Peter Neuenschwander

Importance of biological control for tropical Africa

Bedeutung des biologischen Pflanzenschutzes für das tropische Afrika

Abstract

Though studies in biological control belong to the best documented research in ecology the actual decision to release a beneficial organism is often influenced by diffuse fears of anything foreign. Yet, agriculture is largely based on exotics; others remain inconspicuous and integrate themselves without problems into the existing ecosystems; and only few actually cause damage. It is against this latter group that the introduction of adapted predators from the region of origin, so-called classical biological control, offers most promise. Here we present four projects from tropical Africa, which were documented throughout all stages from the introduction of predators and parasitoids to the calculations of economic benefits: cassava mealybug, mango mealybug, cassava green mite, and waterhyacinth. Apart from specific conclusions, the high returns of these projects and the various impacts on non-target organisms are discussed.

Key words: Classical biological control, cassava mealybug, mango mealybug, cassava green mite, waterhyacinth, economic analysis

Zusammenfassung

Obwohl die Begleituntersuchungen zur biologischen Schädlingsbekämpfung zu den am besten dokumentierten ökologischen Studien zählen, wird die Entscheidung, ob ein exotischer Nützling eingesetzt werden darf, oft auch durch diffuse Ängste vor Fremdorganismen bestimmt. Dabei basiert unsere Landwirtschaft zu einem großen Anteil auf solchen Exoten; andere verhalten sich meist unauffällig und fügen sich bleibend in die Ökosysteme und nur wenige führen zu Schäden. Den letzteren wird am besten mit der Einfuhr von angepassten Prädatoren aus dem Ursprungsgebiet, d.h. der klassischen biologischen Schädlingsbekämpfung, entgegengewirkt. An dieser Stelle werden vier solche Projekte aus dem tropischen Afrika vorgestellt, welche alle von der Einfuhr von Parasitoiden und Prädatoren bis zum ausgewiesenen ökonomischen Nutzen dokumentiert worden sind: Maniokschmierlaus, Mangoschmierlaus, Grüne Maniokmilbe und Wasserhyazinthe. Es werden allgemein interessante Schlüsse aus diesen Projekten gezogen, der sehr hohe Nutzen dieser Projekte wird aufgezeigt, und die verschiedenen Formen von Einflüssen auf andere Organismen werden diskutiert.

Stichwörter: Klassische Biologische Schädlingsbekämpfung, Maniokschmierlaus, Mangoschmierlaus, Grüne Maniokmilbe, Wasserhyazinthe, ökonomische Analyse

Introduction

Biological control furnishes among the best studies concerning systems' ecology. Ideally, science would have to inform the decision process about the implementation of a particular biological control programme and the eventual judgement concerning 'successes' and 'failures'. We all know that this is, however, not a straight-forward process, not only because knowledge is never complete, but also because people base their judgement on their world view in a given historical context. The implementation of biological control therefore has a lot to do with applied sociology. Increasingly, biocontrol practitioners are faced with a vague fear of anything exotic, which slows down or even stops implementation of classical

Institution
International Institute of Tropical Agriculture (IITA), Cotonou, Bénin

Correspondence
Dr. Peter Neuenschwander, International Institute of Tropical Agriculture IITA-Benin, 08 B.P. 0932 Cotonou, Bénin, E-Mail: p.neuenschwander@cgiar.org

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biological control programmes, i.e., the introduction of exotic beneficials. It is therefore useful to remember that 1- our agriculture depends to a large extent on deliberate introductions like crop plants, trees, etc.; but also (non-necessary) garden plants; 2- many plants are deliberate or accidental introductions that fit into the existing food-webs without displacing native plants in a major way (and as it seems without being 'sleepers' awaiting to explode); 3- particularly in the tropics, very old introductions, which are now pests of uncertain origin, offer prime targets for biological control; 4- and then we have the newer introductions that cause pest outbreaks and are the main targets for biological control.

We would like to show how classical biological control under good farming practices and with well adapted crop varieties is the only safe way to combat foreign pest organisms once they have spread beyond a small perimeter that would still allow extermination. Since other pest organisms that are not (yet) targets of biocontrol need to be taken care of too, classical biological control is only successful in the framework of sound Integrated Pest Management (IPM) and particularly the combined use with host-plant resistance (Thomas and Waage, 1996). Sustainability is thereby judged by long-term reduction of pest populations and the impact of a biological control programme is quantified by the economic impact on the entire community. All examples presented here are from tropical Africa, where consumer expectations are lower than in Europe and North America and perceived alternatives like chemical control are often out of reach for the prevailing small-scale farmers (around 70% of the population involved in agriculture!), two conditions that favour the acceptance of biological control in Africa.

