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Boru Douthwaite, Jürgen Langewald, and Jeremy Harris

IITA

Ibadan, Nigeria

Telephone: (+234 2) 241 2626

Fax: (+234 2) 241 2221

E-mail: [iita@cgiar.org](mailto:iita@cgiar.org)

Web: [www.cgiar.org/iita](http://www.cgiar.org/iita)

International mailing address:

c/o L.W. Lambourn & Co., Carolyn House

26 Dingwall Road, Croydon CR9 3EE, UK

Within Nigeria:

Oyo Road, PMB 5320

Ibadan, Oyo State

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# Development and commercialization of the Green Muscle biopesticide

Boru Douthwaite<sup>1</sup>, Jürgen Langewald<sup>1</sup>, and Jeremy Harris<sup>2</sup>

<sup>1</sup>International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

<sup>2</sup>CABI Biosciences, Ascot, Berkshire, UK

## Abstract

*Locusts are the most feared pests of farmers living around the world's major deserts. Millions of liters of environmentally damaging pesticides are sprayed over vast areas of land to control them and their grasshopper cousins. This paper tells the life history of the LUBILOSA (Lutte Biologique contre les Locustes et Sauteriaux) project, set up in 1989, and the development of a biological pesticide which kills locusts and grasshoppers without harming the environment. Commercial manufacture and real adoption has begun, although the benefits have yet to pay for the US\$15 million spent on the project. The project has had some major spin-offs including the development of a similar biopesticide in Australia, and the development of biopesticides to control termites. Good science alone has by no means been the only ingredient of the success so far. One crucial factor has been the willingness of donors to provide funding for the 10 years of research and development often required to turn basic research into a useful product. A second factor is the early forging of partnerships between donors, several research institutes, national agricultural research and extension systems (NARES), nongovernmental organizations (NGOs), the Food and Agriculture Organization of the United Nations (FAO), private sector companies, and farmers that has ensured that sufficient expertise was available when needed. A by-product of this collaboration is the creation of a "constituency of support" around Green Muscle® and it is this constituency which, more than anything, will determine the eventual impact and return on investment of the LUBILOSA project. This is because the eventual level of sales of Green Muscle depends on the correction of the market failure whereby the human and environmental health costs of spraying chemical pesticides are not charged to the purchaser. Policy change is required to correct this and it is in the constituency's power to bring about this policy change. LUBILOSA project management and donors have shown themselves very aware of this reality by proposing and funding a "stewardship" phase for the project to both lobby the constituency and keep it together during the early adoption*

*phase, as well as to ensure a seamless transfer of researcher knowledge about Green Muscle to the private sector manufacturers. The need for product “stewardship” or “championing” has long been recognized in the private sector but has been absent from a research world which has attempted, until recently, to separate “upstream” basic research from “downstream” adaptive research and extension. Product championing may well be essential for creating and cementing synergies between the public and private sectors and between scientific “knowledge” and practical “know-how”.*

## Introduction

Locust plagues have long struck fear into people because, when they descend, the destruction they wreak can be terrible. They “eat every herb of the land, and all the fruit of the trees” (Exodus 10 verse 15, King James version). The Bible records God sending “horrible” locust plagues as a vehicle of judgement not once but three times (Job, Exodus, and Revelation).

Locust plagues are so damaging because they can grow so big. The largest locust swarm this century was reported in Kenya in 1954 and covered more than 1000 km<sup>2</sup>, contained 40 000 million insects and weighed 80 000 tonnes. One tonne of locusts eats as much food in one day as about 2500 people (Steedman 1990).

Luckily, locust swarms are infrequent, occurring only when weather conditions favor the emergence of the nymphs and their survival and growth for successive generations. The last cataclysmic invasion in Africa began in 1986 and reached a peak in 1988 when swarms of desert locusts ranged from Mauritania and Senegal in the west to Iraq, Iran, and Kuwait in the east (US Congress 1990). Each year there is a locust infestation somewhere in the world (Rainey 1963). In 2000, western Australia’s wheat belt was ravaged by the worst infestation for 10 years while a swarm to equal that of 1954 in Kenya threatened to descend on three other states (The UK Guardian 28 April 2000). In 1999 a locust swarm invaded 8 million hectares in Kazakhstan and then moved into neighboring Russia (Lauria 1999). In Spain, the Moroccan locust, *Dociostaurus maroccanus*, has affected 500 000 hectares in recent years and outbreaks of the insect have also affected other Mediterranean areas such as Algeria, Crete, southern Italy, Morocco, Sardinia, and Turkey (Thomas 2000).

Although locusts grab the headlines, their close relatives—grasshoppers—probably do much more crop damage on average, year after year (Duranton et al. 1981). While locusts intermittently swarm, grasshoppers appear in crop-threatening numbers much more regularly. In fact, the spraying program that tackled the 1988 desert locust plague began in 1986 mainly against grasshoppers (Brader 1988). Nearly one-third of the money spent during the 1986 to 1989 campaign went on grasshopper control (Symmons 1992).

The main control measure against locusts and grasshoppers is to spray large areas with broad-spectrum pesticides to prevent the locusts from swarming, or to kill the swarms once they form. Huge volumes of chemicals can be sprayed on vast tracts of land. For example, between 1986 and 1989, donors and national governments spent US\$200 million spraying 10 million hectares with 15 million liters of the broad spectrum insecticides fenitrothion and malathion (Symmons 1992). All the insecticides sprayed had some potentially negative environmental effects. They kill, as their labels suggest, a broad spectrum of insects and arachnids that are important to integrated pest management (IPM) in other systems (Lomer et al. 1997). Fenitrothion and malathion, both organophosphates, are still used today for locust control in Europe and Australia, although the Canadians stopped spraying fenitrothion to control spruce budworm in 1997 because it was found to kill birds (Canada Wildlife Service 1998). The pesticide also harms fish. During the desert locust spraying campaign, humans were poisoned as a result of improper handling and the practice of using empty pesticide containers for storing food and water (US Congress 1990).

