The impact of IITA-led biological control of major pests in sub-Saharan African agriculture

A synthesis of milestones and empirical results

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Abstract

Since the 1970s, the International Institute of Tropical Agriculture (IITA), in collaboration with national programs in sub-Saharan Africa (SSA) and other international organizations, has been working on the biological control of several exotic pests, which have threatened the production of major commodities and the livelihoods of millions of people. This document reviews and presents a synthesis of milestones and impact results of the IITA-led biological control of major pests in SSA agriculture. IITA has been able to control devastating pests, which have inflicted damage on the major staple food crops of the poor, and has used innovative approaches to scaling-up biological control technology in SSA. It has enabled many SSA countries to establish strong national biological control programs.

The few economic impact studies have revealed high benefits of biological control, indicating the considerable success of the programs. The estimated benefit-cost ratios for biological control are 200:1 to 740:1 for the cassava mealybug, 145:1 for mango mealybug, and 124:1 for water hyacinth. Net present values (or benefits) of US$1.7 billion for Nigeria, US$383 million for Ghana, and US$74 million for Bénin were computed for the biological control of the cassava green mite. These studies captured only the conventional financial benefits of classical biological pest control, the ovreall impact is expected to be even higher, including the benefits to ecological and human health. The results thus show that classical biological control is a cost-effective and sustainable option to lower economic and environmental losses due to pests. Countries in SSA should thus value and further strengthen their knowledge and capacity for biological control. The above benefits were achieved using innovative approaches to scaling-up environmentally-friendly technologies through a wide partnership of institutions across continents and by building up the capacity of national programs.

Key words: Africa; Biological control; Cassava green mite; Cassava mealy bug; Impact; Mango mealybug; Water hyacinth.

Introduction

Falling per capita food production and worsening poverty in sub-Saharan Africa (SSA) have increasingly received the attention of national policymakers, international donors, and researchers. Crop losses caused by some important pests have contributed to this declining trend in food production in SSA. Several introduced pests have caused considerable damage to staple food crops and have undermined the potential of agriculture in SSA to meet the growing demand for food (Neuenschwander 2004). Pesticides have rarely been appropriate, feasible, and available to poor farmers in SSA. In most conditions on smallholder farms, insecticides may not be a good option against well-established pests because of their relative inefficiency, side effects, and the difficulty in the proper timing of applications. In reality, insecticides are rarely used because the chemicals and the equipment to spray insect pests are often not available or are too expensive for the smallholder to use, especially on crops such as cassava that are of low cash value (Neuenschwander 1993, 2004). Moreover, in view of the biodiversity losses and health side effects associated with pesticide use, this option has not gained popularity and concerns have been raised among those using it. While the development of resistant crop varieties could always be an alternative solution, this process is usually very slow and cannot deal adequately with newly introduced devastating pests, which would quickly begin to threaten the livelihoods of millions of poor farmers. In such situations, classical biological control, involving the use of natural enemies, has been considered the best solution (Herren et al. 1987).

The cassava mealybug was accidentally introduced to Africa in the early 1970s on infested planting materials from South America. Within ten years, it threatened to wipe out the continent's crop of cassava, the staple food for more than 200 million people in SSA (Herren et al. 1987; Herren and Neuenschwander 1991). The International Institute of Tropical Agriculture (IITA) launched a biological control project to help tackle the problem. IITA's successful experience with the biological control of the cassava mealy bug was later employed to address various other pest problems in SSA.

A biological control program brings about substantial economic benefits to the smallholder farmers in SSA. Excluding ecological and health benefits, biological control projects return benefits to African farmers that amount to a multiple of the research and dissemination costs paid for by development agencies (Neuenschwander 1996, 2004). Ecologists and environmental economists have also stressed the value of nature's services to agricultural production and the importance of maintaining a viable environment. Many crop species have been transplanted to new environments without their indigenous pests and predators and have shown increased productivity. Strong arguments have also been made in support of the quarantine laws and inspection systems that are necessary to maintain the separation. It is unrealistic, however, to expect that separation can be maintained forever. There is therefore a value to knowledge of biological control and the capacity to implement it (Norgaard 1988).

This document presents a synthesis of milestones and empirical results of the impact on agriculture of the IITA-led biological control of major pests in SSA. Specifically, the document brings together IITA's approaches to networking, experiences in scaling up innovations, and empirical evidence of economic impact of classical biological control. The document is divided into six sections. After the introduction, four sections are on the biological control of cassava mealybug, cassava green mite, mango mealybug, and water hyacinth. The last section contains the conclusions.

Biological control of the cassava mealybug

The challenge

Cassava was brought to Africa in the sixteenth century from South America. Since then, it has become an important staple food crop for millions of people in SSA. The cassava mealybug, *Phenacoccus manihoti*, was inadvertently introduced from South America in the early 1970s on infected planting materials. Over the years, *P. manihoti* spread throughout the cassava belt of Africa, with the exception of Madagascar, and caused considerable reductions in cassava yields. The cassava mealybug is a minor problem in South America where it is kept in check as the parasite and its predators have coevolved. However, the cassava mealybug was introduced to

Africa without its natural enemies. Food supplies throughout SSA, where hunger and malnutrition are already commonplace, were soon affected (Norgaard 1988; Herren and Neuenschwander 1991; Zeddies et al. 2000).

The cassava mealybug gained the status of being the worst agricultural insect pest in the tropics (Herren 1981). The damage the mealybug caused in Africa could be as high as 80% of all losses in cassava root yield (Nwanze 1982). Estimates of the portion of potential yield loss to cassava mealybug differed among countries and years. In Ghana, for example, yield losses due to both cassava mealybug and cassava green mite were estimated at 70%, which is 0.8 million t of tubers (Korang-Amoakoh et al. 1987). The economic cost of such crop losses to Ghana, valued in maize equivalents, ranged from US$58 to US$106 million. The price of *gari* (processed product made from cassava) in Ghana rose nine times after the 1983 outbreaks, equivalent to a rise of 2.3 times in real terms. Moreover, the price of planting material rose 21 times, or 5.5 times in real terms (Walker et al. (no date), cited in Norgaard 1988).

Addressing the challenge

The potential of the cassava mealybug to cause famine in Africa attracted the attention of governments, donors and research community, opening up new opportunities for biological control. Research to develop resistant cassava plants was undertaken at the same time but, as expected, progress was slow. In a two-pronged approach, scientists therefore looked at the possibility of using biological control, a method of pest management that exploits the control provided by the pest's own natural enemies. A classical biological control solution, in particular, the reuniting of predators with their previously dislocated prey, was deemed the best because very little or no chemicals are used by subsistence farmers in SSA.

