in most maize systems in Africa, pesticide use is not very prevalent and the development of integrated control strategies is a matter of constructively assembling a number of compatible options, especially to enhance plant health and ensure the sustainability of the complete system. For pre-harvest pests and diseases, working with soil fertility may be an especially important component of the system. Once diagnostic research has indicated the real nature of the problem and the form of a possible solution, the key to progress towards IPM implementation lies with the empowerment of farmers. Usually, neither farmers nor extension workers understand the underlying ecological principles

of pest and disease regulation and it is only when they have acquired some of this knowledge that they may be prepared to undertake the changes, often requiring extra labor, that are involved in the implementation of IPM. Participatory or collaborative approaches may provide a vital entry point to this process.

Postharvest losses from insect feeding and losses in quality from fungal contaminants are multivariate problems that usually start in the field and are carried into the store. Often, there are a series of management practices that lead to poor postharvest storage conditions. To optimize commodity management practices to reduce postharvest losses in maize, and to understand what costs are involved in doing so, requires IPM component testing with farmers.

Ongoing and future activities

5.4.1. Farmers participatory deployment of downy mildew resistant maize

by S.O.A., V.A - in collaboration with World Vision International, B.A. Ogunbodede, E.I. Jolaji, V. Manyong

In continuation of our efforts in 1997 to saturate the Ogbomoso area of Oyo State in Nigeria with DMR maize varieties, the World Vision International (WVI) again provided support in 1998 to the project. For the second year, a total of 111 farmers from 34 villages were aided to produce either a late (*DMRLSR-W*) or an early (*DMRESR-W*) maize population as preferred. Farmer-to-farmer diffusion is being used to quickly saturate the area with an improved technology, in this case, a variety. Our model ensures that an already trained farmer backstops a total of four new farmers made up of three farmers from a new village and one from the trained farmer's village, each year. In effect, from a total of 25 farmers from 9 villages that participated in the first year, we expected 100 new farmers and 25 new villages in 1998, thus bringing the total for the year to 125 farmers from 34 villages.

The level of interaction with the project by different categories of farmers was reflected in the grain yield obtained. For example, an average grain yield of 3.7 t/ha was obtained from the old and experienced farmer (farmers that started with the project in the first year) while the average from the new set of farmers was only 2.5 t/ha. Similarly, yield data were obtained from neighboring but non-participating farmers. Average grain yield for the nonparticipating farmers was 1.9 t/ha while that of the participating farmers was 2.8 t/ha.

5.4.2. Strategic deployment of downy mildew resistant maize

by S.O.A., VA and V. Manyong - in collaboration with World Vision International - J. Olufowote

With the support of World Vision International, the project on the saturation of a designated area with downy mildew-resistant maize varieties was concluded in 1999. For this reporting period, a total of 625 farmers in 159 villages were producing seed of resistant varieties and all had been trained on how to produce a healthy crop in field schools run by IITA scientists. Average yields increased by 50% from 1846 kg/ha for nonparticipating farmers to 2763 kg/ha for participating farmers. Downy mildew-resistant maize is currently being grown on 45 389 ha in Ogo-Oluwa and 240 000 ha in Orire, the two local government areas selected for the deployment exercise.

5.4.3. Exclusion of downy mildew from IITA, Ibadan campus

by V.A., K.F.C. - in collaboration with O. Ayinde, D. Onukwu, G. Ogbe

Given the potential for the downy mildew pathogen to be transmitted via seed, spore fall is being monitored and infected maize plants are being rouged to protect the maize breeding program on the IITA, Ibadan campus. Spore fall is being constantly assessed as the total

catch on a one cm strip of adhesive tape in a Burkhard spore trap per hour. Exclusion of the disease from the IITA campus is continuing, by treating all maize seed with Apron plus®, and/or using DMR varieties. Campus maize plots are periodically monitored for downy mildew infection and rogued. During the 1996 period, 23% of maize plants in research plots were infected and by 1997 incidence of infected plants on the campus was 0.07%. The average spore catch in a Burkhard spore trap in the center of IITA campus dropped from a mean maximum of 5 to around 3 spores/mm²/hr from 1994 to 1995. In 1996, the maximum mean spore catch in the year was about 1.2 spore/mm²/hr, which indicates a marked decrease in epidemic potential. The highest mean central campus spore trap catch in 1997 was .8 spores/mm²/hr, indicating an even further decline in epidemic potential on the IITA campus. Nevertheless, a spot survey of farms around the IITA perimeter, revealed that infection in farmers' fields still ranged from 0 to 94% in June 1997.

In 1998, spore fall and infected plants in and around IITA campus continued to be monitored. In 1998, no single maize plant in IITA research plots was found to be infected. A survey of maize farms outside the IITA campus showed that 71% of the farms surveyed had no infection while the remaining 29% had infection ranging between 0.03 and 27%. The highest mean spore catch in the year was about 1.7 spore/mm²/hr in April, but declined to between 0.7 and 0.8 spore/mm²/hr at the peak of planting. These indicators were a marked reduction from 1997 and may be the result of an unusually dry year.

Continuing the trend started in 1998, during 1999 no downy mildew-infected maize plants were found on the IITA campus. The highest hourly spore catch occurred in July and was 0.25 spore/mm²/hr. For the first time since the epidemic started in 1992, for 9 of the 12 months of the year the spore catch was 0.

5.4.4. Testing of integrated postharvest quality management options

by K.H., K.F.C.

Selected villages were visited with a team of socioeconomists and focus groups assessed the postharvest management problems encountered by farming families in these areas to identify points of intervention. The Aflatoxin Project collaborates in these villages with field agents working for the PADSA Project (a Danish project working in postharvest research) which supports the Beninese NARES (INRAB) in Benin; and with the GTZ Public health project and the Togolese NARES (ITRA).

The aflatoxin control options tested in the villages are:

a. influence of sorting

b. influence of storage structure (traditional vs. storage in polyethylene bags)

c. influence of insect control (with recommended postharvest insecticides)

d. influence of drying

e. toxin contamination in clay stores

In some villages a combination of the control options is being tested.

Trials were established with farmer groups to evaluate the influence of these management practices on aflatoxin development. At 2 months intervals, maize samples are evaluated with the farmers to assess insect infestation, fungal contamination, and market price. Samples will be taken to the laboratory to get a clearer picture of the fungal spectrum and determine aflatoxin levels.

5.4.5. IPM of stored product insect pests

by W.G.M., C.N., R.H.M. - in collaboration with HELVETAS

Six farmer workshops were held in southern Benin and Togo in collaboration with Helvetas, a Swiss-based NGO. The workshops were attended by Stored Product Pest Management workers from IITA, technicians from Helvetas, and approximately 30 farmers (men and women) at each location. The objectives of the workshops were to identify the most important agricultural problems perceived by farmers, to determine how these problems are currently solved by farmers, and to expose farmers to research being done at agricultural research centers. Postharvest pests were considered very important, and visits to grain stores in sites in southern Togo showed high infestations of the larger grain borer. Results from the workshop are being used to design a course for extension workers and farmers on postharvest pest management.

Five farmers each in the southwestern, southeastern, and northeastern regions of Benin (15 farmers), have been involved in the testing of potential IPM strategies for postharvest maize. At each site, usually the farmer's compound, three grain stores were constructed: one store constructed and maintained by the farmer according to his or her own preferences, one store was treated with a grain protectant at the time of stocking, and one store was untreated. All three stores at each site are sampled once a month. The objective of the work is to determine whether application of the simplified sampling plans can be effective, in evaluating the efficacy of the use of grain protectant on whole ears stored in the husk (as farmers usually do in these areas) and to examine, with the farmer, whether the farmers preferred strategy, often involving the application of field pesticide, is really economical and effective. Several of the stores have been severely infested with larger grain borer. One farmer in each region will be selected to host a course in stored product IPM, to be given by IITA and Helvetas. The selected farmer's stores will be sampled, and group evaluations of the results will be conducted, along with lessons on insect identification, available IPM options, and economics of stored products.

Completed studies

Journal articles and book chapters

Adenle, V.O. and K.F. Cardwell. Seed transmission of maize downy mildew (*Peronosclerospora sorghi*) in Nigeria. Euro J. of Plant Pathol. (accepted)

In an area of Nigeria where downy mildew of maize is present, histological assessment of maize seed revealed the presence of mycelium and oospores of *Peronosclerospora sorghi* in the kernels. Seed transmission of downy mildew of maize was demonstrated when grain purchased at local markets gave a mean seedling infection of 14% (untreated seeds) and 11.8% (in metalaxyl treated seeds) within the first 7 days of emergence. When seeds taken from nubbin ears of systemically infected plants from southern Nigeria were planted at 9 days (22% moisture content), and 27 days (10% moisture content) after harvest, 10.0% and 33.3% infected seedlings resulted, respectively. Seeds from northern Nigeria had 13% systemic seedling infection after 9 months of storage at 8% moisture content.

When seeds harvested from maize plants inoculated with *P. sorghi* through silks were examined histologically, hyphae of *P. sorghi* were observed mostly in the scutellum of the embryo. Transmission of disease to seedlings was observed when the silk inoculated seeds (9% moisture content) were planted in pots in a greenhouse. However no disease transmission was observed when such seed was planted in the field.

The epidemiological significance of seed transmission is discussed with particular reference to survival of inoculum, and development of epidemics. Also noteworthy is the overall signifi-

cance of seed transmission in Nigeria, where the major source of seed is saved by farmers from their grain crop, occasionally supplemented by seed bought from the local market.

Adipala, E., G. Bigirwa, J.P. Esele, and K.F. Cardwell. 1999. Development of sorghum downy mildew on sequential plantings of maize in Uganda. Int. J. of Pest Management 2:147–154.

Agboka, K., F. Schulthess, I. Labo, and H. Smith. Intra- and interspecific superparasitism of *Telenomus busseolae* Gahan and *Telenomus isis* Polaszek (Hymenoptera: Scelionidae), two egg parasitoids of the African cereal stem borer *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae). BioControl (submitted).

Host discrimination, oviposition behaviour, self-, inter and intra-specific superparasitism by the scelionids *Telenomus busseolae* and *T. isis* were studied at 0, 24, and 48 hours after eggs of the pink stalk borer *Sesamia calamistis* were first parasitized. Three events marked the oviposition behaviour: antennal drumming, insertion of ovipositor and oviposition, and marking of parasitized eggs. Both *Telenomus* species were able to discern eggs already parasitized. As a result, self-superparasitism was only 37.7% for *T. busseolae* and 27.0% for *T. isis*. Superparasitism was significantly higher when parasitized eggs were offered immediately and 48 h than 24 h later. Apparently, the recognition of parasitized eggs after 24 h and 48 h was based on the presence of parasitoid larvae rather than a specific marking substance. Intra-species superparasitism was 32 and 15%, respectively, for *T. busseolae* and *T. isis* when the parasitized eggs were offered immediately. Inter-species superparasitism after 0 hour was 24.1 and 17.2% when *T. busseolae* and *T. isis*, respectively, was the second species, indicating that both species recognized each other's markings, and emerging offspring were 63.4% *T. busseolae* versus 9.5% *T. isis*, with low mortality. At 24 h, superparasitism was 16.3 and 9.6% when *T. busseolae* and *T. isis*, respectively, was the second species. In this case, the first species emerged more often than the second did but the mortalities were > 40%.

Ayertey, J.N., W.G. Meikle, C. Borgemeister, M. Camara, and R.H. Markham. 1999. Studies on predation of *Prostephanus truncatus* (Horn) (Col.: Bostrichidae) and *Sitophilus zeamais* Mots. (Col.: Curculionidae) at different densities on maize by *Teretriosoma nigrescens* Lewis (Col.: Histeridae). Journal of Applied Entomology 123: 265–271.

Laboratory experiments using whole cobs were conducted to examine the effect of varying densities of the larger grain borer, *P. truncatus* and the maize weevil, *S. zeamais* on rate of population increase by the histerid beetle, *T. nigrescens*, a predator primarily of *P. truncatus*. Densities of all species of insects were determined at the end of the experiment, and an electrophoretic analysis of gut content was conducted on larval and adult *T. nigrescens* sampled during the experiments. Results indicated that *T. nigrescens* has a strong preference for *P. truncatus* and densities of *T. nigrescens* were associated only with densities of *P. truncatus*. Although *T. nigrescens* could complete development on *S. zeamais*, the maize weevil played little role as an alternative prey or in interfering with *T. nigrescens* reproduction.

Bigirwa, G., E. Adipala, J.P. Esele, and K.F. Cardwell. 1999. Reaction of maize, sorghum, and johnson-grass to *Peronosclerospora sorghi*. Accepted. Int. J. of Pest Management.

Bock, C.H., Jeger, M.J., Mughogho, L.K., and Cardwell, K.F. 1999. Effect of dew point temperature and conidium age on germination, germ-tube growth and infection of maize and sorghum by an isolate of *Peronosclerospora sorghi* from Zimbabwe. Mycol. Res. 103: 859–864.

Bonato, O., F. Schulthess, and J.U. Baumgaertner. 1999. A simulation model for carbon and nitrogen allocation and acquisition in maize. Ecological Modelling 124(1): 11–28).

A common demographic model for maize growth and development driven by temperature, solar radiation, soil water, and soil nitrogen is presented. A distributed delay model was used to describe the dynamics of carbohydrates and nitrogen of leaves, roots, stems, and grains in the plant. Light (photosynthesis), water, and nitrogen uptakes were simulated with a modified functional response model based on predation theory. Carbohydrates, water, and nitrogen supply–demand ratios scale growth of different populations of plant organs (leaf, stem, root, grain). The model was validated with field data from a 95 and a 120-days variety grown at the IITA research in Calavi, in the south of the Republic of Benin (West Africa). The effects of drought stress, soil nitrogen content, and planting density on maize growth were investigated.

Bonato, O. and F. Schulthess, 1999. Selecting a character for identifying larval instars of the stem borers *Sesamia calamistis* Hampson (Noctuidae) and *Eldana saccharina* Walker (Pyralidae) on maize. Insect Sci. Appl. 2: 101–103.

In experiments to select a character for identifying larval instars in *S. calamistis* and *E. saccharina*, body length, body width, and head capsule width were measured in populations reared on artificial diet. Seven instars were found in *S. calamistis* and 5 in *E. saccharina*. For both species, body length was determined as the best characteristic to distinguish instars because it was easy to measure and had the smallest error.

Borgemeister, C., K. Schaefer, G. Goergen, S. Awande, M. Setamou, H.M. Poehling & D. Scholz 1999. Host-finding behaviour of *Dinoderus bifoveolatus* (Coleoptera: Bostrichidae), an important pest of stored cassava: The role of plant volatiles and odors of conspecifics. Annals of Entomological Society of America, 92: 766–771.