Another environmental issue is that pesticide residue in crops or animal meat can cause importing countries to ban the produce. For example, Japan has rejected containers of Australian beef even with very low levels of residual pesticides (Milner 2000). Also, any pesticide spraying disbars land from qualifying as organic and prevents farmers from selling in this more lucrative market.

The cash cost of the damage to the environment and to human health of the 1986 to 1989 campaign was never calculated. However, the 1990 US Congress report questioned whether the costs of the chemicals sprayed even amounted to the amount of crop saved. The chemical, environmental, and human health costs, plus the contention by some observers that it was the strong winds that blew the locusts out into the Atlantic, and not the spraying, which ended the plague (L. Brader, pers. comm., 2000; US Congress 1990), led to some serious questions being asked about the economics of locust and grasshopper control programs. The US government, which had been the biggest donor, commissioned the US Congress Office of Technology Assessment to make a report, which ran to 132 pages. The report said that: "Overall, the results of locust and grasshopper control were disappointing" (US Congress 1990, p. 11) and that locust and grasshopper control measures needed to be changed in the future away from uneconomic crisis management by chemical spraying. However, they concluded that: "Research on alternatives (to chemical pesticides) ... must be supported now if alternatives are to be available for future locust and grasshopper upsurges. Experts estimate that it may be 8 to 10 years before alternatives to insecticides are available for large-scale use" (US Congress 1990, p. 12).

As a result of the recommendations of the US Congress report, the United States

Agency for International Development (USAID) began supporting a program to develop a biopesticide against locusts based on the entomopathogenic fungus *Metarhizium anisopliae* var. *acridum*. However, Canada and some of the European donors to the control of the desert locust plague had reached similar conclusions a year before the publication of the report. The LUBILOSA project was set up in 1989 to develop a biological means of controlling locusts and grasshoppers. At the beginning, the project involved the Commonwealth Agricultural Bureau International (CABI) Bioscience in the UK, IITA, and Department de Formation en Protection des Vegetaux (DFPV) in Niger. CABI has managed the project but the technical project leader has been an IITA employee based in Benin since 1992, when LUBILOSA began small-scale field trials. By the end of Phase 3, the number of collaborators had increased to include Comité Inter-État de Lutte contre la Sécheresse au Sahel (CILSS), Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) in Germany, and two private companies, Biological Control Products (BCP) in South Africa and Natural Plant Protection (NPP) in France. Funding has come from the governments of Canada, Switzerland, the Netherlands, the US, and the UK. In the first 10 years, the LUBILOSA project has spent US\$15 million and produced an environmentally benign alternative to chemical pesticides that has already been used in extensive ground and aerial spraying campaigns in Mali and Niger (Douro-Kpindou et al. 1997; Langewald et al. 1999). Demonstration trials and farmer participatory trials have been conducted in most Sahelian countries in collaboration with the national programs (Maiga et al. 1999). A project in Australia has used LUBILOSA research data to develop a biopesticide against Australian locusts (Milner 2000). A company is licensed to manufacture the biopesticide, which has been registered in South Africa under the name Green Muscle<sup>®</sup>. Nevertheless, although no attempt has yet been made on the internal rate of return of this investment, most of the project stakeholders and donors believe that it would be negative at this stage. This consortium of donors has recently funded a fourth phase to “steward” the LUBILOSA biopesticide to higher adoption rates and greater impact.

LUBILOSA is a multidonor, multi-institution, multicountry project with strong public–private sector partnerships that has carried out strategic, cutting-edge research and developed a product that has been picked up by the commercial sector. As such LUBILOSA may well be a template for much more of the activities of the Consultative Group on International Agricultural Research (CGIAR) in the future. Hence an analysis of the impacts that LUBILOSA has had, could have in the future, and how this impact has and can be achieved, can teach us a great deal about public–private partnerships and the management of impact-focused research.

## Methodology

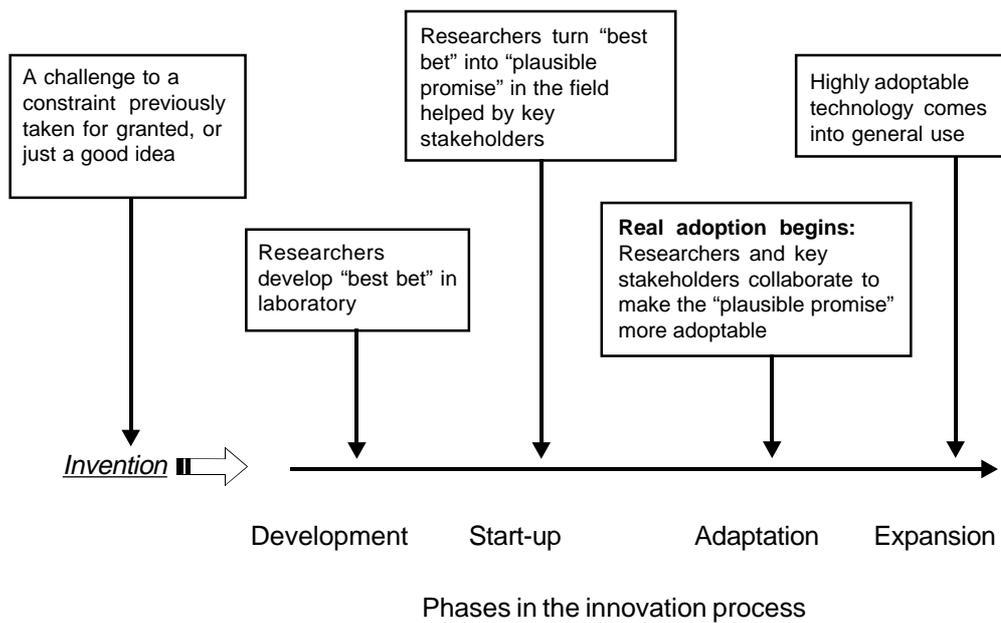
Assessing the ex-post and ex-ante impacts of the LUBILOSA project is complex because the research, development, and innovation process which the project initiated, sustained, and pushed forward is itself complex. LUBILOSA has had, and will continue to have, impacts on many levels, from farmers' fields in the Sahel, to farmers' fields in Australia, to policymakers in FAO, and to the governments of African countries. A number of commentators have recommended the use of case studies for understanding complex processes (Sechrest et al. 1996; Yin 1989; GAO 1987).