The growing concerns expressed by farmers, scientists, and politicians over the devastating crop losses caused by the cassava mealybug called for an international meeting that was held in 1973 in the Democratic Republic of Congo (the then Republic of Zaire). One of the recommendations was that biological control and resistance breeding should be undertaken by IITA in collaboration with other institutions to come up with sustainable solutions to the problem. In 1980, the Africa-wide Biological Control Program of cassava pests (ABCP) was established following requests for assistance from an increasing number of African countries. The objectives were to (a) achieve permanent, ecologically safe, and economically sustainable control of the cassava mealybug and the cassava green mite throughout the African cassava belt, (b) provide specialized training in biological control techniques, and (c) initiate national biological control programs (NBCPs). In the long term, the objective was to establish fully-fledged NBCPs by using ABCP as a model (Herren 1987).

As both the cassava and its mealybug had evolved together in South America, IITA scientists looked to that continent for a solution. Working with scientists from the Centro Internacional de Agricultura Tropical (CIAT) in Colombia and the Commonwealth Institute of Biological Control (CIBC) in Trinidad, IITA scientists found that the cassava mealybug was in fact relatively rare in South America. More detailed investigations revealed that this was largely due to a natural enemy, a parasitic wasp called *Anagyrus (Apoanagyrus, Epidinocarsis) lopezi*, which uses the mealybug as the site for laying its eggs, the developing larvae then kill the mealybug (Herren et al. 1987; Herren and Neuenschwander 1991; Neuenschwander 2001).

Further intensive research, including taxonomic and biological studies to ensure that the wasp would not itself become a problem in its new environment, paved the way for introducing it to Africa. The objective was to establish in Africa the natural balance that existed in South America. The vast biological control project, involving foreign exploration, quarantine, rearing, release, field and laboratory studies, monitoring, coordination, training, awareness building and impact studies was carried out by IITA in collaboration with many other institutions. As part of the ABCP, IITA developed a comprehensive research program and coordinated the collaboration with scientists in Africa, Europe, and South and North America (Herren 1987; Herren and Neuenschwander 1991). The control strategy included (a) a systematic exploration of the likely areas of origin of pests that was conducted from southern California to Paraguay; (b) the rearing of the most promising natural enemies with detailed taxonomic, biological, and ecological studies; (c) the releases of the enemies in Africa over the infested zones; and (d) an analysis of the cropping systems and economic impact of the pests and their indigenous and introduced natural enemies.

International collaboration and capacity building for biological control in Africa

In an undertaking of the size of the biological control of the cassava mealybug as well as cassava green mite, no single institution has the capacity to handle alone all aspects of the required research, training, and implementation. IITA, therefore, took the lead in organizing a network of collaborators in Africa, Europe, North, Central and South America as part of the implementation of ABCP (Herren 1987; Wodageneh and Herren 1987). Collaboration was with universities (23), research institutions, and national biological control programs (24) (Herren and Neuenschwander 1991). In addition, as a member of the Consultative Group on International Agricultural Research (CGIAR), IITA is itself part of a worldwide network of several research institutes, from which it draws logistical and scientific support. Figure 1 illustrates IITA's approach to networking, the scaling-up of biological control technologies, and building the biological control capability of national programs in SSA.

The Inter-African Phytosanitary Council (IAPSC) of the African Union (then Organization for African Unity) was providing regulatory and regional liaison services from the start of the cassava mealybug project, and IITA coordinated collaboration with CIAT in Colombia, CIBC in London, the Nigerian quarantine service, and IAPSC, whose head had to approve the quarantine facilities in London. A coordinated information campaign by IAPSC was considered important because both the cassava mealybug and later its natural enemies spread across political boundaries, which in Africa, as elsewhere in the world, are mostly artificial. Over several years, agreement from quarantine facilities all over Africa was obtained for the import beneficial insects into their respective countries (Neuenschwander 1993). The next step was to intensify foreign exploration. At the same time, rearing facilities were established in Nigeria, first near Abeokuta and later at IITA Ibadan, both located in southwestern Nigeria, and since 1988, at IITA Cotonou in Bénin. This sets the basis for test releases, which were done only after a request had been received from the affected countries and always in close collaboration with the national authorities.

Initial test releases in several countries called for research and this required strong coordination among the entomologists of different national organizations. For this purpose, the training project, which was started by the ABCP and later expanded and supported by the Food and

Agriculture Organization (FAO) with the financial support of the United Nations Development Program (UNDP), stimulated the creation of NBCPs (Wodageneh and Herren 1987). In Nigeria, for instance, IITA entomologists were members of the National Biological Control Committee, which included quarantine services, the National Root Crops Research Institute (NRCRI), various ministries, and other agencies (Neuenschwander 1993).

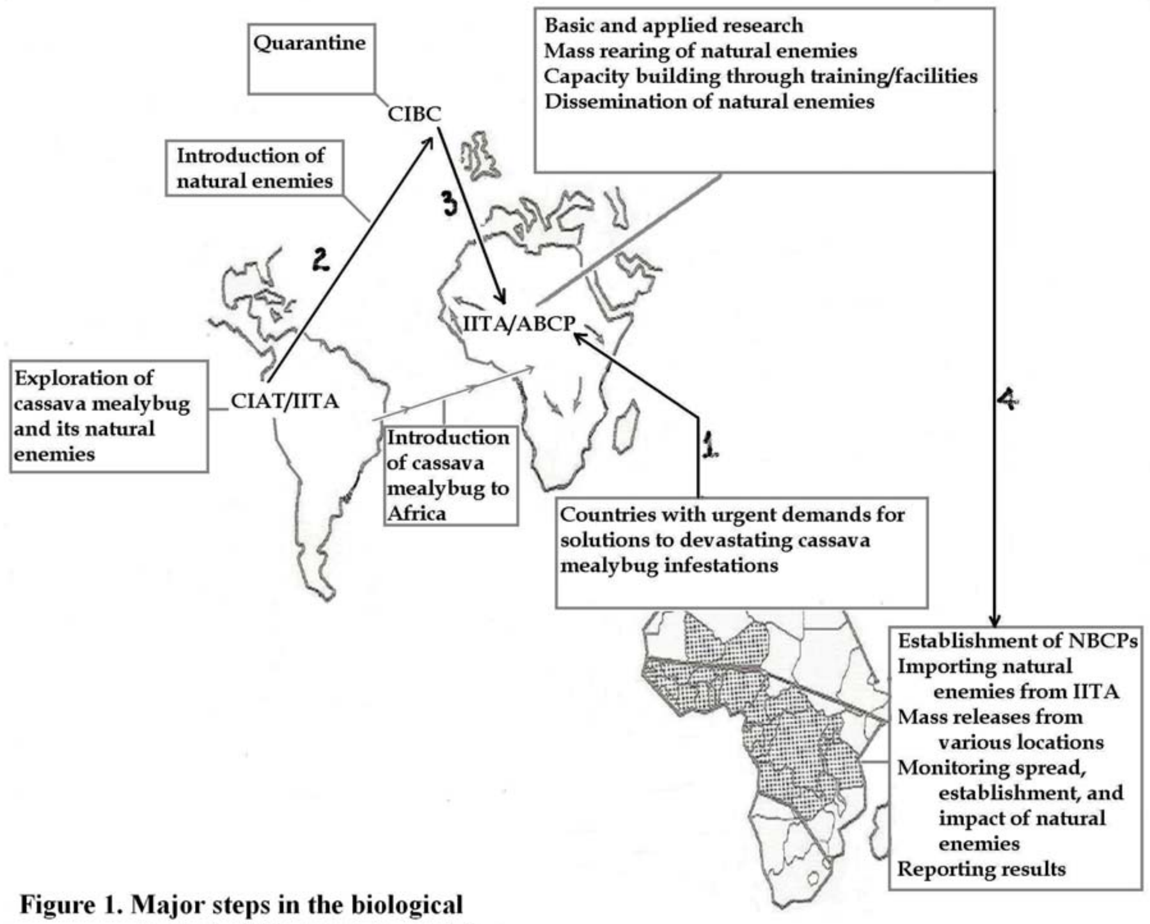

Figure 1. Major steps in the biological control of the cassava mealybug.