In cassava chips, sampled on a local market in Cotonou, Republic of Benin, West Africa, *Dinoderus bifoveolatus* Wollaston was the most predominant pest. In olfactometer experiments, cassava chips infested by *D. bifoveolatus* were highly attractive to both sexes of the beetle, suggesting that male *D. bifoveolatus* produce an aggregation pheromone. Female *D. bifoveolatus* showed a significantly stronger response pattern than conspecific males. Sticky traps, baited with cassava chips harboring male *D. bifoveolatus*, set up in 2 regions of southern Benin, caught consistently considerable numbers of conspecifics. Trap catches differed significantly between regions, and for one region also between the sites. The sex ratio of the trapped *D. bifoveolatus* was significantly female-based. Low numbers of 2 other bostichids, i.e., *Prostephanus truncatus* (Horn) and *Rhyzopertha dominica* (Fabricius), were also recorded in the traps.

Bourassa, C., C. Vincent, C.J. Lomer, C. Borgemeister and Y. Mauffette. Effects of *Beauveria bassiana* (Balsamo) Vuillemin and *Metharrhizium anisopliae* (Metschnikoff) Sorokin on the larger grain borer, Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae), and its predator, *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae). Journal of Invertebrate Pathology.

Four strains of entomopathogenic fungi, three of *Beauveria bassiana* and one of *Metarrhizium anisopliae*, were tested against *Prostephanus truncatus*, a pest of stored maize and cassava introduced into Africa, and against its natural enemy, the predator *Teretriosoma nigrescens*. All strains were pathogenic to adults of the two beetle species. At a concentration of 10^9 spores ml^{-1} mortality rates were nearly twice as high for those *P. truncatus* than for its predator (90–95% vs. 42–56%). Mycopesticides could therefore be used in an IPM approach against *P. truncatus*, as a complement to the use of its natural enemy *T. nigrescens*. Applications of formulations containing 10^8 and 10^9 spores ml^{-1} resulted in 100% mortality of *P. truncatus* larvae on the eighth and fourth day, respectively. P. truncatus eggs were not affected by the strains and fungi tested. When *B. bassiana* (10^9

spores ml^{-1}) was applied to maize grains and cobs under semi-field conditions, approximately 27% mortality of adult *P. truncatus* was observed. This low rate may be explained by poor contact between the insect and the fungal spores applied on the grain.

Cardwell, K.F, J.G. Kling, B. Maziya-Dixon, and N.A. Bosque-Pérez. Relationships among *Fusarium moniliforme* and *Aspergillus flavus* ear rot pathogens, insects and grain quality in four maize genotypes in the lowland tropics of Africa. Phytopathology (accepted).

An experiment was designed to compare maize genotypes for ear and grain quality characteristics, interactions with *Aspergillus flavus* and *Fusarium moniliforme* infection, and insect infestation of the ear over two seasons. Mean infection levels by *A. flavus* and *F. moniliforme* were significantly higher in inoculated rows than in the controls and were inverse to each other under the respective inoculation treatments. The *F. moniliforme* inoculated rows had significantly more coleopteran and lepidopteran borers per ear than the controls and the *A. flavus* inoculated rows. Genotypes were not different with respect to numbers of insects or percent fungal incidence in the ear, but they were for husk extension, percent floaters, and grain hardness. Inoculation with either fungus resulted in a significantly higher percent of floaters and lighter grain weight than the controls. Grain hardness increased with *F. moniliforme* inoculation, particularly in the soft endosperm populations. Aflatoxin (B1 and B2) in the *A. flavus*-inoculated rows averaged 327 ppb in the first season and 589 ppb in the second (and dryer) season. Fumonisin levels in *F. moniliforme*-inoculated rows did not differ between seasons, with an average of 6.2 ppm across seasons. In the non-inoculated control rows, fumonisin was significantly higher in the first season (5.3 ppm) than in the second (3.1 ppm). Husk extension was reduced across genotypes in the fungi-inoculated treatments. General ear rot scoring was significantly correlated with *F. moniliforme* and grain weight loss, but not with *A. flavus* in the grain.

Cherry, A.J., Lomer, C.J., Djegui, D., and Schulthess, F. 1999. Pathogen incidence and their potential as microbial control agents in IPM of maize stem borers in West Africa. BioControl 44: 301–327.

A review of the existing basis for maize stem borer IPM is given and the role of pathogens in the system evaluated. Survey work outlining the major groups of insect pathogens is described; fungi (*Beauveria bassiana* and *Metarrhizium anisopliae*), bacteria (*Bacillus thuringiensis* and *Serratia marcesens*), and viruses (granuloviruses and cytoplasmic polyhedroviruses) were identified. The presence of other unidentified protozoans, nematodes, fungi, and viruses was noted. The virulence of some of the more promising known insect pathogens was explored in preliminary bioassays. Considering the cryptic habits of the insects, and the low-input agriculture practiced by the majority of maize farmers in sub-Saharan Africa, *B. bassiana* isolates possessing the capacity to grow systemically in the maize plant are considered one of the more interesting candidates for development as microbial control agents despite limited control in preliminary trials. Further work should also investigate the potential of pathogens of moderate virulence, such as the protozoans and CPVs.

Cotty, P.J. and K.F. Cardwell. 1999 West African and North American communities of *Aspergillus* section *flavi* are divergent. Applied and Environmental Microbiology 65: 2264–2266.

West African *Aspergillus flavus* S strain isolates differed from North American isolates. Both produced Aflatoxin B_1. However, in NH_4 medium, 40% and in urea medium 100% of West African isolates also produced aflatoxin G_1. No isolate of the North American S strain produced Aflatoxin G_1. This geographical divergence may influence aflatoxin management.

Denké, D., F. Schulthess, O. Bonato, and H. Smith. Effet de la fumure en potassium sur le développement, la survie et la fécondité de *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) et de *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Insect Sci. Appl. (accepted).

L'influence de la teneur en potassium de la fumure appliquée au maïs, sur le développement, la survie, la fécondité, ainsi que sur le poids des larves et des chrysalides de *Sesamia calamistis* et de *Eldana saccharina* a été étudié en laboratoire. Six différents traitements correspondant à des doses de 0, 30, 60, 90, 120 et 150 kg K_2O/ha ont été utilisés. L'augmentation de la dose de potassium n'a pas affecté les durées de développement larvaire et nymphale, ni la longévité des femelles de *S. calamistis*. Les mortalités larvaires les plus élevées ont été enregistrées à 0 et 150 kg K_2O/ha. Concernant les chrysalides les différences ont été beaucoup moins marquées, mais des teneurs élevées en potassium (> 60 kg K_2O/ha) tendent à réduire leur survie. La fécondité a été négativement corrélée à l'augmentation de la dose de potassium. Le poids le plus faible chez les larves et chez les chrysalides a été obtenu à la dose de 150 kg K_2O/ha. Les valeurs du r_m et du R_o ont été maximales à 60 kg K_2O/ha. Pour *E. saccharina* aucun effet du potassium n'a été noté sur les durées de développement larvaire et nymphal, sur la survie larvaire, ainsi que sur le poids des chrysalides. Les valeurs de survie des chrysalides, de la fécondité, du poids des larves, du r_m et du R_o ont été maximales à 90 kg K_2O/ha.

Gudrups, I., S. Floyd, and N.A. Bosque-Pérez. A comparison of two methods of assessment of maize varietal resistance to the maize weevil, *Sitophilus zeamais* Motschulsky, and the influence of kernel hardness and size on susceptibility. Journal of Stored Products Research (submitted).

Fifty-two maize varieties were screened for resistance to infestation by the maize weevil, *Sitophilus zeamais* Motschulsky, using assessment methods proposed by Dobie (1974) and Urrelo et al. (1990). The two methods gave similar assessments of maize susceptibility to *S. zeamais*. The Dobie method is preferred due to the lower total time required for assessment of relative susceptibility of maize varieties. The greatest disadvantage of the Urrelo method is the intensive labor requirements in the early stages of a trial, when numbers of eggs have to be counted, although it has the advantage that the assessment may be terminated upon emergence of the first F1 adult. Two explanatory variables, kernel size and hardness, were investigated to determine whether they may be used as indicators of resistance. Results suggest kernel size is more important in determining resistance to attack by *S. zeamais*, with large kernels appearing to show greater resistance than small ones. Contrary to expectations, of the varieties tested, including local, hybrid, and improved open pollinated (OPs) varieties, the local varieties were generally more susceptible. This may be related to kernel size, as all improved OPs and hybrids tested had large kernels, whereas the majority of the local varieties had small ones. However, it is possible that kernel size does not have a direct effect on susceptibility, but rather that it is related to other factors which influence it. No clear relationship between weevil susceptibility and kernel hardness could be detected, although there was an indication that differences associated with kernel size varied depending on kernel hardness. None of the varieties tested showed high levels of resistance to attack by *S. zeamais*.

Hell, K., K.F. Cardwell, M. Sétamou and H.-M. Poehling. Maize storage practices and their influence on aflatoxin contamination in stored grains in four agroecological zones in Benin. West Africa. J. Stored Prod. Res. (accepted).

Aflatoxin levels in 300 farmers' stores in four agroecological zones in Benin, a West African coastal country, were determined over a 2-year period. At sampling, a questionnaire helped

to evaluate maize storage practices. Farmers were asked what storage structure they used, their storage form, storage period, pest problems in storage and what was done against them. Beninese farmers often changed their storage structures during the storage period. Maize would be transferred from a drying or temporary store to a more durable one. Most of the farmers complained about insects damaging stored maize. Often, storage or cotton insecticides were utilized against these pests. Regression analysis identified the factors associated with increased or reduced aflatoxin. Maize samples in the southern Guinea savanna and Sudan savanna were associated with higher aflatoxin levels and the forest/savanna mosaic was related to lower toxin levels. Factors associated with higher aflatoxin were: storage for 3–5 months, insect damage, and use of Khaya senegalensis bark or other local plants as storage protectants. Depending on the agroecological zone, storage structures that had a higher risk of aflatoxin development were the "Ago", the "Secco", the "Ava" or under the roof of the house. Lower aflatoxin levels were related to the use of storage or cotton insecticides, mechanical means or smoke to protect stored grains, or cleaning of stores before loading them with the new harvest. Storage structures in which fewer aflatoxins were found were the "Ago" made from bamboo or when bags were used as secondary stores.

Holst, N., R.H. Markham, and W.G. Meikle. Submitted. Integrated pest management of postharvest maize in developing countries. IITA Publications [http://www.agrsci.dk/plb/bembi/africa/ project.htm.]

A CD-ROM was developed containing downloadable simulation models, sampling plans, associated computer programs, and field data, along with a brief introduction to research on the larger grain borer. The weather-driven models include *Prostephanus truncatus*, *Sitophilus zeamais*, and *Teretrius nigrescens*, and they are linked to grain damage and weight loss. Sequential sampling plans are presented.

Holst, N., W.G. Meikle, and R.H. Markham. Grain injury models for *Prostephanus truncatus* (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae) in rural maize stores in West Africa. Journal of Economic Entomology (in press).

Prostephanus truncatus (Horn) and *Sitophilus zeamais* Motschulsky have been reported as the two most serious pests of stored maize in sub-Saharan Africa and smallholder farmers are in urgent need of guidelines for their proper management. In this paper we investigate the injury rates attributable to these two species in terms of percentage weight loss and percentage grain damage, and we derive functional response models for the two species on maize. The models successfully described the progression of grain injury in an extensive data set compiled from previously published studies, comprising 43 time series of data relating maize injury and insect pest density. The grain injury models can be used, in conjunction with predictive models of pest population dynamics, to guide the development of integrated management strategies for postharvest maize pests in West Africa and comparable regions elsewhere.

Meikle, W.G., N. Holst, and R.H. Markham. 1999. A population simulation model of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) in grain stores in the Republic of Benin. Environmental Entomology 28: 836–844.

A distributed-delay, demographic simulation model of *Sitophilus zeamais* Motschulsky populations in rural maize (*Zea mays* L.) stores was developed. Published equations describing the effects of temperature, humidity, and density effects on fecundity, juvenile survivorship, and development and emigration were used or equations were estimated from published data and from laboratory experiments. The simulation model output was compared to *S. zeamais* density observed in field experiments before and after the introduction of *Prostephanus truncatus* (Horn) to West Africa. The overall phenology of the

simulated beetle dynamics reflected that of field data, although the model output tended to overestimate beetle population growth early in the season. The model was modified using published data to simulate dynamics of populations developing on resistant and susceptible maize cultivars. The model is intended as part of a cost-effective tool for evaluating factors influencing population dynamics of stored-product pests and their natural enemies and to provide a framework for assessing different control strategies in an integrated control context.

Meikle, W.G., N. Holst, and R.H. Markham. An evaluation of sequential sampling plans for the larger grain borer (Coleoptera: Bostrichidae) and the maize weevil (Coleoptera: Curculionidae) and of visual grain assessment in West Africa. Journal of Economic Entomology (submitted).

Two surveys of rural maize stores in Benin were conducted in order to evaluate published sequential sampling plans for *Prostephanus truncatus* (Horn) (Col.: Bostrichidae) and *Sitophilus zeamais* Motsch. (Col.: Curculionidae). Two sampling plans were evaluated: Iwao's confidence interval plan and Wald's sequential probability ratio test for a Negative Binomial distribution. Wald's plan was chosen as the most appropriate since Iwao's plan required many more ears on average to make a decision. A computer program was used to re-randomize the data and evaluate the effects, in terms of average sample number and error rates, of different sampling plan parameter values. With respect to *P. truncatus*, lower and upper thresholds of 0.2 and 1.0 insects per ear and parameter values of $k = 0.5$, $a = b = 0.1$ were found to be adequate. With respect to *S. zeamais*, lower and upper thresholds of 10 and 20 insects per ear and parameter values of $k = 1.0$, $a = 0.01$ and $b = 0.1$ were found to be adequate. Simplified sampling rules were proposed in which 5 ears would be sampled and if no *P. truncatus* are found, the population is low; otherwise the Wald plan would be followed. Owing to the lower per capita rate of damage, simplified sampling rules for *S. zeamais* were difficult to construct. The visual assessment scale was correlated with pest density but not of sufficient precision to substitute for a count-and-weigh procedure.

Nansen, C., S. Korie, and W.G. Meikle. CANOCO and SADIE - two software packages used for spatial analysis of pheromone trap catches. Journal of Tropical Forest Resources (accepted).