“A case study is a method for learning about a complex instance, based on a comprehensive understanding of that instance obtained by extensive description and analysis of that instance taken as a whole and in its context” (GAO 1987, p. 9)

The case study is the general methodological approach adopted in this paper. The analysis of contextual influences on events is helped by constructing the case study as a life history, that is, the organization of events by the time they happened (Sechrest et al. 1996; GAO 1987).

Case studies require focus, otherwise they can become too long and present irrelevant data. One device for assisting focus is to employ a “theory of the case” (Sechrest et al. 1996). Douthwaite (in press) has found that technologies ranging from agricultural equipment to computer software and community banking often follow an innovation process shown in Figure 1, particularly if they are successful. The “theory of the case” for the LUBILOSA life history is that the LUBILOSA innovation process is also following this process. Comparing the LUBILOSA innovation history with that of other technologies will help in lesson learning and generalization of the findings from this paper.

Understanding the normative process described in Figure 1 requires some explanation. An innovation process usually needs an “invention” to start it. An invention is something new, a challenge to a constraint that people previously had taken for granted, or just a good idea. The new idea stimulates researchers to develop a prototype that is their “best bet” at a workable solution to a problem. While researchers define what their “best bet” is, the key stakeholders—the people who will produce, use, profit, and lose from the technology—define what a “plausible promise” is. A “best bet” only becomes a “plausible promise” if some individuals in the key stakeholder groups actually believe it will be useful to them, and thus decide to invest in the new technology. Obviously, the more the researchers consult the key stakeholders in the development phase, the more likely it is that the “best bet” is going to make a “plausible promise”. During the start-up and adaptation phases the key stakeholders gain more and more stake in the “plausible promise” while the research group gradually withdraws, until at the beginning of the expansion phase the key stakeholders have completely taken over. In general the research group will



**Figure 1. Stages in the research, development, and innovation process.**

include all the “supply” side stakeholders, that is, the collaborating research institutes and the donors. The key stakeholders are the groups on the “demand” side.

## The life history of the LUBILOSA project

### *Invention*

The LUBILOSA project was motivated by the discovery by Chris Prior that fungal spores (aerial conidia), when mixed in oil rather than water, not only remain potent much longer in dry conditions but are also much more infective and kill insects much faster (Prior and Greathead 1989). Prior’s discovery was an invention as Mokyr (1990) defines it as a challenge to the status quo, an attack by an individual on a constraint that everyone else has taken for granted. No one had considered suspending fungi spores in oil before because many oils are toxic to fungi (Bateman et al. 1993). Although the potential of entomopathogenic fungi was well known (Müller-Kögler 1965), no one believed that it would be possible to develop a successful fungus-based biopesticide that would work under the very dry desert conditions where locust swarms emerge.

There were other reasons for LUBILOSA initially identifying fungi as the most promising agents for biocontrol. Prior wrote an article for the FAO Plant Protection Bulletin together with D.J. Greathead (Prior and Greathead 1989), which identified fungi as being the most promising agents for biocontrol. Fungi are a frequent cause

of death in insect populations and have the big advantage over other potential biocontrol agents that they do not have to be ingested to infect their hosts because they invade directly through the cuticle (Milner 2000).