Source: Adapted from Megevand et al. (1987).

Source: Adapted from Megevand et al. (1987)

Figure 2. Major steps in the biological control of cassava mealybug.

Given that one of the objectives of the ABCP was to develop the biological control capability in Africa through the establishment of strong NBCPs, several short- and long-term training programs were organized for crop protection practitioners from various countries. The establishment of NBCPs was accomplished in two phases: the initial phase of two years during which specialists would be trained on a short-term basis to enable them to carry out releases of natural enemies of cassava pests as well as pre and postrelease surveys, and the establishment of full-fledged NBCPs run by personnel trained at MSc and PhD levels (Wodageneh and Herren 1987).

Since national agricultural research systems (NARS) are viable only if their scientists are dedicated and well trained, a number of training courses were conducted with the financial support of FAO and UNDP, including training courses at IITA 2–3 times in a year, in-country training courses, and degree-related training at African universities (Wodageneh and Herren, 1987; Herren and Neuenschwander 1991). IITA's research (basic and technology development) was thus linked with the training sponsored by FAO/UNDP and coordination of country programs supported by Gessellschaft für technische Zusammenarbeit (GTZ) financed by several donors (Neuenschwander 1993). Research based on a systems approach became interwoven with mass releases that were facilitated by technological innovations; both activities also served in training future biological control practitioners (Herren and Neuenschwander 1991). This has enabled IITA and other collaborating institutions to build the capacity of NBCPs and to raise the general level of awareness among African plant protection practitioners and policy-makers of the benefits of biological control.

The wasp was brought to Africa, large numbers were reared at IITA, and was released in some 30 countries and from various locations in each country covering the cassava belt of Africa. Most releases were made in the second half of the dry season by releasing the predators in fields with high cassava mealybug populations, and all were conducted in collaboration with national and international organizations and local entomologists (Herren et al. 1987). The collaborating national and international organizations that were actively involved in the various releases included the Office of Overseas Scientific and Technical Research for releases in the Republic of Congo, Projet de Recherche Agricole Appliquée for releases in the Democratic Republic of

Congo, NRCRI, and Anambra State University of Technology for releases in Nigeria, the Department of Agriculture of Ghana for releases in Ghana, the Ministry of Agriculture of Guinea-Bissau for releases in Guinea-Bissau, the Ministry of Agriculture and Water Development of Zambia for releases in Zambia, and CIBC and Institut de Sciences Agronomiques du Rwanda for releases in Rwanda. Releases in the rest of the countries, including the Gambia, Malawi, Senegal, Sierra Leone, and Togo were carried out by IITA in collaboration with the respective agricultural ministries and NARS. By the end of 1985, more than 50 releases of *A. lopezi* in a total of 34 regions were made in 12 countries. Following its establishment in 28 regions and spread in across at least four international borders, the parasitoid was recovered in 13 countries (Herren et al. 1987). By 1990, following releases at about 120 sites, *A. lopezi* was established in 25 African countries. Reduction in mealybug damage was seen in the first season following release and full control was typically achieved within 2-4 years (Herren and Neuenschwander 1991; Neuenschwander 2001).

Establishing collaboration among technical agencies (IITA, CIAT, CIBC, NARS), and regulatory agencies (IAPSC, national quarantine services) has thus been considered the key to the success of the classical biological control program. All releases were done in collaboration with the national institutions and were often accompanied by interviews and reports in local newspapers, and supported with pamphlets produced by IITA. Thus, the idea of classical biological control was spread also to farmers and consumers and awareness of its value was created in Africa. IITA's Biological Control Program moved to Cotonou in the Republic of Bénin in 1988. In recognition of its achievement, IITA, together with CIAT, won the CGIAR's King Baudouin Award in 1990 (Neuenschwander 1993).

The effect of natural enemies on the cassava mealybug population

The effectiveness of *A. lopezi* in controlling the mealybug populations was evaluated using exclusion experiments, long-term population dynamics studies, laboratory and field experiments, and large-scale surveys (Neuenschwander 1996). Physical and chemical exclusion experiments demonstrated the effectiveness of *A. lopezi* in southwestern Nigeria. Under rainforest conditions in Ghana, when cassava mealybug was protected from *A. lopezi* either totally by sleeves or partially through interference with ants, their populations were much higher. More importantly, seven years of continuous monitoring in numerous fields in two areas of southwestern Nigeria revealed that mean cassava mealybug population peaks never reached the height (means of up to 90 cassava mealybug/shoot tip) and the duration (7 months with over 10 cassava mealybug/shoot tip) observed during the first season of release. Similar results were obtained from experiments in Burundi, Malawi, Mozambique, and Zambia. A survey carried out in the Republic of Congo, Gabon, and the Democratic Republic of Congo, in which fields were chosen at regular intervals and shoot tips were collected at random, demonstrated the effectiveness of biological control (see various unpublished results, cited in Neuenschwander 1996). A survey covering the whole of Nigeria and Bénin revealed low cassava mealybug infestation levels of below 10 mealybugs/tip, with only 3.2% of all tips being stunted (Neuenschwander et al. 1990). Repeated surveys in Malawi (six years) and Zambia (four years) indicated similar or even better impact results. In Malawi, wherever *E. lopezi* had been present for two years or more, cassava mealybug populations were reduced on average by seven times and tips infested with more than 100 cassava mealybugs became rare (Neuenschwander et al. 1991). In Zambia, cassava mealybug populations declined on average 5.8 times between 1986 and 1990 (Chakupurakal et al. 1994). The mealybug population reduction remained stable, with small peaks at about 10% of outbreak levels. In a large-scale survey across different ecological zones in Ghana and Côte d'Ivoire, regression analysis showed that the loss due to cassava mealybug was reduced significantly (Neuenschwander et al. 1989). The presence of *A. lopezi* was thus translated into an increase in yield by 2.5 t/ha and this value was subsequently used by Norgaard (1988) to estimate the economic impact of this classical biological control.