Pheromone trapping of the larger grain borer (*Prostephanus truncatus*), a serious pest on stored maize, and its predator, *Teretriosoma nigrescens* was conducted at 16 sites during 21 weeks in the Lama Forest in southern Benin. The main purpose was to outline an analytical method for examining the distribution pattern of the pest and its predator in the forest environment. Variation in weekly trap catches was analyzed using two different software packages, CANOCO and SADIE. *P. truncatus* trap catches were significantly higher in the northeastern part of the forest throughout the trapping period. Vegetational variables suggested that high trap catches were significantly associated with the abundance of teak trees (*Tectona grandis*) on trap sites. Examination of the spatial distribution pattern of trap catches revealed that *P. truncatus* catches were significantly aggregated in 16 of the 21 weekly trap catches, while *T. nigrescens* catches were only significantly aggregated in 5 of the 21 weeks. Analysis of the spatial association between trap catches of *P. truncatus* and *T. nigrescens* was not significant for any of the 21 weeks of trapping. The analyses, using CANOCO and SADIE, gave very similar results although based on different mathematical approaches, and in combination, these two software packages seem relevant for a broad range of entomological studies.

Nansen, C., A. Tchabi, and W.G. Meikle. Phytosociological study of disturbed dry semi-deciduous forest in Benin, West Africa. Journal of Tropical Ecology (submitted).

Southern Benin comprises the Dahomey Gap, and human pressure on forest resources has lead to a dramatic reduction and disturbance of remaining forest patches. The largest remaining forest reserve in southern Benin is the Lama Forest, which is a heterogeneous and unique genetic forest reserve for many endangered species. As part of the ongoing plans for the conservation of this forest patch, an analysis of the existing forest types and the vegetative trends was conducted. Three objectives were established: assess the tree species composition by fitting it to a theoretical abundance distribution; ordinate the floristic composition in order to identify forest types; outline the hierarchical association of forest types as levels in a succession sequence. The number of conspecific trees on vegetation plots could be fitted to a geometric series distribution, suggesting that species abundance composition resembled that of a disturbed forest. Five forest types were defined according to their floristic composition and vegetative characteristics such as tree density, number of species, Shannon index of diversity, basal tree cover, and girth at breast height. Geographical variables were also used to examine the spatial distribution of identified forest types. The forest types were interpreted as subsequent levels in a secondary succession sequence, and plantation of the most important tree species in the initial succession sequence levels is recommended in order to improve the natural reforestation.

Ndemah, R., F. Schulthess, M. Poehling, and C. Borgemeister. Species composition and seasonal dynamics of lepidopterous stem borers on maize and the elephant grass, *Pennisetum purpureum* (Moench) (Poaceae), at two forest margin sites in Cameroon. African Entomologist (submitted).

Lepidopterous stem borers were monitored on maize and Pennisetum purpureum plots during two consecutive cropping seasons and the off-season at two forest margin locations, Nkolbisson and Minkomeyos, in Cameroon. The noctuids *Busseola fusca* (Fuller) and *Sesamia calamistis* (Hampson), and the pyralid *Eldana saccharina* Walker were found on both hosts. Additionally, the tortricid Cryptophlebia leucotreta (Meyrick) and the pyralid *Mussidia nigrivenella* Ragonot were collected from maize and the noctuid *Poeonoma serrata* (Hampson) from elephant grass. *Busseola fusca* was the most abundant species on both host plants. The numbers of eggs per m^2 between plant hosts was not significantly different, whereas numbers of larvae and pupae were three to nine times higher on elephant grass than on maize. Analyzing numbers of *B. fusca* larvae according to size/age classes, all sizes tended to be more abundant on elephant grass than on maize, but significant differences were only found during the second season at Minkomeyos when densities were high. No significant differences were found between plant hosts for diapausing larvae and pupae. The implication of these findings for the possible function of the grass as a trap plant or reservoir for natural enemies in the management of *B. fusca* are discussed.

Ndemah, R., F. Schulthess, M. Poehling, and C. Borgemeister. Spatial dynamics of lepidopterous pests on *Zea mays* (Linnaeus) and *Pennisetum purpureum* (Moench) in the forest zone of Cameroon and their implications for sampling schemes. J. Appl. Entomology (submitted).

The most common lepidopterous borers attacking maize and/or the wild host *Pennisetum purpureum* in the forest zone of Cameroon are the noctuids *Busseola fusca* (Fuller), *Sesamia calamistis* (Hampson), and *Poeonoma serrata* (Hampson), the pyralids *Eldana saccharina* (Walker) and *Mussidia nigrivenella* (Ragonot), and *Cryptophlebia leucotreta* (Tortricidae). The within-plant distribution on maize and elephant grass was studied for the predominant species *B. fusca*, and on maize only for *E. saccharina* to determine the basic sampling unit. On both plant species, *B. fusca* showed a strong oviposition preference for young plant parts. By contrast, *E. saccharina* larvae and pupae on maize were only

found on older plant parts, indicating that it does not oviposit on young plants. None of the plant strata showed to be a stable sampling unit and it is recommended to do whole plant or whole tiller sampling for maize and grass, respectively. For the development of sampling plans, dispersion was described for all species using Taylor's power law and a non-linear model which gives the relationship between the proportion of infested plants [P(I)] and mean density (m). *B. fusca* egg batches as well as diapausing larvae and pupae on maize showed a random distribution while all the other cases were aggregated, with *B. fusca* egg batches on elephant grass exhibiting the lowest and *M. nigrivenella* on maize the highest aggregation. Optimal sample size/mean density curves were developed for groups of insects with low and high aggregation.

Ndemah, R., F. Schulthess, M. Poehling, and C. Borgemeister. Natural enemies of lepidopterous borers on maize and elephant grass in the forest zone of Cameroon with special reference to *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) Bull. Ent. Res. (submitted).

The geographic and temporal distributions of parasitoids of lepidopterous borers on maize and elephant grass, *Pennisetum purpureum*, were assessed during surveys in farmers' fields in six villages and two on-station trials in the forest zone in Cameroon between 1994 and 1996. The borer species encountered were *Busseola fusca*, *Eldana saccharina*, and *Sesamia calamistis* on both host plants, and *Mussidia nigrivenella* on maize only. *B. fusca* was the predominant host accounting for 96.1% and 43.7–57.3% on elephant grass and maize, respectively, followed by *E. saccharina* on maize with 27.2–39.1%. Fifteen hymenopterous, two dipterous, and one fungal species were found on these stem and cob borers. Among those were six pupal, six larval, four egg, one larval–pupal parasitoid and four hyperparasitoids. The scelionid parasitoids *Telenomus busseolae* and *T. isis* were found on *B. fusca* eggs in all locations. During the first season, mean egg parasitism was low and ranged between 3.1% and 26.6% versus 56–87% during the second season. Species belonging to the *Tetrastichus atriclavus* complex were recovered from all four borer species. The majority and most common larval and pupal parasitoid species belonged to the ingress-and-sting guild. Larval and pupal parasitism were very erratic and on more than 50% of the sampling occasions, no parasitoids were recovered. Parasitoid diversity was higher on elephant grass than maize.

Ngoko, Z., K.F. Cardwell, F. Schulthess, W.F.O. Marasas, J.P. Rheeder, G.S. Shephard, and M.J. Wingfield. Factors affecting maize grain quality and fumonisin content in some villages of the Western Highlands of Cameroon.

A survey was conducted in three of the Western Highlands (WHL) of the Republic of Cameroon to assess the biological and physical constraints on maize grain quality. Thirty-two of the 36 samples analyzed tested positive with a concentration ranging between 0 and 8.2 ppm. Questionnaires were administered to 36 farmers in 1997. A backward regression analysis revealed that several agricultural practices were associated with the infection of maize grains by *Fusarium* species and subsequently contamination with fumonisin. Harvesting maize in June (11.1%), sorting right from the field (16.7%), drying maize over the fireplace with husk (19.4) or without husk (33.3%) or in the cribs, were factors that significantly reduced the infection by *F. moniliforme* and the risk of contamination with fumonisin. Yellow maize was less contaminated with fumonisin when compared to white maize. The storage weevil, *Sitophilus zeamais*, significantly increased the risk of contamination by fumonisins. Other factors such as harvesting in August, storing in bags, maize as previous crop, and the education level of the farmers were nonsignificant factors retained by the regression analysis.

Ngoko, Z., Cardwell K.F., Marasas, W.F.O., Wingfield M.J., Ndemah, R., and Schulthess, F. Biological and physical constraints on maize production in the humid forest and Western Highlands of Cameroon (submitted to Plant Dis.).

A study was carried out to identify biological and physical factors responsible for the reductions in maize production in Cameroon. Two surveys were conducted in 72 fields in two of the five agroecological zones in the country in 1995, 1996, and 1997. The combination of these biological factors (diseases and insects), and soil fertility were responsible for reducing maize yield in these selected benchmarks of Cameroon. In the humid forest (HF), *Bipolaris maydis, Stenocarpella macrospora, Puccinia polysora, Rhizoctonia solani* and soil fertility were factors that reduced maize production in 1995 and 1996. In the Western Highlands (WHL), *Cercospora zeae-maydis*, and the interaction between soil fertility and maize variety were the most important constraints to maize production in 1996. In 1997, in addition to *C. zeae-maydis, S. macrospora*, physiological spot, and insect damage expressed as the number of holes bored in the stem by *Busseola fusca* were negatively related to ear weight. Average yield reductions were 68.2% due to *B. maydis* and 9.2% due to *S. macrospora*, respectively, in the HF in 1995. In 1996, yield reductions were estimated at 34.3%, 41.4%, and 29.6% due to *S. macrospora, P. polysora*, and *R. solani*, respectively, in the HF. In the WHL, *Cercospora zeae-maydis* caused a yield reduction of 78.5% in 1996. The interaction between *C. zeae-maydis* and *B. fusca*, the stem diseases, and the physiological spot caused reductions of 37.9%, 33.6%, and 39%, respectively, in the WHL in 1997. Insects were considered in 1997.

Ngoko, Z., W.F.O. Marasas, J.P. Rheeder, G.S. Shephard, M.J. Wingfield, and K.F. Cardwell. Fungal infection and mycotoxin contamination of maize in the humid forest and the Western Highlands of Cameroon.

Maize samples from the first season crop were collected from 72 farmers' stores in 1996 and 1997 in the humid forest (HF) and Western Highlands (WHL) of Cameroon. Mycological assays of these samples revealed several fungal species in the kernels. *Nigrospora* spp. were the most prevalent fungi in both the HF (32.1%) and the WHL (30.2%) in 1996. *Fusarium verticillioides* (22%) and *F. graminearum* (27%) were also isolated from the samples. In the WHL in 1996, no significant difference ($P > 0.05$) was found among villages for the incidence of mycotoxic spp. in samples collected two months after harvest, but at four months, percentages in Bamunka and Njinikom were significantly higher. In 1997 the levels of Fusarium contamination were not as high as in 1996, with the highest level of 7% recorded in Njinikom. The incidence of *Aspergillus* spp. was low, but tended to be higher in samples collected four months than those collected two months after harvest. Analysis with thin layer chromatography did not detect quantifiable levels of aflatoxins in most samples. The *F. verticillioides* mycotoxin fumonisin B_1 (ranging between 300 and 26 000 ng/g) and the *F. graminearum* metabolites deoxynivalenol (< 100–1,300 ng/g) and zearalenone (< 50–110 ng/g) were determined by means of polyclonal antibody (PAb-based) competitive direct enzyme-linked immunosorbent assay. A significant correlation ($r = 0.72$; $P = 0.0001$) was found between the incidence of *F. graminearum* and the contamination with deoxynivalenol. Storage time had a significant positive effect ($r = 0.39$; $P = 0.013$) on the level of fumonisin B_1 in one village, and the levels found between villages were significantly different. This is the first report of the natural occurrence of fumonisins, deoxynivalenol, and zearalenone in stored maize in Cameroon.

Olatinwo, R.O. K.F. Cardwell, M.L. Deadman, and A.M. Julian. 1999. Epidemiology of *Stenocarpella macrospora* (Earle) on maize in the midaltitude zone of Nigeria. J. Phytopathology 147: 347–352.

Disease progress of *Stenocarpella macrospora* (Earle) Sutton was monitored on selected maize breeding lines over two seasons at three locations. Tagged plants were assessed at 10-day intervals for foliar lesions on a 1–9 scale and for ear rot on a 1–5 scale. Locations with holdover debris from previous crops had significantly greater infection than locations without. There was a significant negative correlation between the leaf severity score and grain weight. However, no correlation existed between ear rot and leaf disease severity. Spatial disease progress diagrams indicated that *S. macrospora* was initiated form random foci from which secondary spread occurred.

Olatinwo, R.O. K.F. Cardwell, A. Menkir, M.L. Deadman, and A.M. Julian. 1999. Inheritance of resistance to *Stenocarpella macrospora* (Earle) ear rot of maize in the midaltitude zone of Nigeria. Euro. J. of Plant Pathol. 105: 535–543.

Inheritance of resistance to *Stenocarpella macrospora* (Earle) Sutton ear rot of maize was studied among selected maize populations in the midaltitude (1280 m) agroecological zone of Nigeria. Diallel analysis among the populations showed significant values for general combining ability (GCA) and specific combining ability (SCA). Variance components of GCA and SCA on ear rot symptoms were 0.019 and 0.627, respectively, indicating non-additive gene effects. The GCA and SCA effects were relatively dependent on the materials involved in the evaluations. Generation mean analysis was used on five selected parent inbreds (2 resistant and 3 susceptible, crossed to give P1, P2, F1, BC1, BC2, and F2 generations). Estimates of the six parameters on ear rot indicate that dominance gene effects made the major contribution to variation in ear rot in the crosses studied.

Olatinwo, R.O, M.L. Deadman, A.M. Julia, and K.F. Cardwell. 1999. Survey of the incidence and severity of *Stenocarpella macrospora* (Earle) leaf blight of maize in the midaltitude zone of Nigeria. Int J. of Pest Management, 45:259–262.

Surveys were conducted on the incidence and severity of *Stenocarpella macrospora* (Earle) Sutton on maize in the midaltitude zone of Nigeria in 1995 and 1996. The results indicated a possible link between disease severity and plant density. Fewer symptoms were observed at altitudes below 700 m. There was no significant correlation between cropping system and disease incidence or severity.

Oussou, R.D., W.G. Meikle, and R.H. Markham. 1999. Factors affecting the survivorship and development rate of larvae of *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae). Insect Science and its Application 18: 53–58.