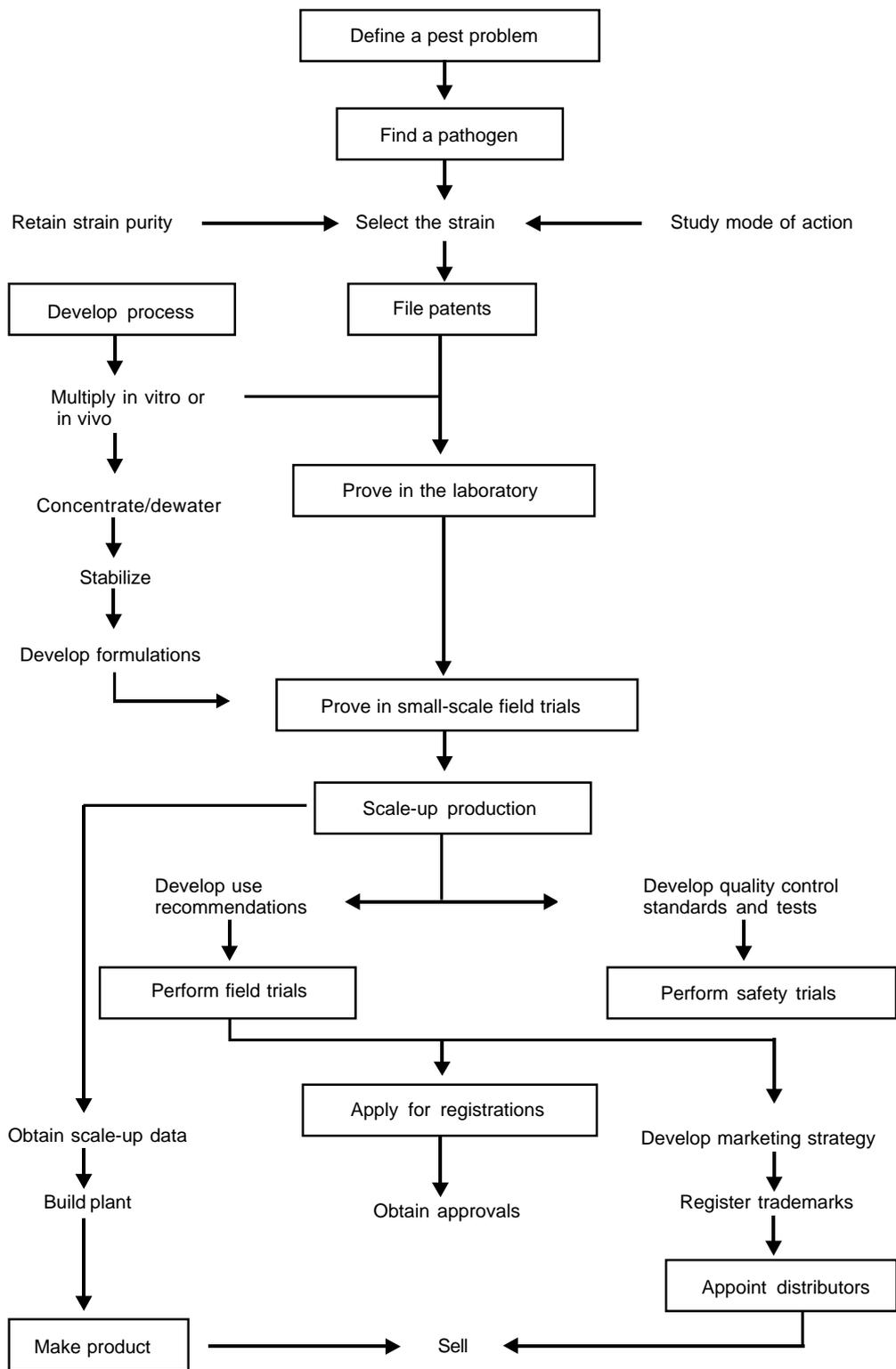
*Development phase: coming up with a “best bet”*

LUBILOSA’s objective from the beginning was to develop a commercial microbial pesticide, following the process shown in Figure 2.

The 1986 to 1989 grasshopper and locust plagues in the Sahel had defined the pest problem. The next step was for LUBILOSA to select a pathogen. From the beginning, the LUBILOSA project concentrated on developing a biopesticide based on the Deuteromycotina fungi subdivision. This is because the conidia (spores) of Deuteromycotina are relatively easy to reproduce and had already been studied so there were already some isolates and data on pathogenicity and mammalian safety (Lomer et al. 1997). The principle genera of interest were *Metarhizium* and *Beauveria* because fungi in both genera infect many different species of insect. Moreover, clades (homogeneous groups, often at subspecies level) can often be found which only attack a closely related set of insect species, thus giving the potential of developing a wide range of bioinsecticides that only kill a specific pest, leaving beneficial insects unscathed. This makes “mycoinsecticides” (from *myce*, the Latin name for fungus) suitable for use in IPM programs.

Project staff screened African grasshopper and locust populations to find indigenous Deuteromycotina fungi that attacked the pests. They found that *Metarhizium* was more common in Africa, while other research established that *Beauveria* was more common in the US and the Mediterranean. Therefore the LUBILOSA project decided to concentrate on *Metarhizium* while the USAID project mentioned previously focused on *Beauveria*.

LUBILOSA has accumulated more than 150 isolates of *Metarhizium* and *Beauveria* species, 50 of which are virulent *Metarhizium* strains. The research identified for the first time the morphologically distinctive *Metarhizium anisopliae* var. *acridum* attacking grasshoppers and locusts in West Africa and Madagascar (Lomer et al. 1997; Driver et al. 2000). LUBILOSA selected one of these isolates, strain IMI330189, as the basis of its biopesticide. The project made the decision partly because its research suggested that *M. anisopliae* var. *acridum* was distributed throughout Sahelian Africa, which meant licensing and phytosanitary requirements would be easier to fulfil because the product would not be introducing an exotic fungus into sensitive ecosystems. Secondly, it became clear that in Africa *M. anisopliae* var. *acridum* had coevolved with grasshoppers and locusts, making the strains very host specific (Lomer et al. 1997). In fact *M. anisopliae* var. *acridum* has only ever been found on Orthoperan (an order of insects that includes locusts,



**Figure 2. Stages in the commercialization of a microbial pesticide (Dent 1998, after Baldwin 1986).**

grasshoppers, and crickets) hosts, and LUBILOSА field testing has found no transmission or evidence of any risk of infection to nontarget insects in the field. This makes Green Muscle environmentally benign and suitable for use in IPM programs (Lomer et al. 1997).