Measuring the economic impact of biological control of the cassava mealybug

The approach

Norgaard (1988) analyzed the impact of the biological control of the cassava mealybug based on extrapolation of data from a few West African countries over the entire continent. A "reasonable, least-favorable" scenario was formulated to facilitate the benefit-cost analysis by actually imposing very stringent assumptions, including diminishing impacts of *A. lopezi* and greatly reduced levels of the cassava mealybug (without *A. lopezi)* over the years. First, the percentage yield loss from cassava mealybug if *A. lopezi* had not been introduced was assumed to build to a maximum of only 20% and to reduce linearly to 1% per year and to 0% at the end of the period of analysis. This was attributed to the likely development of resistant varieties, better cultural practices, and the evolution of indigenous parasites and predators. Second, the percentage yield loss saved because of the presence of *A. lopezi* was assumed to rise to a maximum of only 60% as the parasite becomes established and to decline to zero towards the end of the period. This was attributed to a lower likelihood of *A. lopezi* becoming established when the mealybug populations (i.e., host of *A. lopezi*) begin to decline.

Zeddies et al. (2000) later analyzed the benefits and costs of the biological control of the cassava mealybug over 40 years (1974–2013) for 27 African countries: Angola, Bénin, Burundi, Cameroon, Central African Republic, Congo, Côte d'Ivoire, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea Bissau, Guinea, Kenya, Liberia, Malawi, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Togo, Uganda, Democratic Republic of Congo, and Zambia. The information assembled for this purpose was the estimated number of hectares of cassava harvested/year, production/year, percentage distribution of cassava production by ecological zone, spread of *P. manihoti* through the years within the different ecological zones expressed as a percentage of the total area under cassava in the country, spread of *A. lopezi* within the different ecological zones expressed as proportion, damage coefficients from the pest alone (before the release of *A. lopezi*) and when pest and its exotic parasitoid occurred together.

The economic evaluation of the biological control project aimed at determining the benefit-cost ratio under four different scenarios (Zeddies et al. 2000). Scenario 1 relates to additional cassava production for the situation where action with *A. lopezi*'s results in a country-specific, additional quantity of cassava that could be harvested, as compared to the situation where *P. manihoti* had caused uncontrolled damage. Scenario 2 relates to additional cassava under import condition for the situation where the amount of cassava lost from unchecked damage by *P. manihoti* was to be imported. Biological control would then reduce this importation. Costs for transport to the interior of the country were added to the world market price of the first scenario. Scenario 3 relates to additional production of an alternative crop, i.e. maize, for the situation where locally grown maize compensated for losses from *P. manihoti. A. lopezi* reduced this need or allowed the additional maize to be sold. Scenario 4 relates to additional maize under import conditions for the situation where maize was imported to compensate for losses from *P. manihoti*, e.g., as food aid. The reduction of this loss by biological control was computed using the (world market) price of maize in the third scenario and by adding costs for transport to the interior of the country.

Results from the benefit-cost analysis

Norgaard (1988) estimated a benefit-cost ratio of 149:1 for the biological control of the cassava mealybug for the "reasonable, least-favorable" scenario. Despite the strong assumption imposed on the analysis, the study demonstrated the high profitability of the project. Furthermore, because Norgaard (1988) did not take into account the ecological and health benefits and the benefits to other cassava producing countries that could be threatened in future, the benefit-cost ratio of 149:1 is arguably a conservative estimate.

Zeddies et al. (2000), on the other hand, estimated the value of cassava from about 9 million ha of cassava harvested in SSA, with an average yield of 8 t/ha. This amounted to 72 million t/year of fresh cassava or 21.5 million t/year of dried marketable cassava. The total benefit of *A. lopezi* was directly related to the total cassava production in each country. The benefits were derived as crop loss reduction in ton multiplied by the world market price of US$90 per ton as well as the average African price of US$167/t dry weight. The costs of the biological control project included the total costs for IITA, the donor agencies, and African governments, and these totaled US$47 million.

Using the basic assumptions of the world market price of US$90/t, a discounting/compounding factor of 6%, a yield loss reduction of 90%, and a 40 years period of analysis, the benefit-cost ratios were 199:1 in Scenario 1; 430:1 in Scenario 2; 170:1 in Scenario 3; and 297:1 in Scenario 4 (Table 1). That is, benefit-cost ratios under the basic assumptions range from 170:1 to 430:1. Using the African price of US$ 167, the benefit-cost ratios range from 315:1 to 800:1, as expected. The robustness of the benefit-cost ratios was shown using sensitivity analyses carried out by relaxing one of the basic assumptions at a time as follows: (a) reducing the period of analysis to 27 years, the benefit-cost ratios range from 118:1 to 306:1; (b) increasing the discounting/compounding factor to 12%, the benefit-cost ratios range from 104:1 to 268:1; (c)

Assuming the yield loss reduction to be only 50%, the benefit-cost ratios range from 94:1 to 239:1 (Zeddies et al. 2000). In summary, the benefit-cost ratios of the biological control of cassava mealybug range from 94:1 (under very pessimistic assumptions) to 800:1 (under optimistic assumptions), showing the substantial net benefits of the biological control program.

Table 1. Benefits and costs of the biological control of cassava mealybug.

Variant	Standard assumptions (US$/t) [a]	
	90	167
Costs in million US$	47.0	47.0
Benefits in million US$ [b]		
Scenario 1	9372	17320
Scenario 2	20226	37620
Scenario 3	7971	14826
Scenario 4	13970	25984
Benefit-cost ratio [b]		
Scenario 1	199	371
Scenario 2	430	800
Scenario 3	170	315
Scenario 4	297	553

[a] Duration 40 years, discounting/compounding factor 6%, yield loss reduction depending on ecological zone (about 90%), for two different price levels. [b] Benefits and benefit-cost ratios for four scenarios: 1=cassava price at farm gate; 2=cassava price plus transport; 3=price of local maize as substitute; 4=maize price plus transport. Source: Zeddies et al. (2000).

Biological control of the cassava green mite

The challenge

In the same way and from the same continent as the cassava mealybug, the cassava green mite (CGM), *Mononychellus tanajoa*, was inadvertently introduced to Africa in the early 1970s. In major agroecological zones, this pest severely damaged cassava crops. Once the cassava mealybug was brought under control through the ABCP led by IITA, CGM became the most important pest of cassava and the next threat to food security in the cassava producing areas in SSA. From the early 1970s, CGM began spreading throughout the continent's cassava belt from East to West, reaching West Africa in 1979. It caused major yield losses and affected both the quality and the quantity of cassava planting materials. The area infested by CGM in West Africa has been estimated at about 1 817 000 km^2 across Bénin, Cameroon, Ghana, and Nigeria (Coulibaly et al. 2004).