Laboratory experiments on the role of humidity, and density and species of prey, were conducted in order to better understand the ecology of *Teretriosoma nigrescens*, a predator introduced into West Africa to control the larger grain borer, *Prostephanus truncatus*. Duration of *T. nigrescens* development was very similar among individuals exposed to 30, 40, 70, and 90% relative humidity at 30 °C, although survivorship varied. Larvae fed only first instar *S. zeamais* larvae as prey took longer to develop, and weighed less at emergence, than those larvae raised on first instar *P. truncatus* when both were kept under optimal temperature and humidity conditions. Larvae feeding on *Tribolium castaneum* took longer to develop with only 10% surviving to adulthood, and no larvae offered *Gnatocerus maxillosus* survived. In an analysis of prey consumption rates, no larvae survived on one *P. truncatus* first instar larvae per day, 50% survived on 2 per day, and almost 90% survived on 5 per day. In an analysis of density effects on *T. nigrescens* reproduction and survivorship, no difference in the number of F1 offspring was found among *T. nigrescens*: *P. truncatus* ratios of 15:300, 30:300, 60:300, or 90:300, suggesting that the low density treatment was the most efficient production ratio of the four.

Schaefer, K., G. Goergen, and G. Borgemeister. 1999. A simplified identification key to distinguish four different species of adult *Dinoderus* (Coleoptera: Bostrichidae), commonly attacking dried cassava chips in West Africa. Journal of Stored Products Research (in press).

Schulthess, F. and K.F. Cardwell. 1999. Effect of *Fusarium verticillioides* infection in maize on infestations of stem and ear borers. Phytopathology 89:S70.

In field trials at the International Institute of Tropical Agriculture, Ibadan, Nigeria, maize cobs artificially inoculated with *Fusarium moniliforme* had double the number of lepidopteran and four times the number of coleopteran pests than the noninoculated controls. Surveys in Benin revealed that *F. moniliforme* was present in 73% of plants with stem borer damage compared to 43% in stems without borers. Field and greenhouse trials were designed to explore the relationship between the fungus and lepidoptera in maize stem. In the field, a significant gradient of *F. monillforme* infection was induced by (a) stem inoculation with *F. moniliforme* (81% infection), (b) natural incidence (22%), and (c) hot water seed treatment and soil fungicide (3.6% infection). Numbers of *Eldana saccharina* larvae were significantly higher in the inoculated plots. Oviposition and life table studies showed that plants with high *F. moniliforme* had significantly larger *E. saccharina* egg batches and higher numbers of larvae. It is concluded that reducing *F. moniliforme* incidence in stems and ears would also significantly reduce pest infestations.

Sétamou, M., F. Schulthess, H-M. Poehling, and C. Borgemeister. Monitoring and modeling of field infestation and damage by the maize ear borer *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) In Benin, West Africa. Journal of Economic Entomology (in press).

In many countries in West Africa, the pyralid ear borer *Mussidia nigrivenella* Ragonot occasionally causes severe damage to pre- and postharvest maize. Between 1992 and 95, the distribution of and damage caused by *M. nigrivenella* were studied in Benin using survey data and an on-station field experiment. The borer was distributed across the whole country, and at maturity an average 25% of the ears sampled in maize fields was infested. Damage levels varied with agroecological zones and were highest in the Guinea savannas. However, borer-related yield losses were comparatively low. Three applications of cypermethrin over the growing season did not provide sufficient control in the on-station field experiment. A model was developed to estimate maize losses caused by *M. nigrivenella*, using the percentage of infested ears, which explained 93% of the variance. Extrapolation of field data indicated a 25% yield loss once a 100% infestation of maize ears was reached. For surveys in maize fields the model is a valid tool for a rapid assessment of crop losses caused by *M. nigrivenella*.

Sétamou, M., F. Schulthess, H-M. Poehling, and C. Borgemeister. Host plants and population dynamics of the cob borer *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) in Benin. Journal of Environmental Entomology (accepted).

The maize ear borer, *Mussidia nigrivenella* Ragonot, is a polyphagous insect pest that feeds on various cultivated and wild plants. Surveys in 4 agro-ecological zones of Benin, conducted between 1993 and 1997, revealed about 20 plant species from 11 plant families hosting the borer, but only 13 host plants enable the borer to develop to the pupal stage. Whereas a maize crop usually supports one generation per season, several generations of *M. nigrivenella* were recorded on *Parkia biglobosa* (Jacq.) Benth. and *Gardenia* spp. Agroecological variation in the availability of wild host plants was noticed. The high abun-

dance of wild hosts in the Guinea savannas reflects the diversity of the natural flora in these zones. This abundance of *M. nigrivenella* host plants, coupled with their overlapping fruiting periods, may be the main reason for the high pest densities on maize, although only one maize crop per year is grown in the northern Guinea savanna. In a field experiment, the highest infestation levels and densities of *M. nigrivenella* occurred on *Canavalia ensiformis* (L.) DC. and *Mucuna pruriens* DC., 2 popular cover crops in West Africa. Maize and cotton were about equally suitable hosts. Thus, fruiting periods of *C. ensiformis* and *M. pruriens* should not precede that of maize, to avoid emerging *M. nigrivenella* populations shifting from the cover crops to maize.

Sétamou, M., F. Schulthess, N.A. Bosque-pérez; H-M. Poehling, and C. Borgemeister. 1999. Effects of different host plants on the bionomics of *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae). Bull. Ent. Res. 89: 465–471.

Life table studies on *Mussidia nigrivenella* (Lepidoptera: Pyralidae) fed maize ears, and pods of jackbean, *Canavalia ensiformis*, and velvetbean, *Mucuna pruriens*, showed significant host plant species effect on larval survival and developmental time as well as on adult fecundity. Highest larval survival was recorded on jackbeans, *C. ensiformis* (36.2%) and lowest on maize (18.4%). Mean larval developmental period was longest on maize (19.8 days) and shortest on *C. ensiformis* (17.2 days). Pupal survival, weight, and mean developmental time were not significantly affected by the host plants. Oviposition rate was highest for females emerging from larvae fed on *C. ensiformis* (mean = 176, SE = 13), followed by *M. pruriens* (mean = 143, SE = 11), and lowest on maize (mean = 127, SE = 13). Likewise, longevity of ovipositing females was highest on *C. ensiformis*. According to the growth index and life table statistics (r, R0 and G), *C. ensiformis* was the most suitable host plant followed by *M. pruriens*. Thus, in mass rearing programs of *M. nigrivenella*, using natural host plants, *C. ensiformis* should be used especially since it requires only one diet replacement throughout larval development. Because of the high suitability of *C. ensiformis* and *M. pruriens*, planting of those cover crops should be timed such that the emergence of females moths from mature pods does not coincide with the presence of maize in a stage attractive to ovipositing female moths and suitable for development larvae.

Sétamou, M., F. Schulthess, G. Goergen, H.-M. Poehlingand C. Borgemeister. Natural enemies of the maize cob borer, *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) in Benin, West Africa. Biocontrol, Science and Technology (submitted).

Surveys conducted in the different agroecological zones of Benin during 1994–1997 revealed one egg parasitoid, three larval parasitoids, and one pupal parasitoid attacking the pyralid maize cob borer *Mussidia nigrivenella* Ragonot. Egg parasitism was scarce on all host plants sampled and in all agroecological zones. Parasitism by larval and pupal parasitoids was usually low (< 10%), and was varied with the different host plant species. Both larval and pupal parasitoids were rare or absent in maize fields. The solitary chalcid pupal parasitoid, *Antrocephalus crassipes* Masi, was the predominant species, contributing approximately 53% of the observed mortality. Logistic regression analysis suggested that this parasitoid was more prevalent on fruits of *Gardenia* spp. than on the other host plant species, and was abundant between February and September.

Sétamou, M., F. Schulthess, H-M. Poehling, and C. Borgemeister. Spatial distribution of and sampling plans for *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) on cultivated and wild host plants in Benin. J. Economic Entomology (submitted).

Spatial distribution of *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae) was studied in maize fields and on 4 major wild host plants in the Republic of Benin, West Africa.

Maize ears were sampled at harvest in 1994 and 1995, and fruits of the wild host plants were collected monthly from January 1996 to December 1997 during the fruiting periods of the respective host species. The spatial distribution was analyzed using Southwood's index of dispersion (s^2/m), Iwao's patchiness regression, and Taylor's power law (TPL). Iwao's patchiness regression was inappropriate for our data as shown by the non-homogeneity of variance, whereas TPL fitted the data quite well. Based on Southwood's index of dispersion and TPL, *M. nigrivenella* was aggregated on maize ears and fruits of 3 wild hosts, i.e., *Adansonia digitata* L. (Bombacaceae), *Parkia biglobosa* (Jacq.) Benth. (Mimosaceae) and Ximenia americana L. (Olacaceae). On *Gardenia* spp. (Rubiaceae) however, the distribution was either regular or random according to the season. Density and aggregation of *M. nigrivenella* was strongly positively related with the fruit size of the host plants. The optimal number of minor sampling units needed to estimate *M. nigrivenella* densities on the respective host plants in Benin, varied from 4 fruits on *Gardenia* spp. to 10 pods on *P. biglobosa*. These values were used to calculate the number of maize fields or host plant trees required to estimate *M. nigrivenella* densities in a given area, at a predefined precision level and for a certain cost.

Udoh, J.M., K.F. Cardwell, and T. Ikotun. Storage structures and aflatoxin content of maize in five agroecological zones of Nigeria. J. Stored Prod. Res. 36: 187–201.

A survey was conducted in 1994 to describe the maize storage systems, quantify the aflatoxin levels in these storage systems, and identify the primary constraints recognized by male and female farmers in five agroecological zones in Nigeria. Maize storage in plastic bags was the most common among all farmers. The clay Rhumbu was used in 4 out of 5 agroecological zone by both male and female farmers. The woven Oba was found only in the southern Guinea savanna and was used predominantly by women. Only 13% of the male farmers in the southern Guinea savanna and none in the other zones stored in an improved crib while no female farmers across all the zones used the crib system of storage. Male and female farmers across all the zones identified insect infestation and fungal and rodent attack as primary constraints in their stored maize. Insect infestation was reported by 83% of the female farmers in the southern Guinea savanna zone who stored maize in bags. The highest fungal attack on stored maize was reported by 71% of the male farmers who stored maize in bags in the humid forest zone, while 75% of the male farmers (the highest percentage) who stored in bags in the Sudan savanna zone complained of rodent attack. Across all zones, farmers of both genders identified insects as the most common storage problem. Farmers who reported insect problems were significantly more likely to have aflatoxin in their stores. The highest zonal mean aflatoxin level of 125.6 mg/kg was obtained from maize samples provided by male farmers in the Sudan savanna zone who stored maize in bags or in a Rhumbu. Across the storage systems, 33% were contaminated with detectable levels of aflatoxin. No aflatoxin was detected in the storage systems of male or female farmers in the northern Guinea savanna zone in 1994. Storing maize in plastic bags is probably a relatively new practice in Nigeria, having replaced more traditional materials. It apparently is a practice that should be discouraged because of the negative effect on grain quality.

Vowotor, K.A., W.G. Meikle, J.N. Ayertey, C. Borgemeister, C. Adda, B. Djomamou, P. Degbey, K. Azoma, A. Adda, and R.H. Markham. 1999. Intra-specific competition between larvae of the larger grain borer, *Prostephanus truncatus* (Horn) (Col.: Bostrichidae) within maize grains. Insect Science and its Application 18: 171–175.

The effects of egg clutch size on development and survivorship of *Prostephanus truncatus* (Horn) (Col.: Bostrichidae) were measured using single grains of the white maize variety, TZSR-W, at 30 °C and 70% rh in the laboratory. The objective of the work was to deter-

mine the maximum carrying capacity of a single grain, and to examine the effects of competition in terms of physiological parameters. A maximum number of 6 adults emerged from a single grain. At high densities (> 4 per kernel), some *P. truncatus* larvae reduced competition by moving out of the grain (since the grains were single, these larvae died of starvation). The mean number of adults that emerged per grain for initial egg densities of 8 and 16 were 3.3 and 3.5, respectively. Mortality of first instar larvae was high, suggesting that most competition effects manifested themselves very early on. Some emerged adults proceeded to bore into the grain, often killing pre-emerged adults. *P. truncatus* adult weight at emergence was not significantly influenced by initial larval density except in the case of initial egg density of 16. Sex ratio (female:male) of emerged adults was unaffected by competition, and was 1:1. First instar larvae fed mainly on the floury endosperm tissue whereas the second and third instar larvae fed on the germ tissue. Complete developmental period within grains was between 28 and 32 days. The implications of intra specific competition under storage conditions are discussed.

Conference papers, workshop proceedings, newsletters, thesis abstracts

Brown, R.L., Chen, Z-Y., Cleveland, T.E., Menkir, A., Cardwell, K.F., Kling, J.G., and White D.G. 1999. Resistance to aflatoxin accumulation in maize inbreds selected for ear rot resistance in west and central Africa. USDA ARS Aflatoxin elimination workshop. Oct 20–22. Atlanta.

Cardwell. 1999. Mycotoxins in foods in Africa—Antinutritional factors. In: Improving Human Nutrition Through Agriculture. IFPRI. Oct. 5–7, 1999 Los Baños, Philippines. www.cgiar.org/ifpri/themes/

Mycotoxins come under regulatory limits in foods and feeds because they are carcinogens. In addition to tumorigenic properties, many mycotoxins are anti-nutritional factors causing unthrifty growth and immune suppression in young animals. In the developed world, human exposure, and particularly exposure of children, to dietary mycotoxins is virtually nonexistent because of regulatory standards. In developing countries, particularly in sub-Saharan Africa, monitoring and enforcement of standards is rare and mycotoxin susceptible foods are often the primary staples in rather undiversified diets. People are being exposed to unsafe levels of various mycotoxins, often in mixtures, and the consequences in terms of public health burden have been ignored. This paper presents information on the health effects that have been attributed to mycotoxin exposure from medical research literature; data on existing mycotoxin levels in maize in West and Central Africa; and nutritional indicators on Béninese children. There is coincidental appearance of growth faltering and increased illness (symptoms associated with sub-acute mycotoxin exposure) with the weaning of children onto solid foods with a high risk of significant mycotoxin contamination. IITA, in its maize IPM project, has recognized mycotoxins as one of the most important constraints to the goal of improving human health and well-being through agriculture. An overview of various research and development activities at the institute is given.