*Start-up phase: turning the “best bet” into a “plausible promise” in the field*

Phase 1 of LUBILOSА identified the IMI330189 strain and demonstrated its virulence in the laboratory. Phase 2 of LUBILOSА then began to demonstrate that the strain worked during small-scale field experiments. This involved testing oil formulations containing the fungi spores on a complete range of spraying equipment. It was during the preparation of these oil formulations that the name “Green Muscle” was coined because of the dark green color that the spores gave the oil. Staff carried out field tests to determine the sprayer application rates and the minimum concentration of spores in the oil formulation that would give effective control. Early on, field workers realized it was difficult to mix the dry spores with oil, so LUBILOSА developed a liquid concentrate that could be mixed with the carrier oil (Bateman 1997).

Field trails gradually increased in size as the application equipment being tested changed from hand-held ultra-low volume sprayers to sprayers fitted onto vehicles and then aeroplanes. As this happened the demand for conidia increased to the point where the project had to set up a production facility, which began working in 1996. The unit is situated at the IITA station in Cotonou, Benin, and consists of a purpose-built 7-room laboratory complex that still employs 6 people full-time to produce Green Muscle (Cherry et al. 1999).

The design of the Green Muscle production unit is an adaptation of a Brazilian *Metarhizium* mass production unit to materials available in Benin. It uses a 2-stage process to produce the conidia in which an inoculum is prepared that is then used to inoculate a rice substrate. The unit can produce about 325 kg of spores per year, enough to spray a minimum of 3250 ha, at a cost of US\$17/ha.

The production plant allowed LUBILOSА to test Green Muscle much more widely, with more partners including plant protection agencies and private companies and NGOs in Benin, Burkina Faso, Chad, Mali, Mauritania, Senegal, South Africa, and Sudan. From the beginning, LUBILOSА staff had realized that including NARES in Sahelian countries, as well as the private sector, would be crucial to the eventual adoption and promotion of a biopesticide in the region and small-scale field testing gave the project the opportunity to build these partnerships. Good field results helped build partner ownership and enthusiasm. For example, aerial spraying in Niger in 1997 demonstrated that Green Muscle, sprayed at 0.5 l/ha—just 25% of the previous recommended application volume—gave greater control of grasshoppers after 10 days compared to the chemical insecticide fenitrothion, which is commonly used for

grasshopper and locust control. Moreover, the numbers of grasshoppers in the Green Muscle plots continued to fall when population numbers in the chemical pesticide plots had started to recover. After 16 days, population counts in the Green Muscle plots had been reduced by more than 95% compared to complete recovery of the grasshopper population in the fenitrothion plots and constant population densities in the control plots (Langewald et al. 1999). These results, achieved on the large plot size of 800 ha, confirmed earlier findings from 50 ha plot size trials in the previous year in Niger and in South Africa (Price et al. 1997).

The overall conclusion from the data was that a single spraying with Green Muscle could control grasshoppers and locusts because the *M. anisopliae* var. *acridum* strain IMI330189 was virulent and persisted over time through recurrent infection. Proper control by chemical pesticides may require more than one spraying, when grasshoppers migrate into previously sprayed sites.

In spite of this, grasshopper and locust control with Green Muscle is still more expensive than with its chemical competitors because production costs are higher. With the present intermediate scale production facility, it costs US\$17 (1997 price) to produce the standard application rate of 100 g of spores of Green Muscle per hectare (de Groot 1997). However, field trials in Mali in 1998 showed that half that dose gives adequate control. Therefore, with the current “intermediate technology” IITA production facility, Green Muscle production costs are between US\$8.5 and 17 per hectare. There is still scope for reducing production costs substantially by further optimizing the production process (Cherry et al. 1999). However, this price does not allow for distribution costs, wholesalers’ and retailers’ mark-up, or spraying costs. In comparison, Karate, one of the most popular insecticides used against grasshoppers, retailed (in 1997) at as little as US\$12 for enough chemical to spray a hectare (de Groot 1997).

Houndekon and de Groot (1998) estimated the animal and human health externalities of pesticide spraying to be approximately US\$1.75 per hectare. Even if Green Muscle could capture this saving by an environmental tax on pesticides, for example, farmers and donors must still be prepared to pay a premium for more environmentally friendly spraying. Participatory rural appraisals carried out by LUBILOSA have found that farmers are willing to pay US\$7 per hectare to spray to protect their millet against grasshoppers (LUBILOSA 1999), which is equivalent to about 10% of the value of their yield. This appears to make sense as surveys reported by de Groot (1997) showed yield loss from grasshopper varying from about 1% to 20%. The implication is that Green Muscle will have to be subsidized by the public sector, or pesticides will need to be taxed for their externalities, if Green Muscle is to compete with pesticides like Karate.

Early indications were that public sector donors, at least, would be prepared to pay the “green” premium for large-scale spraying and were firmly behind LUBILOSA. In

October 1996, LUBILOSA submitted a dossier to the Desert Locust Pesticide Referee Group of the FAO. By early 1997 the group had approved *M. anisopliae* var. *acridum* for operational locust control, especially in conservation and environmentally sensitive areas (Lomer 1999). As of the end of 1999 the FAO Pesticide Referee Group had listed Green Muscle as the only desert locust control product with “low impact on the environment” in all categories and causing “low risk to humans under normal use” (FAO 1999, table 2).

*Adaptation phase: making the “plausible promise” more plausible with the key stakeholders*

LUBILOSA’s submission of a dossier to FAO in 1996 corresponded with the beginning of Phase 3 of the project to “ensure both the development and utilisation of the mycoinsecticides in the control of West African Grasshoppers and Desert Locusts” (LUBILOSA 1996, p. 2).