Yield losses of between 10 and 80% have been reported from agronomic trials in Africa. In a coordinated regional trial to estimate yield loss from CGM using standardized methods, average losses of 10 to 30% were recorded 12 months after planting in seven eastern and southern African countries. Losses were greatest where the dry season was longest (Burundi, western Kenya, Malawi, and Uganda) and less severe where the dry season was shortest (Kenyan coast and Zanzibar). Heavily attacked leaves are stunted and become deformed as they mature (Markham et al. 1987). Tuber yields could be reduced by at least 30% under the best planting conditions (Mégevand et al. 1987).

Addressing the challenge

Initial efforts to control CGM relied mainly upon the use of chemical sprays and cultural practices, and to a lesser extent on host plant resistance. After a decade without effective control, however, other alternatives were explored. The experiences gained from the control of the cassava mealybug and the exotic nature of both the pest and cassava suggested that classical biological control should again be a solution. This involved the use of CGM's natural enemies from its region of origin. The CGM biological control project followed the same pattern of research as that for the cassava mealybug (Herren and Neuenschwander 1991).

A classical biological control of CGM was thus initiated in 1983 as part of the ABCP of IITA. IITA initiated and implemented this program against CGM in collaboration with partner institutions in Africa, South America, and Europe. Important parts of the work on CGM were done in collaboration or under contracts with other institutes or agencies. Figure 2 illustrates IITA's partnerships with many national and international institutions and its strategy of scaling-up the biological control of CGM based on its experiences with the cassava mealybug. These include foreign exploration and preliminary screening of exotic natural enemies at CIAT in Cali, Colombia; international quarantine services at the CIBC, London; simulation modeling of the cassava ecosystem including the CGM at the University of California, Berkeley (UCB);

taxonomy of phytoseiids at the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA), Brazil; taxonomy of tetranychids at the University of São Paulo, Brazil; artificial diets for transporting the natural enemies, survey of entomopathogens of CGM and biotaxonomy of CGM at the International Center of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya; and behavioral studies of exotic phytoseiids at the University of Leiden, The Netherlands.

In 1984, IITA and CIAT, with financial support from the International Fund for Agricultural Development (IFAD), successfully identified 10 promising species of predatory phytoseiids from South America as the primary agents for the introduction against CGM. In late 1993, a joint IITA/CIAT program financed by IFAD, UNDP, Brazil, Denmark, and Germany achieved biological control in many African countries using the predator mite *Typhlodromalus aripo*, with up to 50% reductions in pest populations and 30% increases in cassava yields in 11 African countries (IFAD 1998). Moreover, an IITA-NARES collaborative project, the Ecologically Sustainable Cassava Production Project[1] (ESCaPP), financed by UNDP, was initiated to co-ordinate efforts for the release, monitoring, and evaluation of the establishment and effectiveness of the predator *T. aripo* (Coulibaly et al. 2004).

This collaborative effort to control CGM has now spanned more than a decade, and the predator has become established in many SSA countries, including Bénin, Ghana, Nigeria, and Togo. In Nigeria alone, the area where the predator is found is estimated to exceed 200 000 km^2. The beneficial impacts of the biological control agents include substantial increases in crop yields, large reductions in mite populations, and unquantified, but probably large, environmental benefits due to the non-use of persistent chemical insecticides (Coulibaly et al. 2004). Yield assessment trial results showed that biological control by *T. aripo* increased yields by 30% in infested fields whilst reducing the CGM population between 30% and 90% (with an average of 50%) (Yaninek et al. 1992).

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[1] The goal of ESCaPP is to develop, test, and implement ecologically sound cassava plant protection technologies by helping scientists at the centers and in national institutions in four West African countries, Bénin, Cameroon, Ghana, and Nigeria, to work directly with farmers and extension agents (CGIAR 1997).

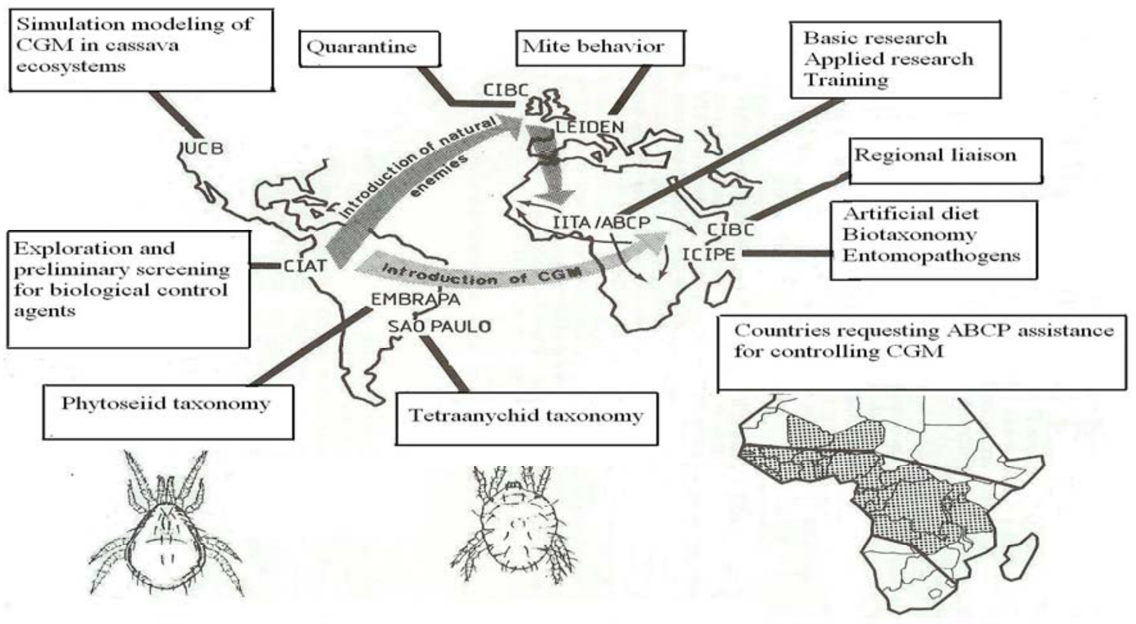

Figure 2. Partnerships and scaling-up biological control of CGM in Africa.

Source: Megevand et al. (1987).

Source: Megevand et al. (1987)

Figure 2. Partnerships and scaling-up biological control of CGM in Africa.

Measuring the economic impact of biological control of the cassava green mite

The Approach

Economic surplus models are commonly used to assess the impact and distributional effects of a technology or research activity (Alston et al. 1995). Assuming market equilibrium, the impact of the biological control of CGM can be assessed through yield increases. The net gain is the difference between the increased production value and the costs of research and extension of biological control. Coulibaly et al. (2004) used the economic surplus model to estimate the net benefits of the biological control of CGM to Bénin, Ghana, and Nigeria in terms of net present values (NPV) and the distribution of such gains between producers and consumers. The NPVs were computed as the difference between the simulated gross real discounted benefits and the real discounted costs of research and extension over the period from 1983 (beginning of research on biological control of CGM) to 2020. Moreover, the internal rates of return (IRR) were estimated.