Cardwell, K.F., Hell, K., Udoh-Mafon, J., and Ngoko, Z. 1999. Factors associated with contamination of maize with mycotoxigenic fungi in small-scale traditional farming systems in Bénin, Nigeria, and Cameroon. FAO/WHO Mycotoxin meeting, Feb. 1999, Tunis www.fao.org-/waicent/faoinfo/economic/esn/mycoto

Degbey, P., R. Oussou, W.G. Meikle and R.H. Markham. 1999. Des outils de prise de décision efficace dans la gestion des stocks. Presented at the African Association of Insect Scientists, Ouagadougou, Burkina Faso, 14–21 July 1999.

A decision-support tool, consisting of simulation models and sampling plans, was presented. The objectives of the decision-support tools are to reduce prophylactic pesticide use on stored grain, and to permit a market-oriented approach to pest management, by allowing farmers to use information (on pest density) to exploit economic opportunities.

Meikle, W.G., N. Holst, C. Nansen, J.N. Ayertey, B. Boateng and R.H. Markham. 1999. Developing decision-support tools for postharvest pest management in grain stores in West Africa. Pages 145–155 in Borgemeister, C., O. Mueck, and A. Bell (eds.) From biological control to a systems approach in postharvest. Proceedings of the workshop on integrated control of insect pests in rural maize stores, with particular reference to the larger grain borer Prostephanus truncatus (Horn) (Col.: Bostrichidae), and the future development of the postharvest sector in sub-Saharan Africa. 13–15 October, 1997, Calavi, Benin. Organized by IITA and GTZ.

Models simulating the interaction between stored grain, insect pests, biocontrol agents, and measures of farmer intervention are a valuable tool to organize scientific research and to predict the outcome of various IPM strategies. In combination with Geographic Information Systems (GIS) and general agroclimatological data, different IPM scenarios can be visualized on regional or continental scale and thus used to help direct IPM resources to where they are most needed and are expected to work most efficiently. A farmer may use IPM strategies to achieve different goals: One goal of an effective IPM strategy could be simply to diminish the loss of stored grain, and another could involve maximizing the economic outcome. Decision rules to opt for one strategy or the other can be derived from simulation models that are integrated with maize market price dynamics. Simple sampling plans must be developed which farmers can use to gauge the current pest status, as well as to make decisions about pest management. In this presentation we review our efforts with regards to (1) modeling the grain store ecosystem, (2) modeling grain store value through time and (3) developing sampling plans for insect pests.

Meikle, W.G., P. Degbey, R. Oussou, N. Holst, C. Nansen, and R.H. Markham. 1999. Pesticide use in grain stores: An evaluation based on survey data from Benin. Pages 5–9 *in* PhAction News, the Newsletter for the Global Postharvest Forum (published jointly by IITA, GTZ, NRI, and CIRAD), edited by S. Ferris and J. van S. Graver. October 1999, No. 1 [see http://www.cgiar.org/iita].

Rather than present pest population dynamics and grain losses as inexorable and inevitable processes, the goal of the Stored Product Pest Management group is to offer the farmers and extension agents an understanding of the management options available, along with an idea of their costs and benefits. Important questions must first be addressed: "Is there a need for such information?" and "Can the information be used to reduce losses or improve living standards?" To answer these questions, surveys were conducted of maize stores in Benin Republic. The first survey, from January to March 1997, involved 39 grain stores in the Mono and Zou provinces and the second survey, from October 1997 to July 1998, involved 63 grain stores in all the provinces in Benin. Up to 60 cobs were sampled from each store once per month for up to 7 months. Farmers were interviewed to establish their choice of pest management strategy. This information was used to a simple extension message:

1. Store the maize as usual, but do not apply pesticides.
2. Sample the store for insect pests after the maize has had a chance to dry, about 3 or 4 months into the storage season. Depending on the outcome of the sampling, and on the economic situation of the farmer.

3a. Pest densities were found to be low enough to ignore. Farmer will have saved on pesticides and has the option to keep the maize longer, and wait for higher prices, without a high risk of large losses.

3b. Pest densities were found high enough to worry about, and farmer anticipates serious losses in grain value before the end of the season. Shell the maize and consume it, sell it, or treat it and store it longer. The farmer has avoided the use of pesticides, and albeit with some losses (usually minor at this point of the season, even if *P. truncatus* is present) would now have the maize in a form that could keep for several more months, while prices go up. Farmers should be urged not to treat their grain stores with potentially dangerous pesticides intended for field crops. (1) Store the maize as usual, but do not apply pesticides.

R. Ndemah, 1999. Towards developing a sustainable pest management strategy for the African stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in maize systems in Cameroon. PhD thesis, University of Hanover, Germany, 135pp.

This study attempts to produce baseline data on importance and geographic distribution of stem borers and identify key interactions among and between abiotic (soil nutrients) and biotic (different life stages of pests, beneficials, host plants, vegetation indices, intercrops) factors in the stem borer ecosystem in Cameroon, which is a prerequisite for the development of evironmentally sound IPM-technologies. From 1993 to 1997, 297 farmers' maize fields in six benchmarks in the forest zone and three benchmarks in the midaltitude were visited periodically. In the forest zone only, the benchmarks were grouped into three blocks representing gradients in human population density and, thus, in length of fallow period.

Five borer species were found on maize (*Busseola fusca, Eldana saccharina, Sesamia calamistis, Mussidia nigrivenella*, and *Cryptophlebia leucotreta*) and four (*B. fusca, E. saccharina, S. calamistis, Poeonoma serrata*) on elephant grass, the most common wild host. Larvae and pupae per m^2 of *B. fusca* were three to nine times higher on *P. purpureum* than on maize, whereas for *E. saccharina* the situation was the reverse. It was concluded that *P. purpureum* is not a good trap plant because larval mortalities were too low.

Enumerative sampling procedures, based on Taylor's power law, were developed for the most common pest species in order to make estimation of pest densities as cost-efficient as possible without losing accuracy.

For any of the variables measured, there were no significant block effects in the forest zone; within field variability was highest and between field variation contributed more to total variability than location, emphasizing the insular character of forest fields. In the forest zone, *B. fusca* was the predominant species during the first and *E. saccharina* during the second season. In the midaltitude, *B. fusca* was predominant during both seasons whereas *E. saccharina* was not found in any of the fields. In both zones, negative relations could be found between cob weight and stem or ear damage, with *B. fusca* the most damaging species. *B. fusca* numbers at harvest increased with egg infestation, but was negatively related to egg parasitism or parasitoid sex ratio earlier in the season. Soil Mg had a negative effect on yield by increasing *B. fusca* densities whereas egg parasitism had a significant positive effect. Increasing density of cassava in the system had a negative effect on *B. fusca* densities, probably because of increased mortality of migrating first instar larvae.

Fifteen hymenopterous, two dipterous parasitoids, and one fungal species were found. The scelionid egg parasitoids *Telenomus busseolae* and *T. isis* were the most common parasitoids found in all locations in the forest zone. Most larval and pupal parasitoids belonged to the ingress-and-sting or planidial ingress guild. *Cotesia sesamiae*, the most common larval parasitoid of noctuid stem borers in eastern Africa was very scarce.

Recommendations are given for further research into habitat management (management of soil nutrients, trap plants, and intercropping with nonhosts), biological control options

('redistribution' approach, microbial control using viruses) and on how to increase uniformity of field infestations for host plant resistance screening.

Schulthess F. and S.O. Ajala. 1999. 'Recent advances in the control of stem borers in West and Central Africa' in Strategy for sustainable maize production in West and Central Africa, Proceedings of a Regional Maize Workshop, Cotonou, Benin, 21–25 April, 1997, 35–52.

The major field pests of maize in West and Central Africa are the lepidopteran stem borer species *Sesamia calamistis*, *Eldana saccharina*, *Busseola fusca*, and the ear borer *Mussidia nigrivenella*. IITA's first approach to combat stem borer problems was host plant resistance. IITA identified sources of moderate levels of resistance to *S. calamistis* and *E. saccharina* whereas CIMMYT and ICIPE have developed genotypes with strong antibiosis to whorl feeding species such as *B. fusca*, *Diatrea* spp., and Chilo spp. Levels of cross resistance among borer species are continuously determined through germplasm exchange between centers. This approach has led to the development of broad-based genotypes with resistance to *S. calamistis* and *E. saccharina*. Concomitantly, IITA is looking for other means of control, including biological control and habitat management. In a first step, the ecosystem of stem borers is being analyzed and compared across countries within a region and between regions via surveys, followed by multitrophic level studies on-farm at selected sites, or on-station, in the laboratory or green house. The aim of this system analysis is first, to delineate the area of problem and to identify key components in the system that could be manipulated to reduce stem borer infestations on maize. Because of the complexity of the pest problem and the size and ecological diversity of the maize growing area in Africa, this required a high level of involvement of NARES, other IARCs, and advanced laboratories in Africa and overseas. The target ecozones for stem borer work identified via these surveys were the zones south of the southern Guinea savanna, the midaltitudes, and highlands. The ecosystem analysis yielded several control options such as forms of biological control [new associations (i.e., the use of non-coevolved natural enemies), redistribution (i.e., expanding the geographic range of natural enemy species and strains) and biocidal control] as well as habitat management solutions (e.g., trap plants and management of soil nutrients). They are being developed and tested in collaboration with various NARES and IARCs.

IITA Research Project 5: Improving yam-based systems

Objectives

- Characterize farmers' management strategies in yam-based systems and the potential for the acceptance of improved technologies
- Develop strategies for integrated management of pests and soil fertility in yam-based systems
- Produce yam genotypes with high and stable yield of tubers with good food and storage qualities and disseminate them to NARS
- Develop technologies for improved postharvest systems and disseminate them to NARS
- Strengthen research, training, and leadership skills for NARS scientists and personnel working on yam-based systems

Activities

- Survey farmers' perceptions of the resource management constraints in intensified yam-based systems

- Conduct economic analysis of the yam seed sector and ex-ante adoption studies of improved varieties
- Assess the economic viability and acceptability of planted legume fallows for soil fertility maintenance
- Conduct ex-ante adoption studies on hot-water therapy for disinfection of yam seed tubers
- Investigate the domestication of wild yams in Benin and Nigeria
- Establish the geographic distribution of yam nematodes in Benin and yam viruses in Ghana
- Improve the methodologies for screening of yam host plant response to nematodes and viruses
- Screen yam germplasm for resistance to major field and storage pests
- Conduct vector studies on known yam viruses and characterize new ones
- Study integration of herbaceous legumes and woody legumes into yam-based systems
- Study nutrient requirements of yams and efficient use of fertilizers in yam-based systems
- Develop broad-based populations for improved performance of yams in the moist savanna of West Africa and in the midaltitude ecologies of East Africa
- Develop special populations for improved tuber quality and anthracnose resistance
- Develop procedures for regular farmer participatory evaluation and selection of superior yam genotypes
- Produce virus-tested propagules of yams for export and exchange germplasm with collaborators
- Conduct regional varietal trials with NARS
- Study differential responses to abiotic environmental stresses in yams
- Identify factors controlling the cooking quality of yams and develop screening methods
- Develop screening methods and control measures for enzymatic browning of yam tubers
- Develop methods for artificial sprout induction in dormant yam tubers and for the control of flowering
- Improve in vitro mass propagation and post flask management of yam plantlets
- Develop regeneration and transformation systems for yams
- *Establish molecular markers for genes conferring resistances to yam viruses, nematodes, and anthracnose disease*
- *Develop molecular maps for* D. alata *and* D. rotundata
- Characterize chemical and physical components affecting food quality and industrial processing quality of primary yam products
- Develop technologies for improved storage and expanded utilization of yams

- Improve and promote processing of yam tubers into dry food products in West Africa
- Supervise degree-related research of NARS personnel
- Provide technical backstopping to specific NARS-centered projects
- Establish a database for geographic information, manpower resources, projects, and improved technologies relevant to yam research and development in Africa

Expected Outputs

- Understanding of farmer management strategies and potential for acceptance of new technologies
- Better knowledge of yam pests and diseases and the strategies for their integrated control
- Appropriate strategies for management of soil fertility and weeds for yam producing areas
- Stable high-yielding genotypes with good quality tubers, suited to relevant cropping systems
- Protocols for artificial induction of flowering and tuber sprouting
- Modern tools for increasing efficiency of genetic improvement

Improved capability of NARS for research and development of yams

Annex 1

Research Projects

1. Short fallow systems
2. Agroecosystems development strategies
3. Biological control and biodiversity
4. Integrated management of legume pests and diseases
5. Integrated management of maize pests and diseases
6. Integrated management of cassava pests and diseases
7. Improving plantain- and banana-based systems
8. Integrated management of *Striga* and other parasitic plants
9. Improving postharvest systems
10. Farming systems diversification
11. Cowpea–cereals systems improvement in the dry savanna
12. Improvement of maize–grain legume systems in West and Central Africa
13. Improvement of yam-based systems
14. Cassava productivity in lowland and midaltitude agroecologies of sub-Saharan Africa
15. Molecular and cellular biotechnology for crop improvement
16. Conservation and utilization of plant biodiversity

CGIAR Systemwide and Ecoregional Projects

Ecoregional Program for the Humid and Subhumid Tropics of Africa (EPHTA)

Systemwide Program on Integrated Pest Management (SP-IPM)

Annex 2

Narrative summary	Indicators by the year 2002	Means of verification	Assumptions
Overall Goal: Increase the well-being of poor people in SSA	▪ Higher level of food production ▪ Better income and nutritional status of poor people ▪ Reduced drudgery for women	▪ National and regional statistics and other data	▪ Political conditions and macroeconomic environment remain stable
Purpose: Through research and related activities, in partnership with NARS and other institutions, develop and deliver technological options to increase food production in a sustainable manner in IITA's mandated zones for the benefit of farmers, other entrepreneurs, and consumers	▪ Adoptable technologies available and widely used ▪ NARS delivery of technologies increased ▪ Better access to food ▪ Increased gender equity ▪ Increased and sustainable production demonstrated	▪ NARS and IARC reports ▪ Agricultural and anthropometric statistics ▪ Impact studies	▪ Financial support to agricultural research and development maintained or increased ▪ Favorable government policies and services ▪ Enabling infrastructures
Outputs: Plant Biodiversity Improved availability and more efficient utilization of plant genetic resources by NARS and other partners	▪ Greater food security through enhanced collection and conservation of genetic diversity ▪ Improved breeding strategies adopted which increase the efficiency of breeding programs ▪ Diverse source germplasm available and utilized by NARES ▪ Increased exchange of disease-tested planting materials between IITA and research partners ▪ Systematic collection, conservation, and utilization of plant genetic resources by NARS in sub-Saharan Africa	▪ NARS and IARC repor ▪ Seed-sector reports ▪ Workshop proceeding ▪ NARS cultivar releases	▪ Countries' willingness to share plant genetic resources