LUBILOSA had originally planned to achieve impact by transferring the technology developed at the IITA production facility to national programs or to the private sector in collaborating Sahelian countries. If the Green Muscle strain of *M. flavoviride* was as robust, competitive, and productive as some of the other Deuteromycotina fungi then “artisanal” production, as carried out in China or Brazil, might have been possible. LUBILOSA did attempt to set up a cheap “artisanal” production system but gave up due to high levels of contamination (Cherry et al. 1999). LUBILOSA staff realized that the output from their pilot production unit was too low, required unrealistically high levels of quality control, and the unit production cost was too high for the technology to be successfully transferred at the “intermediate technology” level. Moreover, cottage industry-type production would not produce the very large amounts of Green Muscle that might be required to fight a major locust infestation. After much debate, the project opted to pursue the capital-intensive and “high tech” approach of large-scale solid-state fermentation, of which only about 12 companies in the world have the requisite expertise (LUBILOSA 1999).

LUBILOSA established contact with two companies with the capacity to carry out solid-state fermentation: BCP in South Africa and NPP in France. LUBILOSA made contact with BCP through the Plant Protection Research Institute (PPRI) in South Africa when a PPRI scientist, Roger Price, visited LUBILOSA project staff in the UK in 1993. Soon afterwards PPRI began testing *Metarhizium* against brown locust. The testing was successful and the results impressed PPRI enough to introduce LUBILOSA to Diane Neethling, BCP’s Managing Director. BCP began collaborating with LUBILOSA and PPRI in joint field trials. LUBILOSA organized a workshop in

Pretoria, South Africa, in March 1998, to facilitate the registration and commercialization process (LUBILOSA 1998). After the workshop LUBILOSA worked with BCP to produce a registration document which was submitted in October 1998, and accepted. The following month BCP signed a licensing agreement with LUBILOSA.

The second company, NPP, submitted a registration document to Comité Sahélien de Pesticides (CSP) of CILSS. Registration is expected for June 2001. CSP will implement biopesticide registration regulations in May 2001 and register Green Muscle under the new regulations. One of the reasons for choosing NPP is that the company is owned by Nichimen and Sumitomo, two Japanese pesticide manufacturers. Donors provide many of the pesticides supplied to grasshopper and locust control programs at a subsidized rate. LUBILOSA hopes that NPP is well placed to provide Green Muscle to the Japanese KR2 program, which supports spraying against the commercially viable West African grasshopper market (Dent 1998). Moreover NPP has a distribution network in West Africa through its mother company, Calliope.

One of the prerequisites to commercializing Green Muscle is sorting out issues relating to the intellectual property rights (IPR) to the biopesticide, which is a highly complex and sensitive issue in a multidonor, multi-institutional project (LUBILOSA 1999). LUBILOSA produced a position statement on IPR, which has the two objectives of ensuring that benefits of Green Muscle reach as many people as possible in Africa, and that the royalties resulting from commercialization are distributed equitably. To achieve the latter LUBILOSA has set up a trust fund that collaborating agencies can use for studentships, collaborative research, etc.

An additional benefit of the licensing process is that the licensing fee is a very effective test of whether the private sector partner is really committed to the product. Putting it another way a license fee is an excellent test of whether a commercial company thinks the researchers' "best bet" makes a "plausible promise" to them. Douthwaite (in press) found that key stakeholders who had invested their own money in a new technology were much more motivated and committed to sorting out the inevitable complications and obstacles that arise when bringing a complex new technology to the market.

Another prerequisite to successful commercialization through licensing is that there is a detailed specification of the product that the company is going to produce. Without this specification the company could use the Green Muscle trademark owned by CABI Bioscience and the LUBILOSA name and reputation to sell an inferior quality product. This could quickly kill off an incipient market for the new product. One of the benefits of the IITA production plant is that it has given sufficient firsthand experience to develop a workable, stable, and clearly defined specification for Green Muscle.

Not only BCP and NPP were impressed with the performance of Green Muscle. As outlined in the introduction, locusts plague Australia and people are concerned about the effect of chemical sprays on the environment. Not surprisingly, then, Australia's Commonwealth Scientific and Industrial Organisation (CSIRO) set about applying LUBILOSA's well-documented findings to Australia (Milner 2000). Small-scale field trials in 1997 were successful and as a result a collaborative project was set up with CSIRO, the Australian Plague Locusts Commission (APLC), NSW Agriculture and the Queensland Department of Natural Resources. In 1999, 2000 ha were sprayed in Queensland with *Metarhizium* spores suspended in mineral oil, as pioneered by the LUBILOSA project. The biopesticide has consistently achieved over 90% control of migratory locusts in a range of conditions. As with the LUBILOSA project, a private company has begun working with the public-sector researchers to develop commercial manufacturing procedures. The name Green Guard has been registered for the product (Milner 2000).

#### *Beginning the expansion phase: stewarding Green Muscle to impact*

Phase 3 of LUBILOSA finished at the end of 1998 with two companies licensed to manufacture Green Muscle and launch it on the market. However, the stakeholders involved in the project reached the consensus that "launching the product will not necessarily lead to the scale of adoption which the project sponsors, participants, clients and spectators feel justifies the investment to date; indeed, without further support the product may fail" (LUBILOSA 1999). Thus, a modest Phase 4 was funded to "steward" the technology by continuing to work with the two licensed companies on product specification and quality control, and to improve the political environment and market for Green Muscle. A second objective of Phase 4 is to continue to develop use strategies for Green Muscle, particularly in IPM programs. In fact this can be seen as part of product stewardship because by developing usage strategies and making farmers, NGOs, national agricultural research and extension systems, and other stakeholders aware of them, LUBILOSA is helping to create a market for the product.