In Africa, classical biological control started in the late 19th century, peaked in the 1980 s, with 150 introductions per year, led to establishment in 65% of all introductions, among which 10% contributed to control (Greathead, 2003). Since the 1980 s, special attention is given to quantify the impact on the plant, on yield and income, combined with a better scientific understanding of all processes, including effects on non-target organisms. While many more projects have led to the discovery, release and establishment of successful biological control agents, particularly in the Republic of South Africa (Neuenschwander et al., 2003), we only deal here with projects from tropical Africa that have run through the whole process, including, additionally, the quantification of spread, long-term follow-ups, and impact assessments at all levels.

Examples

Cassava mealybug

The cassava mealybug, newly described as *Phenacoccus manihoti* Matile-Ferrero of South American origin, was accidentally introduced into Africa in the 1970 s, where it spread at 100 km per year, causing total devastation of cassava fields. On request by various governments and in international collaboration under the coordination by H.R. Herren of IITA, the encyrtid *Anagyrus lopezi* (DeSantis) was discovered in 1981 in Paraguay by T. Bellotti of the sister institute CIAT and later in Brazil by GTZ. Several agents were shipped through quarantine at CABI, England, first to IITA-Nigeria and then IITA-Benin, where they were mass-reared with newly developed equipment. Behavioural studies at IITA and various European (mainly France, Germany, Switzerland, The Netherlands, U.K.), African (mainly Benin, Democratic Republic of Congo, Ghana, Malawi, Nigeria, R.S.A., Senegal, Uganda, Zambia) and American (Canada, U.S.A.) universities clarified the life-cycles and ecologies of *A. lopezi* and some of its exotic and indigenous competitors. In collaboration with the respective national programs, about 150 releases were made all over tropical Africa between 1981 and 1995 and followed-up systematically in about 10 countries (reviews: Herren and Neuenschwander, 1991; Neuenschwander, 2001).

Highlights of these studies that point to important conclusions that should be useful for other projects:

1- The misidentification of a cassava mealybug from northern South America led to the importation of unadapted parasitoids, which were never released; but delayed the project. Taxonomy of the concerned important insect families lies in the hands of a few individuals and still does not receive the needed support. Similarly, in most projects, the all important foreign exploration phase is cut short for financial reasons. These two activities are absolutely crucial for a successful project. The creation of BioNET-INTERNATIONAL, an international body for support of taxonomy particularly in developing countries, was a good step (IITA-Benin is the coordinating centre for West and Central Africa); but the organisation does not receive sufficient funds and can only rarely assist African taxonomists.

2- Detailed behavioural studies on a sister species, *Anagyrus diversicornis* (Howard), demonstrated why *A. lopezi* was superior in competition and why *A. diversicornis* could not establish (review: Neuenschwander, 1996). Such studies go a long way to allay fears about released agents that do not establish. The various studies also demonstrated the relatively low value of the popular life-table studies (intrinsic growth rate), showed the complicated influence of plant physiology on biological control, and showed that behavioural studies were key to the understanding of these parasitoids. Concurrent population dynamic models (Gutierrez et al., 1988, 1999) were particularly useful in establishing the contribution of indigenous predators, mainly coccinellids; but were hardly predictive.

3- In the emergency created by the invasion of the cassava mealybug, all countries asked for assistance. Many releases were therefore made to placate officials. In view of the extremely good dispersal capacity of *A. lopezi* (about 25 km per generation of 2 weeks), some of the release points were too close to be useful; but this we knew only after the fact. In view of these findings we suggest that in future preference be given to fewer releases with lots of insects (thousands) instead of a fine coverage of the infested area with small batches.

4- The 8-year follow-up study in Nigeria provided a unique data set. It allowed distinguishing mealybug populations on different cassava varieties. It also demonstrated the importance of assessing the host population before (or shortly after) release, a difficult thing to achieve when so much pressure for action builds up. It demonstrated the long-term equilibrium achieved by biocontrol, in this case characterized by uneven short peaks that gave rise to perennial claims that 'biocontrol had broken down'. For this reason, in several countries, mealybug population densities were assessed at irregular intervals up to 15 years after release, but no 'resurgence' was ever documented. The parasitoid thus did not 'loose efficiency' as sometimes claimed.

5- The data set from Malawi described the spreading front of the mealybug, which was always accompanied by an outbreak that was subsequently subdued by *A. lopezi*. Because over many years, somewhere, the country always suffered from mealybug damage it was difficult to receive official approbation. Hence, official recognition by African scientists for impact by *A. lopezi* arrived only in the mid-1990 s. Fortunately donors stuck to us and continued support. Would this still be the case today?