Narrative summary	Indicators by the year 2002	Means of verification	Assumptions
Agroecosystem Development Strategies & Impact Functional ecoregional research teams directed at poverty eradication through sustainable development of targeted agroecosystems	▪ NARS, IARCs, and ARIs working together in at least 6 ecoregional benchmark areas in the humid forest and moist savanna of West and Central Africa. ▪ Holistic, participatory research programs operational in the launched benchmark areas ▪ Policy decision-makers from West and Central Africa sensitized on relevant policies that facilitate the adoption of improved technologies ▪ Social returns to research demonstrated to convince donors to increase investments on agricultural research in SSA	▪ IARC, NARS, and reviev reports	▪ All partners remain committed to an ecoregional approach
Musa Systems Integrated production technology developed and tested for plantain/banana-based production systems	▪ Feasibility of IPM strategies demonstrated in benchmark sites ▪ Improved cultivars tested and released by NARS ▪ Sustainable resource and crop management practices adopted in benchmark sites and by NARS	▪ Project and NARS reports and publications ▪ Feedback from collaborators ▪ Benchmark site survey reports	▪ Materials meet quarantine standards ▪ Minimum NARS capacity
Maize–Grain Legume Systems Technologies that increase productivity of maize-grain legume systems in the Guinea savanna in a sustainable manner evaluated and disseminated	▪ At least 10% of farmers in the benchmark areas adopt technologies which increase land productivity and sustainability, including improved residue management, use of grain legumes to increase nitrogen fixation, and use of improved nutrient-efficient varieties of maize, soybean, and cowpea	▪ Survey of benchmark areas in collaboration with NARS	▪ Farmer has stake in long-term productivity ▪ Market can absorb increased production of grain legume crops

Narrative summary	Indicators by the year 2002	Means of verification	Assumptions
Cassava Productivity Improved and adapted cassava germplasm and production practices developed and evaluated in collaboration with NARS for sustainable production and utilization systems	▪ Diverse and multiple disease and pest resistant cultivars with superior and stable yield performance and acceptable food and feed characteristics available ▪ Increased yields and productivity for resource-poor farmers using these technologies, with less dependence on pesticide and chemical inputs ▪ Increased availability of low cost carbohydrate staple ▪ Increased cash income especially for women	▪ IITA, NARS, and NGO reports	▪ Current strength and links with NARS maintained ▪ Links with NGOs developed and strengthened
Yam-based Systems Improved technologies targeted at enhanced productivity of yam-based systems evaluated and disseminated by NARS	▪ Increased availability of healthy planting materials of improved varieties to NARES and farmers ▪ Expanded genetic base of NARS' selection programs ▪ Increased inclusion of improved yam genotypes in NARS' agronomic trials ▪ Increased numbers of farmers growing yams	▪ NARS and project reports	▪ Effective networks in yam R & D
Cowpea–Cereals Systems Improved technologies that increase sustainable productivity of cereal/cowpea-based cropping systems evaluated and disseminated by NARS	▪ Improvement of local varieties will not only increase and stabilize food and fodder production but will also ensure in-situ conservation of cowpea landraces ▪ Through the dissemination of improved varieties and new cropping systems, farm families in the marginal lands of the dry savannas and the Sahel will improve their food security, livestock feed security, income generation opportunities, and the sustainability of their cropping systems, without requiring substantial inputs of labor, pesticides, and inorganic fertilizers	▪ NARS and IARC reports ▪ Adoption and impact studies	▪ Market can absorb increased cowpea grain and fodder

Narrative summary	Indicators by the year 2002	Means of verification	Assumptions
IPM Maize Reduced losses of maize to pests and pathogens through the use of IPM technologies	▪ Pest and disease levels will be significantly reduced and maize yields increased at selected locations ▪ Collaborating NARES will have the capacity to identify pests and diseases, assess yield loss, and stabilize maize yields using ecologically sustainable control technologies	▪ Survey data comparing pre- and post-intervention status of losses in target countries	▪ Effective links with implementing agencies maintained
IPM Legumes Reduced crop losses demonstrated in farmers' fields through IPM technologies which increase cowpea and soybean productivity in a sustainable manner	▪ At least 10% of cowpea and soybean farmers in three IPM use IPM ▪ Farmers obtain at least 25% higher revenue that those who do not use IPM	▪ NARS and NGO reports	▪ Conditions for adoption of IPM technologies remain favorable
IPM *Striga* Sustainable integrated parasitic plant management measures and components evaluated and disseminated	▪ NARS testing rotation-based integrated *Striga* spp. management in 15 SSA countries ▪ NARS disseminating integrated *Striga* spp. management in at least 5 SSA countries ▪ Annual reduction in *Striga hermonthica* damage annually corresponds, monetarily, to a $70 million annual gain for farmers in West Africa	▪ Country, IITA, and seed production agency reports	▪ Farmers continue to perceive *Striga* spp. to be problems for which adoption of new behavior/agricultural practices are worthwhile ▪ Market can absorb increased production of and adequate demand for non-host crops

Narrative summary	Indicators by the year 2002	Means of verification	Assumptions
IPM Cassava Sustainable cassava plant protection technologies developed, tested, and implemented in collaboration with NARS	▪ Pest damage will be reduced and cassava yield significantly increased to benefit resource-poor farmers ▪ Participating NARS will benefit from increased capacity to manage cropping systems, increase and stabilize cassava productivity, provide income and food security, foster environmental protection, and also from the exchange of genetic resources and technical information	▪ IARC, NARS, and NGO reports	▪ New major pests do not arise ▪ Good links with NGOs
Biological Control Biological control of pests and weeds in farming systems	▪ Reduced crop damage ▪ Reduced pesticide use ▪ Maintenance of biodiversity and safeguarding environmental quality ▪ Maintenance of sustainability of farming systems	▪ Socioeconomic and faunistic surveys and impact studies ▪ Pesticide use statistics	▪ Efficient biological control agents continue to be identified
Improving Postharvest Systems Postharvest technologies to provide utilization options for the food, feed, and agro-industrial sectors developed and disseminated in collaboration with NARS	▪ Information from selected countries highlighting opportunities for improved postharvest technologies ▪ Increased efficiency on harvesting, drying, storage, processing, and marketing of crops ▪ Expansion in the utilization of crops leading to food security, income and employment generation and poverty eradication ▪ Increased capacity for postharvest research and development within regional networks, NARS, NGOs, and CBOs	▪ NARS and IITA reports ▪ Monitoring tours and surveys	▪ Socioeconomic environment conducive to small business development

Narrative summary	Indicators by the year 2002	Means of verification	Assumptions
Short Fallow Systems Sustainable short fallow management systems developed in partnership with farmers	▪ Farmers in at least 30 communities in the benchmark areas and pilot sites are testing and evaluating short fallow systems, with farmers in those communities recognizing improved soil conditions ▪ Increased productivity through 2 or more improved fallow systems validated in benchmark sites in at least 4 EPHTA countries ▪ At least 10 NARS promoting validated short fallow systems	▪ IARC and NARS reports, ▪ Benchmark and pilot site surveys	▪ Farmers are receptive to longer-term land management interventions
Farming Systems Diversification New and complementary income-generating enterprises developed and evaluated with farmers in benchmark areas	▪ Farmers in benchmark areas achieve higher productivity and cash incomes through integration of new production enterprises	▪ IARC and NARS reports ▪ Benchmark site surveys	▪ Sustained market for enterprise outputs
Biotechnology Molecular and cellular tools and products, for germplasm enhancement and dissemination of IITA mandate crops, available to collaborating scientists	▪ At least 5 countries in SSA will regularly employ new techniques of cellular and molecular biology for germplasm development and dissemination ▪ Transgenic cowpea with *Maruca* and virus resistance, and *Musa* lines with antifungal protein gene will be ready for dissemination to interested parties ▪ Genetic linkage maps for IITA mandate crops for marker-assisted selection will be available	▪ IITA and NARS reports and publications ▪ Training documentation	▪ Increased support of governments in the region to the use of molecular and cellular tools for improvement of crop plants

Annex 3

Project Planning Matrix: **5. IPM-Maize**

	Measurable Indicators	Means of Verification	Important Assumptions
Developmental goal Reduce pre- and postharvest losses of quantity and quality of maize to insect pests, pathogens and *Striga* in sub-Saharan Africa	Losses are reduced in benchmarks of 4 target countries in 10 years starting 1995	Survey data comparing pre- and post-intervention status of losses in the target countries	Effective links with NARES and other implementing organizations (IO) are maintained. IOs remain positive in their attitude to IPM and are effective in transferring IPM message to farmers.
Project purpose 1. Regional implementation projects are facilitated	1. By 2003 at least 2 region-wide plant protection programs are operational (Storage pests, Mycotoxins, Stem borers, striga)	1. NARES and coordinators reports, workshop proceedings & meeting reports	1. Resources are available for networking activities and there is policy level commitment by the various governments to be involved in regional initiatives.
2. NARES research and dissemination capacity strengthened	2. By 2003 country-specific research and implementation programs underway in at least 4 countries	2. NARES annual reports	2. National governments policies committed to strong support to agric. sector.
3. NARES test, adopt, and promote resistant germplasm (from IITA) and use improved infestation/infection methods to screen their local materials	3. NARES breeding programs in at least 4 countries have resistance germplasm and methods for adaptation of the material to their specific conditions	3. NARES reports, seed increase records, decrease in pests	3. Farmer preferences for varietal characteristics are taken care of by NARs breeders and seed multiplication distribution mechanisms are in place
4. Options for pre- and postharvest integrated management of pest and diseases are expanded	4. By 2003 IPM options available for 2 biotic constraints in at least 4 countries	4. IARC and NARES reports	4. Socioeconomic thresholds for adoptability are understood (linkage with Farming Systems Diversification project)

	Measurable Indicators	Means of Verification	Important Assumptions
Outputs/Results			
1. Knowledge of pest, pathogen, and parasitic plant systems in pre- and postharvest maize	1. Regional databases and inventories and decision support tools (e.g., models)	1. Journal publications, concurrence of data predicted vs. observed	1. Effective research links with NARES and IARCs in the region; Biological constraints prioritized at NARES level
2. Disease, insect and *Striga* resistant germplasm (pre- and postharvest)	2. Production and delivery systems which are quantitatively better than natural infestation/infection levels and are sustainable and affordable to IARCs and/or NARES breeding programs Comparative damage levels across accessions showing a quantitative improvement in varietal performance when infested/infected with known levels of a pest or pathogen.	2. Monographs, methods demonstrations & training guides, reports from training workshops, publications IITA archival reports	2. Labs for mass rearing/inoculum production are adequate; sites with high inoculum pressure for testing germplasm are available; NARES resources for research, testing, and multiplication of breeder seed (RTM) are adequate; farmers are willing to adopt new varieties
3. Biological control and habitat/store management options	3. Agent parasitizes or infects the target maize pest or pathogen in screenhouse and field, and pre-introduction safety testing on host specificity/toxicity has been done for at least 3 targets by 2003. On-farm trials have demonstrated the effectiveness of at least 2 feasible habitat/store management tactics in reducing pest populations and losses.	3. Publications	3. Effective agents can be found; import and release permits are granted; management tactics compatible with current socioeconomic constraints can be identified
4. Collaborative development and testing of IPM strategies for pre- and postharvest maize	4. Comparative advantage of new strategies to reduce losses relative to current farmer practices have been tested in benchmark sites and NARES (in at least 4 countries) are trained in systems analysis research.	4. On-farm participatory research, publications with NARES partners on the analyses of maize production systems.	4. NARES resources for RTM are available; socioeconomic context remains favorable for adoption of more sustainable crop protection strategies (i.e., IPM)

Annex 4

Research Highlights

IITA's work is structured as 16 multidisciplinary research projects. Some projects focus on production systems for specific crops or crop combinations; others are thematically oriented and can involve many crops. Most of the projects cut across the agroecological zones for which IITA's work is targeted. IITA also serves as the convening institute for the systemwide program for integrated pest management.

This section presents the highlights of each project for 1999. These summaries are not a complete account of the work begun or completed during the year; rather, they describe some key scientific results and are intended to give the reader an insight into the breadth of the research themes and problems being investigated by IITA scientists.

Project 1
Short fallow systems

- 491 seedlots totaling over 800 kg of herbaceous seed of cover crops were distributed to international agricultural research centers (IARCs), national agricultural research systems (NARS), and nongovernmental organizations (NGOs) in and outside Nigeria. This can be compared to a total of 355 seedlots weighing just over 300 kg in 1998 and 171 seedlots weighing just over 100 kg distributed in 1997.
- The ^{13}C natural labeling technique demonstrated that ^{13}C analysis of weed samples could be used to quantify how the proportion of C_3 and C_4 weeds in the biomass changes in response to shading by crops.
- Site- and species-specific responses of *Mucuna pruriens* and *Lablab purpureus* to the addition of Togo rock phosphate (RP) were observed for a series of trials on a toposequence representative of the northern Guinea savanna (NGS). *Mucuna* significantly enhanced the release of P from RP and increased grain yields of the following maize crop.
- Improved maize production and soil fertility management practices were tested in a participatory on-farm trial in the NGS. The improved practices (plant density, variety, fertilizer application) increased the yield and gross margin from 1.6 t/ha and 4600 naira/ha (farmers' practice) up to 4.1 t/ha and 19 600 naira/ha.

Project 2
Agroecosystems development strategies and policies

- About 180 maize varieties and 200 cassava cultivars were released by NARS of 20 countries in SSA between 1965 and 1998. IITA materials represented about 50% for maize and 80% for cassava of the germplasm incorporated in the new varieties for the 1990s, which resulted in a yield advantage of about 53% for maize and 49% for cassava. This increase in annual production could deliver food security to a further 23 million people.
- Ex-post impact assessment at household level indicated high returns to investment (increases of 65–88% for maize yield, 31–71% for net income, efficiency in the use of other inputs, and risk reduction in both physical and financial returns) for farmers who had adopted *Mucuna* cover crop technology.
- An analysis of food consumption in the 2 major cities in the humid forest of Cameroon indicated that 43–50% of urban households consumed less than the minimum requirement of 2400 kcal/day/adult equivalent. Between 18% and 46% of children aged 6–59 months were deemed stunted.
- Farmers in the dry savannas of Nigeria with good market infrastructure ranked indicators for measuring the likely impacts of the new dual-purpose cowpea variety as follows: income generation (55.1% of responses), food security (17.9%), social benefits (14.2%), and ecological benefits (12.8%). The same ranking was recorded in villages with poor markets though there was a higher preference for food security.
- Potential monetary returns (measured as discounted net present value) could range from US$550 to US$740/ha if carbon sequestered by conversions of degraded *Chromolaena odorata* bush land to multistrata cocoa agroforest were to be traded in a carbon market.