Since the stewardship phase began at the beginning of 1999, the benefit of, and need for "stewarding" has become even more evident. LUBILOSA has provided help to NPP in France on aspects of quality control, and to BCP in South Africa on spore extraction and with the training of technicians.

However, the main emphasis in Phase 4 has been on the demand rather than the supply side. Green Muscle is expensive to produce at the IITA production facility. Steady-state fermentation will bring the production costs down, but only on large production runs. However, a large production run needs a large market, which does not exist because the price is too high. This is a common problem for many new products on the market: solar cells are just one example.

LUBILOSA has been working with a number of organizations involved in the control of grasshoppers and locusts to develop the market for Green Muscle, with some success. In 1999, Secours Catholique du Mali, an NGO in Mopti in Mali which collaborates with LUBILOSA, supported farmers in Mali to purchase and spray Green Muscle against grasshoppers as part of their normal control program. This was the first time that Green Muscle had been bought and used by farmers without specialist support. Then, in August 2000, the Niger Plant Protection Agency used Green Muscle to spray 2000 ha against rice grasshopper, supported by the Luxembourg government, one of their principal donors. This was the first time that Green Muscle had been used as “standard practice” in a government spraying program. At the same time the Plant Protection Agency launched Green Muscle officially in Niger, and is now fully committed to microbial grasshopper control. Both the Mali and Niger sprayings are signs that the expansion phase is beginning.

The aerial spraying in Niger would not have occurred without Phase 4. In fact the original plan was to spray the area five times, but NPP was not able to supply the Green Muscle as expected. Instead, the Green Muscle used was manufactured at the IITA production facility in Cotonou, which would have been closed without Phase 4.

LUBILOSA decided to specifically look at Green Muscle use strategies in Phase 4 because different species of grasshopper require different IPM approaches to control them. For example, the Senegalese grasshopper, the most important grasshopper pest in the Sahel, cannot be controlled by blanket spraying or other simple approaches that might work for other species (Lomer et al. 1999). In Phase 4 LUBILOSA is continuing, with its collaborators from previous phases, to develop IPM use strategies for Green Muscle. One collaborator, the FAO-EMPRES (Emergency Prevention Scheme), has emerged as an important and natural ally to LUBILOSA because of its objective: “To promote and catalyse the realisation of regional self-sufficiency for averting locust plagues through strengthening existing national, regional, and international components of desert locust management systems” (FAO 1995). LUBILOSA is also collaborating with the UK Department for International Development (DFID) on a project to develop use strategies to control red locusts in South Africa and with the European Union for the control of Italian locusts and Moroccan locusts in Spain and Italy. These projects will help develop the market for Green Muscle.

## Discussion

The life history of the LUBILOSA project outlined in the previous sections used a “theory of the case” to focus and give structure to the life history narrative. The “theory of the case” is that the LUBILOSA innovation process is similar to that of other types of technology shown in Figure 1.

Clearly the “theory of the case” was valid. The project began with an invention, which was Prior’s discovery that suspending fungi spores in some oils, rather than killing them as previously believed, actually made the spores more efficient. This invention was then the catalyst for a group of donors and research institutes to set up the LUBILOSA project to develop a “best bet”, which was *M. anisopliae* var. *acridum* strain IMI330189. Phases 2 and 3 of LUBILOSA corresponded to the start-up and the beginning of the adaptation phase where researchers then turned the “best bet” into a product that provided potential manufacturers and users with a “plausible promise” of something better than they had before. In Phase 4 LUBILOSA started to “steward” Green Muscle to the beginning of the expansion phase.

As already discussed, similarity between the model in Figure 1 and the LUBILOSA innovation process is important because it means that lessons learned from LUBILOSA may well be relevant to the development of technologies other than biopesticides, and conversely, that LUBILOSA managers can learn from experiences of the early innovation of other types of technology. The lessons to be learned from LUBILOSA all hinge on whether it has been a successful project or not.

#### *LUBILOSA's ex-post and ex-ante impact*

LUBILOSA has clearly been successful in many spheres, as the life history shows. In short, the project has achieved what the US Congress report said was needed after the 1986 to 1989 desert locust outbreak—an environmentally friendly alternative to spraying broad-spectrum pesticides to control locusts and grasshoppers. LUBILOSA has also built up a constituency of support for Green Muscle including FAO-EMPRES, donors, NGOs, and advanced research institutes. LUBILOSA has contributed greatly to the scientific body of knowledge on biopesticides, publishing 111 refereed journal papers and book chapters as well as conference proceedings, LUBILOSA socioeconomic series papers, project reports, and other deliverables. Many of these papers are available on LUBILOSA’s web site (<http://www.lubilosa.org>). Never before has such detailed research been carried out on fungus–host ecology and such detailed findings published about the production process of a mycoinsecticide. While some of LUBILOSA’s findings may not be new, before they resided only as industrial secrets. Putting such a large body of knowledge into the public domain has spawned the development of similar mycoinsecticides in Australia and elsewhere. Moreover, LUBILOSA staff and the IITA production facility have been pivotal in the development of a biopesticide to control termites, also based on a strain of *M. anisopliae*.

However, the real impact of the LUBILOSA project will be judged not in these terms, but in the amount of crop Green Muscle manages to save from grasshoppers and locusts, weighed against the cost of developing the biopesticide, manufacturing it,

distributing it, and spraying it. In this context people might see the failure to produce a robust commercial product after 10 years as a bad sign. Why, they might ask, if Green Muscle is environmentally safe, if it can control grasshoppers for a season with just one spraying, and if two “high tech” companies are licensed to manufacture it, does LUBILOSA need a Phase 4?