6- Though the generation time of the parasitoid (2 weeks) was only a fraction of the one of its host, wide-spread and long-term impact on mealybug populations could be documented only after 2-4 years, depending on the environment. We think that this has to do with the early dispersal of the parasitoid after emergence.

7- Across large areas, the reduction of mealybug populations was 10-fold (down from an initial average 80% yield loss). On 5% of all fields the reduction was judged unsatisfactory. Invariably, these fields were on sandy, unmulched soils. We concluded and proved that the solution to this problem consisted in good farming practices; in this case, the maintenance and increase of organic material on the soil, which strengthened plant growth and made the plants less susceptible to mealybug and a better shelter for *A. lopezi*.

8- For the economic analysis, highly stratified data (according to ecozone, time of mealybug invasion, time of *A. lopezi* release, and time of biocontrol impact) were tabulated for 27 countries (ZEDDIES et al., 2001). The cassava dry weight savings due to biocontrol were translated into $ with a 6% discount rate (base line 1994) over 40 years according to different market scenarios and with various sensitivity analyses. The costs by donors and governments (but none by farmers!) were equally discounted. The results: a total savings of $ 9 to 20 billion with benefit:cost ratios of 170 to 430 depending on scenario.

Mango mealybug

The mango mealybug, newly described as *Rastrococcus invadens* Williams, was introduced from India in the 1980 s and spread all over West and Central Africa, and more recently also to East Africa, inflicting often total loss of the mango crop through tree felling (review: MOORE, 2004). In a biological control programme with the same institutions as before, the two newly discovered (by CABI) encyrtid parasitoids *Gyranusoidea tebygi* NOYES and *Anagyrus mangicola* NOYES were imported first to Togo for a GTZ project (AGRICOLA et al., 1989) and later to IITA-Benin. Between 1988 and 1993, we made about 40 releases in ca. 14 countries (NEUENSCHWANDER et al., 1994). In collaboration with universities in The Netherland and U.S.A., we found out that the two parasitoids (contrary to the two *Anagyrus* spp. mentioned before) had sufficiently separate niches (different host stages) that they could co-exist and probably reinforce biocontrol impact (BOKONON-GANTA et al., 1996).

Highlights:

9- The parasitoids (mainly *G. tebygi*) caused a total local collapse of the mealybug population, approaching the predictions of a local extinction model rather than a lower equilibrium, which presumably could only be seen when data from larger areas were pooled.

10- As mealybug populations collapsed, the originally observed polyphagy gave rise to a rather strict monophagy on mango.

11- The economic analysis was based on structured interviews with randomly chosen farmers, (3 interviews in 15 villages (1989–1991) followed by a final assessment by entomologist (1999) on a total of 300 producers: BOKONON-GANTA et al., 2002). The total benefits for Benin alone were calculated as $ 531 million over 20 years.

Cassa green mite

The cassava green mite *Mononychellus tanajoa* Bondar was accidentally introduced from South America into Uganda in the 1970 s, and then spread quickly across the continent (review: YANINEK and HANNA, 2003). Biological control was started in the early 1980 s by IITA in collaboration with CIAT in Colombia and later with EMBRAPA in Brazil. Many species of phytoseiid mites were imported; but only three species could be established. One species, *Typhlodromalus aripo* DeLeon, however, became successful and, following numerous releases across Africa, became established as an efficient control agent in all cassava growing areas that were not too dry or too cold (YANINEK et al., 1993). In addition, the exotic fungus *Neozygites tanajoae* Delalibera Jr., Humber & Hajek was introduced from Brazil and established (YANINEK et al., 1996).

12- Interestingly, *T. aripo*, though less voracious than other species, turned out to be the best natural enemy for biological control on a continental scale. It was shown to use plant structures like hairs of the tips as shelter ('domatia'), from where it makes its nightly forays down the plant, where it competes with indigenous phytoseiid mites. *T. aripo* thereby actively searches and locates its prey by means of host-plant induced volatiles (ONZO et al., 2003, 2009). This, together with the capacity to survive on pollen and extrafloral exudates, explains its success.

13- Economic evaluation in 3 West African countries demonstrated that the benefits, $ 2.517 billion, from this biological control programme rivalled the one against the cassava mealybug (R. HANNA, J.S. YANINEK, O. COULIBALY, et al. IITA, yet unpublished).