Project 3
Biological control and biodiversity

- In Benin, socioeconomic studies confirmed that termites are a priority pest, paving the way for the development of a microbial control product.
- Green Muscle™, developed by Lutte biologique contre les locustes et sauteriaux (LUBILOSA), has been recommended by the FAO locust pesticide referee group as the only product having "low environmental risk" over all categories, and "unlikely to present acute hazard in normal use" according to the WHO human toxicity classes, opening the doors to the widespread use of this novel technology.
- Under the stewardship of LUBILOSA, and following its successful registration in South Africa, NPP, a commercial producer of Green Muscle™, has applied for registration to the Interstate Committee on Drought Control in the Sahel (CILSS) Pesticide Committee in most Sahelian countries.

- Commercialization of Green Muscle™: NGOs in Mali and Niger have bought Green Muscle™ for the first time, and a large order has been placed by a major stakeholder (Lux-Development together with the Niger DPV) involved in grasshopper control.
- The impact of biological control on water hyacinth is now clearly visible over large areas and was publicly acclaimed in Uganda, Tanzania, and Benin by the local population and by national authorities.
- Within the framework of functional biodiversity, the insect museum has been updated by 21 000 specimens and now houses the second largest insect reference collection in West Africa.
- More than 100 national scientists, technicians, and students were trained at various levels in biological control methods, IPM, geographic information systems (GIS), and impact assessment. Audio and visual materials were produced on water hyacinth and *Striga* control.

Project 4
Integrated management of legume pests and diseases

- Orchid and snowdrop lectins were found to be insecticidal to *Maruca vitrata* and hence may be used to control this pest through transgenic approaches.
- Affinity-purified lectins from African yam beans (*Sphenostylis stenocarpa*) were tested against pod-sucking bugs (*Clavigralla tomentosicollis*) and cowpea weevils (*Callosobruchus maculatus*) using an artificial seed system, and were demonstrated to be lethal to both pests.
- A thorough screening of *Mucuna* spp. as a possible source of insecticidal compounds revealed a novel protein that is highly toxic to *M. vitrata*.
- Pre-release surveys to assess thrips species composition and their natural enemies on cultivated and wild host plants were carried out from the coastal savanna of Ghana through the Sudan savanna of Burkina Faso between March and September 1999. The flower thrips *Megalurothrips sjostedti* was present on all known host plants. The local parasitoid *Ceranisus menes* was the only species found associated with the thrips on some host plants. This confirms results from previous studies in Benin.
- The exotic thrips parasitoid *Ceranisus femoratus* was successfully established at the IITA Benin Station. After the initial release on *Tephrosia candida*, the parasitoid is already spreading on adjacent cowpea fields and on *Centrosema pubescens*. First experimental releases in southern Ghana were effected late October on *C. pubescens*.
- Investigation of the efficacy and dynamics of *C. femoratus* in Cameroon was continued. The parasitoid is now ca. 150 km from Yaoundé, where it was first seen.
- Twentyseven extension trainers from 9 countries participating in the cowpea IPM project were trained as facilitators of participatory learning and experimentation in farmers' field schools. They, in turn, trained 125 farmers at 5 cowpea IPM farmers' field schools.

Project 5
Integrated management of maize pests and diseases

- A sustained reduction of downy mildew of maize in Nigeria has been achieved through a combination of public and private support for the extension of agrotechnological solutions.
- Simplified store evaluation procedures, designed to help farmers reduce pesticide use and make sound economic decisions, were developed and incorporated in extension courses conducted by IITA in collaboration with NGOs.
- It was discovered that planting of trap plants (grasses) as border rows of maize fields is not a viable option for stem borer control in West Africa because it considerably increased maize damage by rodents.
- As part of collaborative research work with the US Department of Agriculture (USDA), 76 IITA inbred lines were evaluated for resistance to aflatoxin accumulation, using a laboratory kernel screening assay. At least 18 inbred lines were found to have aflatoxin levels as low as or lower than the most promising resistant genotypes identified by USDA. These lines also showed protein profiles which were not found among inbred lines developed in the US.

- Five maize varieties with varying levels of resistance to *Sesamia* and/or *Eldana* were identified to have cross-resistance to *Busseola fusca*. These varieties were successfully deployed in on-farm trials in the Cameroon forest region.

Project 6
Integrated management of cassava pests and diseases

- Africa-wide implementation of cassava green mite (CGM) biological control by exotic phytoseiid predators continued. The exotic phytoseiid predator *Typhlodromalus aripo* is now found in 17 countries, and has newly colonized parts of the dry savanna of West, Central, and East Africa. The predator has been recently established in parts of the subhumid tropics in Malawi, Mozambique, and Zambia. Where this predator has been present for 3 or more years, cassava productivity has increased between 15 and 43%.
- Brazilian isolates of the fungus *Neozygites floridana* have been successfully established in southern Benin. This pathogen can potentially complement CGM biocontrol on cassava varieties that are not preferred by exotic phytoseiid predators.
- To combat cassava mosaic virus disease (CMD) in northwestern Tanzania, Kenya, and Uganda, IITA, in collaboration with its public and private sector partners, facilitated the multiplication and distribution of resistant cassava and imposed phytosanitary restrictions on the movement and cultivation of CMD-diseased cassava germplasm.
- The hybrid virus associated with the spread of severe CMD in East Africa, and known to be present only in the Great Lakes region, was recently found in a CMD outbreak area in the central plateau of Congo.
- Among 24 widely grown cassava varieties in Togo, 4 from IITA and 4 from Togo were shown to be resistant to several highly virulent cassava bacterial blight strains collected from wide geographic origins.
- Two MSc and 3 PhD students completed their studies, and 72 NARS staff received training on various aspects of integrated management of cassava pests. In addition, NARS and farmers in 7 countries participated in field evaluation of the impact of pests and diseases on cassava productivity.

Project 7
Improving plantain- and banana-based systems

- RAPD and AFLP markers were used to assess the genetic diversity and phylogenetic relationships of representative samples of East African highland bananas (EAHB) and West African plantains. Safety duplication of the *Musa* collection was also achieved.
- Ploidy levels and genome composition of elite *Musa* germplasm were determined, and genetic bridges for crossing between plantain cultivars (triploids), that cannot be directly intercrossed, were developed. A silver staining procedure was developed to visualize pre-prophase meiotic *Musa* chromosomes and facilitate analysis of reproductive behavior across ploidy and genome groups. This has enhanced breeding methodology for plantain improvement at Onne.
- One diploid and 3 tetraploid hybrid progenies of EAHBs were selected for their superior bunch weight and resistance to black Sigatoka. The first seeds from tetraploid × diploid crosses were also obtained.
- A root sampling method based on soil cores, which captures more than 80% of the root size but only requires 5% of the time needed for whole plant excavation, was developed. Likewise, an efficient screening method for resistance to plant parasitic nematodes was developed, enabling host resistance assessment within 3 months from inoculation of single root segments.
- Screening of 45 accessions against banana weevil showed that plantains were the most susceptible, followed by EAHB, exotic bananas, and then wild or hybrid diploids. Antibiosis associated with corm hardness, corm size, and resin/sap production was the most important resistance mechanism. The heritability of total inner damage was 87%, indicating that selection for resistance would be efficient. Insect-repellent green manures *Canavalia*, *Mucuna*, and *Tephrosia* had no effect on weevil adult numbers or rhizome damage, due to the sedentary life of the weevil.
- IITA collaborated with NGOs (Shell, Agip) in Nigeria to disseminate new cooking banana varieties which have now been adopted by farmers and occupy about 26% of total fields, representing a 9-fold increase since introduction nearly 2 decades ago.

- To promote the use of clean planting materials and reduce the spread of nematodes, training was carried out for 1623 farmers in Uganda, 659 in Zanzibar, and 234 in Rwanda, resulting in the treatment of 4480 suckers in Uganda, 5000 in Zanzibar, and 1050 in Rwanda.

Project 8
Integrated management of Striga and other parasitic pests

- Results of on-station legume rotation trials in Mokwa, Nigeria, showed that 2 years of legume rotation is more beneficial than 1 year legume rotation or continuous cereal cropping for improving soil conditions and reducing the impact of *Striga* on subsequent cereal crops.
- Two *Striga hermonthica*-tolerant varieties of maize, EV DT-W 99 STR C0 and TZEW-Pop ' 1368 STR C0, showed superior performance in regional *Striga* trials.
- Results of experiments conducted to improve methods for artificial infestation with *Striga* in maize breeding trials and to reduce the cost of infestation revealed that higher levels of infestation were attained when maize was grown in single stands at 25 cm intra-row spacing than with 2 plants per hill at 50 cm spacing. Rates of 3000 germinable *Striga* seeds per hill were sufficient to achieve a good level of infestation.
- Tests revealed that the modified agar gel assay method works well for screening maize genotypes for low production of *Striga* germination stimulant, and for identifying maize genotypes that are high stimulant producers and yet tolerant to *Striga* infestation due to other mechanisms of resistance.
- Molecular markers have been identified that show polymorphism between *Striga*-susceptible and -resistant genotypes. Reliable phenotype data were obtained in field trials at two locations, which will be utilized in mapping the resistance genes in these populations.

Project 9
Improving postharvest systems

- Four groups of 15 farmers from Burkina Faso, Cameroon, and Côte d'Ivoire were trained by farmers from Benin in the technique of yam chip processing and derived culinary preparations in Benin. The trained farmers have started to disseminate the technique in their own countries.
- A regional agricultural research and development network called FOODNET was set up in Eastern and Central Africa to focus on market research and promote production and sale of value-added agricultural products. It seeks to strengthen links between the private and public sector and to provide regional training in market analysis. A web site for the project (http://www.cgiar.org/foodnet) became accessible in December 1999.
- For the first time, cassava germplasm was screened for iron and zinc content in the tuberous roots; a wide genetic variation was found (1.3–64.80 ppm for iron content and 1.40–36.10 ppm for zinc content). A weak and positive relationship was observed for iron and zinc.
- Fifty improved cowpea varieties were evaluated for food composition and physicochemical characteristics. Results obtained indicated that there were significant differences among the varieties for all the parameters evaluated.
- Studies on tropical ataxic neuropathy (TAN) in Nigeria showed that the condition is still prevalent, but that low intake of fish and beef, the major sources of sulphur-containing amino acids in this community, rather than dietary cyanide exposure from cassava consumption is the likely causative factor. It was also established that excessive cassava production was not necessarily linked to high dietary cyanide exposure and the disease "konzo" when cassava processors adhered to safe processing practices.
- An auger-type husking and polishing mechanism (rice mill) coupled with a suction blower for cleaning was developed. The mill, which has a capacity of 60–80 kg/h, tested satisfactorily for parboiled rice with a milling recovery as high as 68%, hulling efficiency up to 90% on first pass and 98% on second pass, and with broken milled rice below 20%.
- In Ghana, two small-scale companies, Delabac Ventures and Darkruby Enterprise, were given training in soybean processing and were assisted to obtain a grant from the Organization of African Unity (OAU)/Semi-Arid Food Grain Research and Development (SAFGRAD) Technology Transfer and Commercialisation Program. Delabac Ventures has launched 5 soy-based products: Soya Yoghurt, Soya Vita, Soya Vita Plus, Soyalac, and Pure Soya Powder.

Project 10
Farming systems diversification

- Long-term cocoa agroforest establishment trials were initiated on degraded lands with 34 farmers in southern Cameroon.
- Ongoing characterization of existing cocoa agroforests in southern Cameroon revealed that these are among the most biologically diverse and the most "forest like" of agricultural land-use systems in SSA.
- The Multi-institutional Sustainable Tree Crops Program in West and Central Africa was launched. A program coordinator to be based at IITA will be in place early in the year 2000.
- Agronomic factorial trials showed significant yield response from wood ash in combination with poultry manure on 2 important peri-urban agricultural enterprises—tomatoes and the leafy vegetable known as jute mallow *Corchorus olitorius*. The combined use of ash and manure proved more profitable than the predominant practice of using inorganic fertilizer.
- Estimates on the economic efficiency of mixed farming systems in the drier savannas of Nigeria indicated that there are high potentials for improving crop–livestock systems because only 15% of farmers achieved more than 80% of efficiency and only 1.25% could be considered as having reached the efficiency frontier (> 90% of efficiency), out of a random sample of 559 crop–livestock farmers.
- Results from goal mathematical programming models from another sample of farmers with livestock in the northern Guinea savanna of Nigeria indicated that making systems efficient in areas with poor market access produces benefits to the small-scale farmers that are similar to those achieved by systems in areas with good market infrastructure.

Project 11
Cowpea–cereals systems improvement in the dry savannas

- Some of the new improved cowpea varieties combining resistance to major diseases, insect pests, and *Striga gesnerioides* showed over 50% higher yield potential than existing improved varieties, with 1.5 t/ha grain and 3 t/ha fodder in the Sahel and 3 t/ha grain and 5 t/ha fodder in the Sudan savanna.
- Dry season cowpea became very popular in Nigeria and over 2000 farmers grew the improved cowpea variety IT89KD-288.
- A date of planting trial in the dry season indicated that some heat-tolerant cowpea varieties can be successfully grown between 25 March and 25 June permitting a wheat–cowpea–rice intensive crop rotation in northern Nigeria where large irrigation schemes are in operation.
- Screening for drought tolerance and root characteristics revealed that cowpea varieties IT96D-604, IT95K-222-3, IT90K-222-5, and IT95K-1115-10 were most drought tolerant. IT96D-605 also showed a deeper root system under water stress condition compared to other varieties.
- An IITA/German Agency for Technical Cooperation (GTZ) initiative on farmer-to-farmer diffusion of improved cowpea seed gained popularity in northern Nigeria. From the initial 36 farmers in 1997, over 2500 farmers produced seed of the improved cowpea variety IT90K-277-2 in 1999.
- Food quality analysis of 52 cowpea varieties indicated significant genetic variability for protein, fat, and iron content. The top 4 improved varieties had 17% higher protein and 12% higher iron content than the mean of 4 popular local varieties.
- IITA, ILRI, ICRISAT, the International Fertilizer Development Center, and the University of Durham, UK, have begun working together to develop a novel holistic approach to on-farm research, bringing together complementary component technologies from the various institutes in a "best bet" (BB) package. The BB package includes recommended crop varieties as well as crop, livestock, and soil management practices. These are being evaluated in terms of biophysical and socioeconomic parameters, together with the farmers. With funding from the Systemwide Livestock Program, and working with NARS partners in northern Nigeria, the approach expanded from 11 farmers in one village in 1998, to 23 farmers in this same village and a further 21 farmers at a new location in 1999. Crop grain and fodder yields were substantially more for the BB treatments as compared to local practices; likewise, small ruminants fed with the harvested fodder gained more weight on BB than on local treatments. Similar trials have also commenced with 18 farmers in Niger, and preparatory characterization studies are underway in Mali.