Results from the economic analysis

Using a discount rate of 10%, the NPVs of the investments over the period from 1983 to 2020 were about US$74 million for Bénin, US$383 million for Ghana, and US$1.7 billion for Nigeria. A more pessimistic scenario with 15% discount rates yielded NPVs that would have dropped only to US$28 million for Bénin, US$153 million for Ghana, and US$647 million for Nigeria (Table 2). The IRR estimates are 101% for Bénin, 111% for Ghana, and 125% for Nigeria. Apart from the test for high discount rates, Coulibaly et al. (2004) also analyzed the sensitivity of the net benefits to lower yields. The reduction in yields by 30 to 25% would still correspond to the very high IRR of 84% for Bénin, 104% for Ghana, and 93% for Nigeria. These results clearly demonstrated the high profitability of the classical biological control of CGM. Therefore, these investments have been rewarding in all the three countries studied. There are also clear ecological benefits that have not been incorporated into the analysis. Also, as classical biological control of CGM has now been applied in a total of 35 African countries (Coulibaly et al. 2004), considerable benefits remain to be derived from the project.

Table 2. Economic returns to the biological control of cassava green mite in Bénin, Nigeria, and Ghana (1983–2020).

	NPV (US$ million)			
Country	10% discount rate	13% discount rate	15% discount rate	IRR (%)
Bénin	74.25	40.53	27.89	101
Ghana	383	217.03	152.55	111
Nigeria	1688	936.49	646.77	125

Source: Coulibaly et al. (2004).

Biological control of the mango mealybug

The challenge

Mango (*Mangifera indica* L., Anacardiaceae), an ancient fruit of Indian origin, constitutes an important source of energy and nutrients for millions of people in the tropics. In Africa, mango used to be relatively free from damage by insect pests and diseases (Bokonon-Ganta et al. 2002). In 1986, however, the mango mealybug, *Rastrococcus invadens* Williams (Homoptera:

Pseudococcidae) of Southeast Asian origin, which was accidentally introduced to West Africa, probably on infested plant material (Williams 1986), was reported to cause serious damage to various fruit trees, especially mango, in Bénin, Ghana, and Togo (Agounké et al. 1988). It has since invaded Cameroon, the Republic of Congo, Côte d'Ivoire, Democratic Republic of Congo, Gabon, Nigeria, and Sierra Leone. Owing to the heavy accumulation of honeydew and the resulting sooty mold, *R. invadens* severely inhibited the growth, flowering, and fruiting of the mango trees (Neuenschwander et al. 1994). As with the cassava mealybug, the pest status of the mango mealybug was so obvious that no quantitative crop loss assessment was done before the first releases of the biological control agents (Neuenschwander 1993).

Addressing the challenge

In 1986, a biological control project was initiated, involving the plant protection services of Togo and Bénin and CIBC, sponsored by GTZ and FAO (Agricola et al. 1989). In 1987, a regional project on the biological control of the mango mealybug was launched at a conference in Lomé, Togo, with the agreement of IAPSC. The conference recommended close collaboration between CIBC and IITA in training, introduction of natural enemies, and research. By then, a special project on the biological control of the mango mealybug, separately funded by the Swiss government, had already been added to IITA's Biological Control Program (formerly ABCP). The aim was to introduce exotic parasitoids to supplement indigenous predators that were not capable of controlling *R. invadens* (Agounké et al. 1988). A parasitic wasp, *Gyranusoidea tebygi* Noyes (Hymenoptera: Encyrtidae), was imported from India and studied in quarantine. The wasp was reared, released, and established in different places in Africa. In Bénin, ten batches of *G. tebygi* were released at different times from 1988 to 1993 (Neuenschwander et al. 1994).

The impact of *G. tebygi* on populations of *R. invadens* was demonstrated by exclusion experiments and population dynamic studies (Boavida and Neuenschwander 1995; Boavida et al. 1995). Later, the impact was demonstrated on a large scale in Bénin by multiple regression analysis of survey data. The percentage of infested trees declined from 31% in 1989 to 17.5% in 1991, and average mealybug densities declined steadily from 9.7 females/48 leaves in 1989 to 6.4 females/48 leaves in 1991 (Bokonon-Ganta and Neuenschwander 1995). However, reports of persistent "hot spots" of infestation despite the presence of *G. tebygi* (Bokonon-Ganta and

Neuenschwander 1995) led to the importation, rearing, and release of a second parasitoid wasp, *Anagyrus mangicola* Noyes (Hymenoptera: Encyrtidae). In Bénin, fifteen batches of *A. mangicola* were released at different times from 1991 to 1993 (Neuenschwander et al. 1994). The successful establishment of this second wasp brought a further local reduction of pest populations. For example, mango mealybug populations eventually collapsed and disappeared from two orchards studied in Bénin (Boavida and Neuenschwander 1995). The parasitoids are also well established in Nigeria and the mango mealybug populations have been greatly reduced (Pitan et al. 2000).

Measuring the economic impact of biological control of the mango mealybug

The Approach

The economic impact of biological control of the mango mealybug in Bénin was evaluated using survey data. In view of the lack of official statistics about mango production in Bénin and the widely observed unnecessary tree felling following the attack by the mango mealybug, the study documented the impact of the pest and its biological control based on information on mango yields and prices, before and after the establishment of natural enemies. A random sample of 300[2] mango producers, selected from six infested provinces, were interviewed in three rounds between 1989 and 1991 using semistructured questionnaires. Data were obtained on the host plant, the pest and its social effects, the control efforts, and the damage on fruit production. A final survey was conducted in 1999 to assess the impact of the biological control agents on fruit production. The survey elicited the perceptions of producers about the evolution of mango production from the beginning of the invasion until 10 years later (Bokonon-Ganta et al. 2002).

The impact of the mango mealybug and its biological control was estimated by comparing the average production during the years of peak infestation with the average production during the last few years, after the successful establishment of the control program. This is referred to as the situation *before* (i.e., the peak of the infestation) and *after* biological control. Yields showed severe depressions from 1986 to 1990, the peak of the mealybug infestation, and stayed fairly

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[2] Because of unreliable responses obtained from some respondents, only a subsample of 142 mango producers were retained for the analysis (Bokonon-Ganta et al. 2002). However, the issue of the possible influence of sample selection bias on the results of the analysis needs to be acknowledged as a limitation.

stable from 1993 to 1996, after the biological control. The average yield during the infestation period (i.e., 1986–1990) was 25.55 kg/tree for local varieties and about 4 kg/tree for grafted varieties, whereas the average yield after recovery (i.e., 1993–1996) was 41.16 kg/tree for local varieties and 34.21 kg/tree for grafted varieties. The average benefits were extrapolated to the whole country. The total yearly gain in a particular province was derived as the product of the number of households in the province, the proportion of rural households, the proportion of the province affected, the proportion of farmers producing mangoes in the affected area (i.e., two-thirds, by assumption), and the average benefit/farmer (Table 3). The aggregate benefits accruing to the six provinces represented the total yearly gain for the country, which was also considered as the loss due to mango mealybug at the peak of its infestation (Bokonon-Ganta et al. 2002).