Water hyacinth

Water hyacinth, *Eichhornia crassipes* Solms.Laub. was introduced from South America into Africa in the 1970 s and today is found in practically all areas of tropical and subtropical Africa, obstructing fishing, transport, and affecting the health of the local populations (review: JULIEN et al., 1999). In this case, we were able to collaborate with an existing long-term project led by the U.S.A, Australia and South Africa. The weevils *Neochetina eichhorniae* Warner and *N. bruchi* Hustache (as well as other unsuccessful agents) were introduced, reared at IITA-Benin, and released in 11 localities between 1991 and 1993. Additional weevils were provided for national programs in Ghana, Uganda, Kenya and Tanzania, together with those from the Republic of South Africa. Long-term follow-up studies in Benin showed a slow impact by *N. eichhorniae*, with reduction of water hyacinth cover to 50% within about 10 years (AJUONU et al., 2003), without any resurgence beyond the annual fluctuations. Since then, it seems that water hyacinth cover continues to be reduced. In Lake Victoria, reduction to 5% by *N. bruchi* was much faster and spectacular (WILSON et al., 2007). Overall, weevils were hampered by eutrophisation of some water bodies and in some places by cold weather.

14- Interviews in 1999 in 24 randomly chosen villages in 192 households with 365 people, stratified according to profession and sex (no anecdotes!) gave for the first time indications of the magnitude of the economic impact of water hyacinth and its subsequent 50% biological control (values discounted by 10% accrued over 20 years). Thus, water hyacinth had reduced the income of 200 000 people by $ 84 million per year. Benefits by biological control amounted to $ 30 million per year, with a benefit:cost ratio of 124, not including the unspecified benefits from improved water quality and human health (DE GROOTE et al., 2003).

Overall impact of biological control

15- These impressive impact figures (review: NEUENSCHWANDER, 2004) demonstrate that classical biological control rivals perennial, well supported plant breeding programmes of the Consultative Group for International Agricultural Research (CGIAR), to which IITA and CIAT belong (EVENSON and GOLLIN, 2003). Yet, biocontrol does not have the same acceptance as plant breeding and therefore has a much reduced core support.

Non-target impacts

One of the reasons for increased hesitance to use classical biological control stems from the increased awareness of the potential for unintentional non-target effects (review: WAJNBERG et al., 2001). While old introductions of vertebrate and snail predators have indeed caused major ecological disruptions, the use of specific insect and mite predators and pathogens has led to a great number of successes against crop and forest pests. For the many positive impacts on the environment see particularly the upcoming review 'Classical biological control for the protection of natural ecosystems: past achievements and current efforts' by ROY VAN DRIESCHE et al. (2010), in biological control.

16- In our own studies, we have retrospectively searched for possible effects on the environment and found that the concept of 'non-target impact' needs careful consideration. All the encyrtids we imported, like *A. lopezi*, *G. tebygi*, *A. mangicola* and others, did not attack other, indigenous mealybugs, but had of course major effects on the local predators and hyperparasitoids, which lost their newly acquired hosts. The predatory mites attacked also other phytophagous mites than the cassava green mite; but exhibited some specificity because of topographical separation. Moreover, at times, they needed these species as alternate food-sources. By reducing the cassava green mite populations, the introduced species removed prey for indigenous phytoseiids, which survived, however, outside the cassava system. Moreover, some of the introduced predators even fed directly on cassava, which allowed them to pass periods of prey scarcity.

17- As water hyacinths belong to the small and economically unimportant family of *Pontederiaceae*, specificity of the water hyacinth weevils, which had been tested before, was no problem: only one indigenous species, which was structurally unsuitable, and another exotic species had to be considered. On the food-webs in their environments, biological control of water hyacinth had, however, major impacts. In the freed water courses, more oxygen became again available, but hiding places for fish fry and arthropods got lost. As concerns the local people, it depended on whom you asked: The fact that different groups saw different benefits for themselves reminds us that, before any implementation of biological control against an exotic plant can be started, a political decision weighing the different interests was needed. For water hyacinth, public consensus was achieved in the course of several regional congresses. In each of these meetings, water hyacinth was declared a 'weed' and releasing *Neochetina* spp. was recommended as the preferred solution.

Some (banal) recommendations

a- For quarantine and subsequent introductions apply the FAO Code of Conduct and professional good practices.
b- Never introduce vertebrates (fish, birds, and mammals), molluscs or hyperparasitoids as biological control agents because they have proven to be capable of major ecological disruptions due to their inherent lack of specificity.
c- Avoid unwanted non-target effects by following expert opinion.
d- In the decision to introduce or not, compare the possible outcome of biological control with the status quo,

not any perceived paradise that existed before the introduction of the exotic pest.

e- In most cases, though, it is better to avoid the pest introduction in the first place. More research and support for exclusion measures (quarantine) are therefore needed.

f- For a better understanding of the benefits and limits of classical biological control it must be repeated again and again that this technique offers a sustained solution at a pest population level determined by the concerned organisms and the environment (not farmers or consumers!), mostly without costs to farmers, without recurrent costs to the public, and – if unwanted non-target effects are avoided – with optimal environmental benefits.

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