Project 12

Improvement of maize–grain legume production systems in West and Central Africa

- In a late-maturing open-pollinated maize variety trial tested across locations, the 3 top ranking new varieties produced 11–15% higher yields than a commercial hybrid check, Oba Super I. A new stem borer-resistant variety, Ama TZBR-W, had 10% higher yield than Oba Super I. A *Striga*-resistant variety, ACR97 TZL COMP1-W, was as productive as the commercial hybrid.
- Two *Striga*-resistant, early-maturing maize varieties produced over 7000 kg/ha yields at Sinematialli under *Striga*-free conditions, which were comparable to yields of the best early-maturing varieties. These varieties also performed well under artificial *Striga* infestation at Ferkéssedougou.
- Thirteen maize varieties were compared at 0, 30, and 90 kg N/ha in Mokwa, Nigeria. Grain yields of the latest cycle of selection from the low N-tolerant pool (C2) were comparable to that of an N-efficient hybrid, Oba Super II, at low and medium N levels. This variety produced higher yields than Oba Super II at the high N level and had good agronomic features.
- Three early-maturing soybean varieties, TGx1871-12E, TGx 1740-2F, and TGx1871-5E, produced 20–35% higher grain yields and 9–27% more fodder than TGx1485-1D in the Guinea and Sudan savanna zones. These varieties also have increased resistance to pod shattering and enhanced nodulation.
- A cowpea–maize rotation trial was conducted for 2 years (1998–99) in 2 villages in the derived savanna. In the relatively poor fields, application of 45 kg urea-N/ha and 45 kg cowpea haulm-N/ha produced maize grain yields comparable to those of plots receiving 90 kg urea-N/ha. In the relatively fertile soils, the combined use of urea and cowpea haulm yielded about 80% of the grain of those plots receiving 90 kg urea-N/ha.
- An on-farm trial comparing the benefits of legume–maize double cropping systems to that of full-season maize with up to 90 kg N/ha fertilizer was carried out for 2 years (1998–99) in degraded fields in the NGS. A partial budget analysis showed that double cropping maize with legumes was more profitable than full-season maize. For each year, grain legume–maize double cropping systems and full-season maize gave higher benefits per hectare than *Mucuna*–maize double cropping.

Project 13

Improvement of yam-based systems

- Only yam mosaic virus (YMV), genus Potyvirus, and *Dioscorea alata* virus (DaV), genus Potyvirus, were found to infect *D. rotundata* and *D. alata* in Ghana while many of the leaf samples with virus-like symptoms tested negative for the 7 viruses known to infect yams in West Africa.
- New sources of genetic resistance to YMV were identified. Five accessions of *D. rotundata*, 2 of *D. alata*, and one of *D. bulbifera* were demonstrated to have high levels of resistance to the virus.
- Application of recently developed screening techniques to 220 accessions of *D. rotundata* revealed variation in susceptibility to the yam nematode (*Scutellonema bradys*) and the root knot nematode (*Meloidogyne incognita*). Two accessions of *D. dumetorum* (from Ghana and Cameroon) proved highly resistant to *S. bradys*.
- A survey was carried out on the domestication of wild yams in 2 regions of Benin as part of an investigation of its potential role in farmer participatory selection. During interviews of 360 farmers in 36 villages, 93% of the farmers in Nago region and 70% in Fon knew of the practice, 36% and 22%, respectively, could describe the techniques used, and 14% in both regions are practicing it or had done so recently.
- The number of virus-tested yam clones certified for international distribution increased to 70 with the addition of 5 each of *D. rotundata* and *D. alata*. About 26 000 in vitro plantlets and 16 000 minitubers of such clones were produced out of which 5400 and 13 906, respectively, were distributed to NARS collaborators.

Project 14

Cassava productivity in lowland and midaltitude agroecologies of sub-Saharan Africa

- Genotypes with high levels of resistance to CGM, CMD, and cassava brown streak disease have been identified for the midaltitude, highland, and lowland ecologies of East and southern Africa.
- 408 genetically broad-based and certified virus-free cassava genotypes were made available for international distribution. A total of 17 085 in vitro plantlets were distributed to 11 NARS in SSA, including 10 000 and 4000 CMD-resistant genotypes provided to Tanzania to combat the CMD outbreak and to Chad national programs for drought mitigation, respectively. In addition, 451 092 seeds from 405 families of genetically broad-based and special trait populations segregating for desirable traits were distributed to 13 NARS in SSA.
- 581, 496, and 263 advanced cassava clones adapted to the midaltitude and highland agroecologies of East and southern Africa were introduced from IITA's Eastern and Southern Africa Regional Center (ESARC), Uganda, to Kenya, Tanzania, and Rwanda, respectively, under the open quarantine facility. 84 and 81 clones from these stocks were also introduced to the Democratic Republic of Congo and Burundi national programs from the national program of Rwanda.
- Over 500 landraces and 400 improved genotypes have been characterized into 6 distinct diversity groups, which will form the basis of future heterotic studies. Furthermore, the landraces had higher sources of resistance to root rots than improved genotypes.
- 400 clones evaluated in performance trials at ESARC gave storage root yields ranging from 8.3 to 114 t/ha with most clones having dry matter content between 35 and 40%, while 30% of the clones outyielded the local check and 4 clones yielded over 100 t/ha. In addition, 10 of the clones evaluated in western Kenya showed a yield potential of over 150 t/ha, suggesting that the cassava yield plateau has been shattered.
- Genotypes with higher root nitrogen (1.1–10.1 g/kg DM), low cyanogenic potential (1.12–12.93 mg HCN/100 mg of fresh weight of roots), and high zinc (1.40–36.10 ppm) and iron content (1.3–64.80 ppm) have been identified. This indicates the potential for genetically fortifying cassava with iron and zinc while enhancing higher root N and low cyanogenic potential.
- Uganda and Malawi officially released 6 and 3 additional CMD-resistant varieties, respectively, from IITA-derived germplasm.
- The capability of NARS and NGOs to undertake cassava research was enhanced through a training workshop for 14 breeders from 9 African countries, and courses on agronomy and rapid multiplication techniques for 110 technicians and extension workers in East and southern Africa.

Project 15

Molecular and cellular biotechnology for crop improvement

- Progress has been made in the optimization of parameters for cowpea transformation through: (a) transient GUS gene expression following *Agrobacterium*-mediated transformation, (b) establishment of antibiotic thresholds for selection of transformed cowpea tissues, and (c) development of shoot elongation and rooting media. Having well-rooted cowpea plantlets in tissue culture helps to avoid loss of these plantlets when they are transferred to soil for hardening.
- T1 plants transformed with viral coat protein and insect resistance genes have been generated and preliminary screening of 30 T1 plants by polymerase chain reaction amplification of the viral coat protein sequence has revealed 6 positive lines.
- A genetic linkage map of yam (*D. rotundata*) based on AFLP markers was developed with 107 markers in 12 linkage groups (total length 585 cM) for the male parent and 116 markers in 13 linkage groups (total of 700 cM) for the female parent.
- A genetic linkage map of yam (*D. alata*) based on AFLP markers was developed. The map consisted of 338 markers mapped on 20 linkage groups with a total length of 1055 cM.
- AFLP and RAPD markers associated with QTL for yam mosaic virus (YMV), genus Potyvirus, were identified.

- Polyclonal antisera were raised against 3 *Dioscorea* viruses, 3 viruses infecting herbaceous legumes, one cassava virus, and one banana virus.
- An improved protocol for cassava cryopreservation was developed with 60% recovery. Cryopreservation of yam meristems gave a maximum of 35% recovery.
- A culture medium that can support growth and plantlet formation of 2 week old immature seeds of *D. alata* was developed and used to rescue one *D. alata* cross.
- Cyclic somatic embryogenesis was achieved from meristems and immature leaf lobes of both local and improved cassava genotypes. Organogenesis (shoot formation) was obtained from cotyledon pieces of those somatic embryos.
- A Memorandum of Affiliation was signed between IITA and the Center for the Application of Molecular Biology to International Agriculture (CAMBIA).

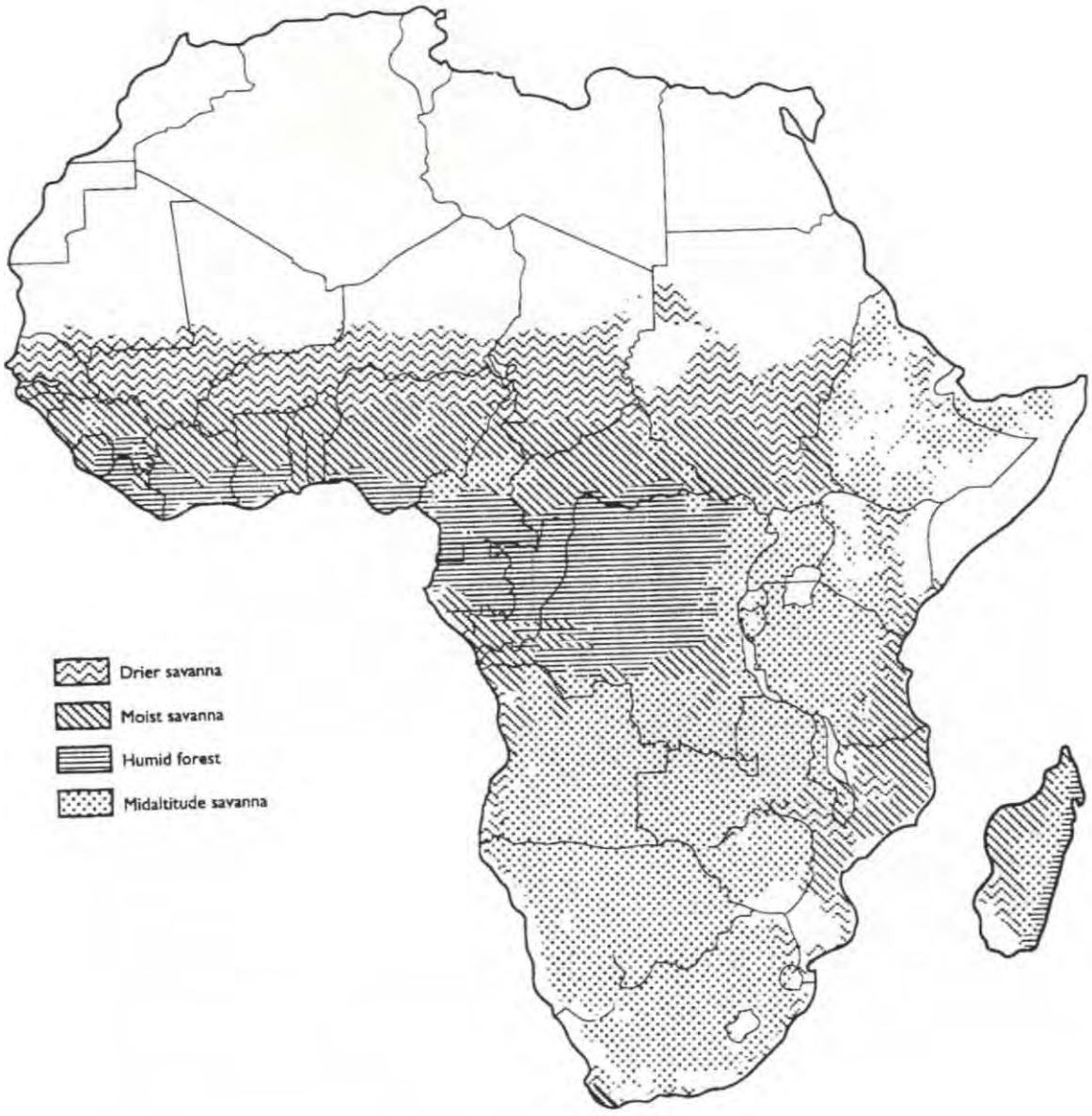
Project 16
Conservation and utilization of plant biodiversity

- Investigation on storage of yam pollen under liquid nitrogen for long-term conservation and for use in hybridization programs showed great promise.
- Through meristem culture, over 200 accessions of germplasm of 5 cultivated yam species and 6 wild species were successfully transferred from fields to in vitro culture. The National Root and Tuber Improvement Program in Ghana was assisted in the cleaning-up of viruses from 7 varieties of sweetpotato for large-scale multiplication and distribution to farmers for cultivation.
- The efficiency of conventional serological diagnostics has been increased by developing protocols that reduce the duration of enzyme-linked immunosorbent assays from about 2 days to just over 1 hour.
- Selective media have been standardized to enhance quick identification of highly destructive bacteria (*Xanthomonas manihotis*, *X. cassavae*, and *Pseudomonas*) in cassava.
- Agronomic and botanical descriptors and RAPD markers were used to assess the potential breeding values and genetic diversity, and to help identify probable duplicates of local cassava germplasm collected from West Africa. Fortyeight accessions identified as having high levels of resistance to African cassava mosaic disease exhibited considerable variation in agronomic performance, morphological characteristics, and DNA banding patterns.
- Ploidy levels and genome composition of elite *Musa* germplasm were determined, and genetic bridges for crossing between plantain cultivars (triploids), that cannot be directly intercrossed, were developed. This has enhanced the breeding method for plantain improvement.
- A computerized database for IITA maize international trials developed over the past 10 years was established. Efforts are being made to link this with a GIS, for use in targeting introduction and development of germplasm for specific environments, to enhance the impact at farm level.

Systemwide program
Integrated pest management

- NGOs are playing an increasingly important role in encouraging farmers to adopt IPM approaches to crop protection problems. With the support of the CGIAR NGO Committee and the SP-IPM, IITA-Benin hosted a workshop for NGO participants from 14 African countries, providing them with insights into the latest IPM technologies and extension approaches. Participating researchers from 4 international research organizations, in turn, gained a better understanding of NGO perspectives on the research-to-implementation process. An e-mail discussion group was formed to enable participants to continue to work together on various IPM research and extension issues.
- Continuing in its efforts to achieve better coordination and broader awareness of the IPM research of the IARCs, the SP-IPM worked with the Impact Assessment Group of the CGIAR to collect information documenting the role of IPM research in sustainable agricultural development. The work of IITA on cassava pests was among the efforts highlighted in a report tabled at International Centers Week and soon to be available for wider distribution.

Annex 5



Map of agroecological zones