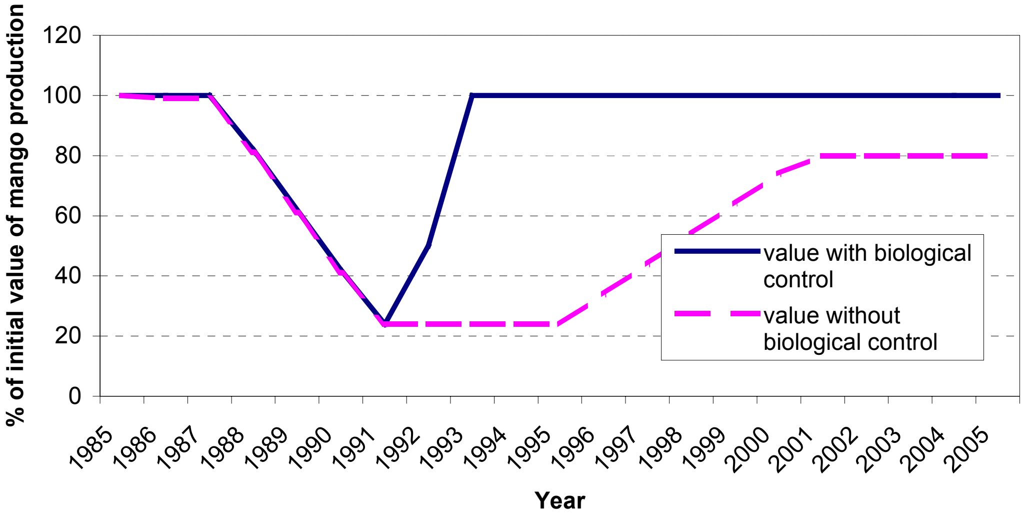
Table 3. Extrapolation of the benefits of biological control of mango mealybug to Bénin, 1986–1999.

		Proportion			Benefits	
Province	Number of households	Farming	Area affected	Mango producers	Average gain (US$/farmer)	Total (US$1000)
Atacora	92513	0.80	0.10	0.66	138	674
Atlantique	205405	0.30	0.80	0.66	484	15747
Borgue	108318	0.80	0.05	0.66	1447	4138
Mono	131492	0.60	0.80	0.66	207	8623
Quémé	169427	0.60	0.80	0.66	226	12130
Zou	150018	0.70	0.50	0.66	242	8386
Total	857170				328	49699

Source: Bokonon-Ganta et al. (2002).

To calculate the total present value of all accrued benefits, the current situation was compared with what would have happened without biological control. The assumptions made for this hypothetical situation are illustrated in Figure 3. The top line represents the evolution experienced by farmers. It was assumed that losses started in 1988 and reached their peak in 1991. Owing to biological control, recovery was swift, and by 1993, production was back to its potential. This evolution was then compared with the situation without biological control. Alternative control methods such as chemical control were not effective and it was thus likely that farmers would have cut the infested trees and planted other crops. Since most fruit trees take

5-10 years to mature, alternative income would start accruing only in 1996, reaching a maximum in 2001. Given the popularity of mangoes, it was assumed that no tree or crop can fully match them and the value of replacement would not reach more than 80% of the value of mangoes, and would take five years to reach that maximum. The benefits accruing each year were derived by comparing the evolution experienced by farmers with the situation without biological control. These benefits would reach a maximum and remain stable between 1993 and 1995, steadily decline over the next five years, and remain constant after 2001 (Bokonon-Ganta et al. 2002). The benefit-cost ratio was then derived based on the present values of benefits and costs (Bokonon-Ganta et al. 2002).



Source: Bokonon-Ganta et al. (2002).

Figure 3. Assumed evolution of mango production with and without biological control.

Results from the benefit-cost analysis

Based on the information about mango production and prices before and after biological control, the average economic gains by mango farmers by province were derived and these average benefits were extrapolated to the whole of Bénin (Table 3). On average, each mango farmer in the sample gained US$328/year through the biological control program. Extrapolation of the average benefits gave a total gain of US$50 million/year. As described in the preceding section, the total yearly gain was US$50 million between 1993 and 1995. From 1996, it was US$10 million less every year for five years, and this remained at US$10 million after 2001.

The discounted/compounded value of these benefits over 20 years added up to a present value (1999) of US$531 million. Similarly, the discounted/compounded value of the costs of the biological control, taking into account the initial activities in Togo, amounted to a present value (1999) of US$3.66 million. The benefit-cost ratio was then estimated at 145:1, which demonstrated the success of the project. The two parasitoids were later disseminated in all of West Africa and some countries in Central Africa at little additional costs (Neuenschwander et al. 1994). Therefore, the benefit-cost ratio for the biological control of the mango mealybug for the entire region is likely to be substantially higher (Bokonon-Ganta et al. 2002).

Biological control of water hyacinth

The challenge

Because of its attractive purple flower, water hyacinth, *Eichhornia crassipes* (Martius), which is of South American origin, gained attention as an ornamental plant and was first distributed by gardeners and horticulturists. Due to its extremely fast growth, however, it soon became the major floating waterweed of tropical and subtropical regions worldwide. Its dense floating mats hinder transport and fishing; it interferes with the use of water for drinking purposes, electric power generation, and irrigation; and it affects biodiversity. In West Africa, water hyacinth was first observed in the late 1970s and became a major pest in the late 1980s. It became a major threat to the highly productive coastal creek and lagoon systems, from which many people derive their living, in particular in Bénin, Côte d'Ivoire, Ghana, Nigeria, and Togo (De Groote et al. 2003).

Addressing the challenge

Several chemical and mechanical control methods were developed to overcome the water hyacinth problem. Chemical control methods, such as insecticide sprays had a negative impact on the environment. Mechanical control, either by hand or machine, has been widely practiced in many countries such as Kenya, South Africa, and Thailand although it is generally considered too expensive (Cilliers 1991). Because of the growing threat of water hyacinth in East and West Africa, two international conferences were organized, the first in Lagos, Nigeria, in August 1988 and the second in Harare, Zimbabwe, in June 1991. The participants at both conferences recommended biological control as the only cost-effective and environmentally friendly control method. As an alien invasive plant, water hyacinth is a prime target for classical biological control, in which natural enemies from their original ecosystems are screened, reared, and released into the invaded areas. Two weevils, *Neochetina eichhorniae* Warner and *Neochetina bruchi* Hustache (Coleoptera: Curculionidae) have been released in Sudan (Irving and Bashir 1982), Bénin (van Thielen et al. 1994), Burkina Faso, Côte d'Ivoire, Ghana, Nigeria, the countries around Lake Victoria, and in Southern Africa. Through biological control, a substantial reduction of water hyacinth has been achieved in these countries (Cilliers et al. 2003).