These concerns can be easily answered. Firstly, developing new technology takes time as the US Congress Report (1990) acknowledged when it said it would take 8 to 10 years to develop alternatives to chemical pesticides ready for widespread use. Moreover, Collinson and Tollens (1994), in a review of the development and transfer of CGIAR technologies, state that when new knowledge is needed from strategic research it is not unusual for it to take 10 years to develop a useful technology, and another 10 years for the technology to gain wide acceptance. LUBILOSA has had to generate more new knowledge than most research projects and so developing a “useful technology” within 10 years has been no small achievement.

Secondly, rather than being a negative sign, LUBILOSA’s stewardship phase should be seen as an astute move based on a very good understanding of the innovation process that will give Green Muscle the best possible chance of success. Douthwaite et al. (2000) found that the “adoptability” (as defined by Rogers 1995) of successful technologies improved during the adaptation phase, that is, between first release on the market and the beginning of widespread adoption. Making a similar observation Mokyr (1990, p. 12) said: “Virtually every major invention was followed by a learning process during which the production costs using the new technique declined”. Douthwaite (in press) found that the improvements in adoptability came mainly from changes made by the key stakeholders—the people key to making use of the technology—to the technology itself, and also through modifications to the environment, including the policy environment. These improvements can make the difference between technology success and failure. Importantly, though, Douthwaite et al. (2000) discovered that whether beneficial adaptations made in the adaptation phase are carried through to the expansion phase depends critically on there being a product champion. The role a product champion plays is almost identical to the concept of stewarding in Phase 4 of the LUBILOSA project. The product champion “nurtures” or “stewards” the technology by working to fill knowledge gaps that the key stakeholders might have, and working to improve the political environment and market for the technology. Two requisites for a successful product champion are that the person or group should be knowledgeable and motivated. This makes it very likely that the product champion will come from the R&D team which developed the technology in the first place (Douthwaite, in press).

The second argument for product championing Green Muscle comes from a market analysis. Microbial pesticides like Green Muscle account for just 1% of the world’s crop protection market, and most of this is taken by products based on *Bacillus*

*thuringiensis (Bt)*. Two of the main constraints to their wider adoption is their specificity and slow “knock-down”: pesticide companies want to produce broad-spectrum pesticides that can be marketed to deal with a wide range of pests while farmers often want a chemical that kills the pest quickly once they decide to spray. As a result, private sector companies have not invested much in microbial pesticide research and product development, leaving this to the public sector (Langewald and Cherry 2000). This is to be expected for products whose main advantage is savings in externalities, savings that by definition the market cannot capture without policy changes. Part of product championing is to lobby for policy changes and so change the environment in favor of the technology.

#### *A new paradigm for impact-driven research?*

As well as delivering Green Muscle, the second impact claim that the LUBILOSA project makes is that LUBILOSA represents a new approach to public sector agricultural research that is needed to move from basic “upstream” research through to real adoption, impact, and benefits in farmers’ fields. Dent (1999) claims that LUBILOSA is different from other public sector-led developments of biopesticides that have relied on a team from a single institute. Such approaches, Dent (1999) argues, have mainly failed because they have not been able to assemble the necessary skills required to commercialize a biopesticide. These skills include exploration, identification, and screening of pathogen isolates, mass production, storage, formulation, application, ecology, ecotoxicology, and registration. Assembling this expertise, Dent says, requires a LUBILOSA-like consortium of public and private sector organizations funded out of necessity from different, and changing, sources.

A broad skill base is not the only advantage of involving multiple stakeholders in a project. By being involved, stakeholders build up feelings of ownership towards a new technology and the political climate changes in its favor.

A second argument why LUBILOSA embodies a new and needed paradigm shift is that the project is probably unique in the field of international agricultural research in having a “stewardship” phase. The good understanding of the innovation process that the existence of a “stewardship” phase demonstrates is often missing from many other agricultural research projects. Instead, many research projects in the CGIAR system have in the past implicitly assumed the classical plant breeding research and innovation model (Kaimowitz et al. 1989) where it is the researchers’ responsibility to develop a “best bet” and no more.

## Conclusions

LUBILOSA has been successful. It has developed a biopesticide called Green Muscle that is safer and better for the environment than any chemical spray alternative. The project has succeeded in getting Green Muscle known and used by Sahelian crop protection programs and by farmers. Two commercial companies are ready to begin manufacture.

However, more than 10 years after LUBILOSA started, most of the project's impact is still to be felt. The project has met expectations derived from previous work that it can take 10 years to develop a useful product when beginning with basic research, and based on past experience it may well be another 10 years before Green Muscle becomes widely adopted. Whether Green Muscle does eventually fulfil people's hopes depends on how the policy and economic environment evolves. LUBILOSA, by having a final "stewardship" phase designed at proactively trying to alter these environments in Green Muscle's favor, has given itself every chance of achieving high impact. Moreover, LUBILOSA has shown itself to embody a new paradigm to impact-driven agricultural research and development that is based on a good understanding of the innovation process. LUBILOSA's approach follows a participatory approach identified as being successful for other types of technology which explicitly recognizes that new technologies need championing, unlike older approaches that separated R&D from commercialization and extension. LUBILOSA's approach also recognizes that technology change in complex political, socioeconomic, or technical conditions can best be brought about through a multidisciplinary consortium approach where a number of stakeholders with a wide skill base work together. LUBILOSA's model almost certainly is applicable beyond the field of biopesticide development.

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