Biological control of water hyacinth in Southern Bénin used a combination of three host-specific natural enemies. The weevil *N. eichhorniae* was released in December 1991 followed by *N. bruchi* in March 1993, and the moth *Sameodes albiguttalis* (Lepidoptera: Pyralidae) in December 1993 (van Thielen et al. 1994). All agents were imported by IITA from Australia, mass reared at IITA's station in Cotonou, and released together with the Bénin Direction des Pêches (Ministry of Rural Development). The weevils were established and spread from the release sites, and were found in all suitable habitats. After many years of uncertain impact, biological control, particularly by *N. eichhorniae*, has finally shown an impact and water hyacinth cover has been reduced (Ajuonu et al. 2003).

Measuring the economic impact of the biological control of water hyacinth

The Approach

De Groote et al. (2003) analyzed the economic impact of water hyacinth and its biological control using survey data in Bénin Republic. Following the observation that water hyacinth populations were reduced and formerly abandoned fishing grounds had been reclaimed, it was necessary to assess the views and attitudes of the people living in the affected areas. An exploratory survey was conducted in nine villages in the flood plain between the Sô and Ouémé rivers between March and April 1999. Based on the results of the survey and discussions with officials from Direction des Pêches, the study area was defined as all villages in the flood plain area between these two rivers in three administrative regions of the country: Atlantique, Zou, and

Ouémé. In 1999, a total of 192 randomly selected households (8 households from each of 24 randomly selected villages), including the husband and one of his wives in each of these households, were interviewed.

The respondents were asked to estimate for how many months in the year, and days in the week they were actually involved in agriculture, fishing, trading food crops, trading fish, and animal husbandry, and how much they would earn during a typical day's work from each activity. The same questions were asked for the periods *before* the arrival of water hyacinth, *during* peak infestation, and *after* peak infestation. Additional questions concerned the importance of the impact of water hyacinth on different economic activities and other perceived impacts of water hyacinth, positive or negative (De Groote et al. 2003).

Annual incomes accruing to both men and women from the different activities were derived for the periods *before* the arrival of water hyacinth, *during* peak infestation, and *after* peak infestation (i.e., at the time of the survey). Given an average of 1.45 spouses per husband, annual household incomes from the different activities and for the different periods were estimated by multiplying the wife's income by 1.45 and adding it to the husband's income. The impact of water hyacinth (or economic loss) was derived as the difference in household income *before* and *during* infestation, whereas the impact of the biological control of water hyacinth was derived as the difference in household income *during* and *after* peak infestation. The overall impact of the biological control of water hyacinth on regional incomes was estimated by extrapolating household incomes from all activities to the 39 000 households in the region. The benefit-cost ratio was estimated by comparing the present value of a future stream of this regional income with the present value of the costs of the biological control over a 20-year period (De Groote et al. 2003).

Results from the benefit-cost analysis

Table 4 presents household incomes *before* the arrival of water hyacinth, *during* peak infestation, and *after* peak infestation (i.e., at the time of the survey). Based on the incomes at these different times, the impacts of water hyacinth and its biological control are also presented. The economic loss due to water hyacinth was estimated at US$2151/household, while the impact of the biological control of water hyacinth was US$783/household (De Groote et al. 2003).

Table 4. Change in household income from activities influenced by water hyacinth.

	Household income (US$)			Impact of water hyacinth		Impact of biological control	
Activity	Before Water hyacinth	During peak	In 1999	Household income (US$)	%	Household income (US$)	%
Fishing	1984	607	1169	1378	64.1	562	71.8
Trading fish	768	201	262	567	26.4	61	7.8
Trading food crops	459	280	412	179	8.3	132	16.9
Trading wood	37	10	37	27	1.3	27	3.5
Total	3248	1097	1880	2151	100	783	100

Source: De Groote et al. (2003).

The results of the extrapolation of the impact of water hyacinth and its biological control on household income to the 39 000 households in Southern Bénin is presented in Table 5. The total economic loss from water hyacinth was estimated at US$83.9 million, mostly in fishing (64%) and in the fish trade (26%). Similarly the region's income has since increased by US$30.5 million, mostly from fishing (72%) and trading food crops (17%). This increase was entirely attributed to the reduction of water hyacinth cover and thus represented the benefit of biological control. The present value of a future income stream of US$30.5 million/year over 20 years, at a 10% discount rate, amounted to US$260 million. Since rearing of water hyacinth weevils requires little equipment or laboratory space, most of the cost of the biological control was attributed to operating costs and salaries for international staff (IITA and GTZ), and for local staff (IITA and Direction des Pêches). The present value of all costs of the biological control of water hyacinth amounted to US$2.09 million.

Table 5. Impact of water hyacinth and its biological control on the income of the people in Southern Bénin (US$ million).

Activity	Region's yearly income			Impact of	
	Before water hyacinth	During peak	In 1999	Water hyacinth	Biological control
Fishing	77.4	23.7	45.6	53.7	21.9
Trading fish	29.9	7.8	10.2	22.1	2.4
Trading food crops	17.9	10.9	16.1	7.0	5.2
Trading wood	1.4	0.4	1.4	1.1	1.1
Region's income	126.7	42.8	73.3	83.9	30.5

Source: De Groote et al. (2003).

Based on the benefits (US$260 million) and the costs (US$2.09 million), the benefit-cost ratio for the biological control of water hyacinth was estimated at 124:1. Because the weevils were subsequently exported, reared, and released in much larger areas, and at much lower costs, in similar lagoon systems in Burkina Faso, Côte d'Ivoire, Ghana, Nigeria, Tanzania, and Uganda, the benefit-cost ratios for these countries can only be much higher than 124:1, demonstrating the substantial economic impact of the biological control of water hyacinth in Africa (De Groote et al. 2003).

Conclusions

Since the 1970s, IITA, in collaboration with national agricultural programs in sub-Saharan Africa and other international organizations, has been actively working on the biological control of several exotic pests, which have been threatening the livelihoods of millions of people. IITA has been able to control devastating pests attacking the major staple food crops of the poor and has employed innovative approaches to scaling up biological control technology in SSA. It has helped establish strong national biological control programs and built the biological control capability of these countries.

Studies carried out to assess the economic impact of biological pest control have revealed high net benefits, indicating the success of the programs. The economic impacts were evaluated based on data from field trials, socioeconomic surveys, published results, and financial information provided by IITA and the national programs of many SSA countries. Because the studies captured only the conventional economic benefits of classical biological pest control, the actual economic impacts are expected to be higher, given the range of ecological and human health benefits of biological control as opposed to chemical control (Neuenschwander 2004). Although attaching monetary values to the services of nature has been a difficult task, ecologists and environmental economists have argued that the benefits are higher than traditional monetary valuations would suggest. The available empirical evidence thus suggests that classical biological control is a cost-effective and sustainable option to overcome the economic losses caused by a range of exotic pests in SSA. It has helped to substantially reduce crop losses due to major pests, which were inadvertently introduced into the continent. Countries in SSA should, therefore, value and further strengthen their biological control knowledge and capacity to deal adequately with other devastating pests in the future.

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