Biocontrol News and Information ***37****(3), 17N–24N*
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General News

Rwanda Produces Nematode-based Biocontrol Agents for Soil Insect Pests

Rwanda's first-ever biocontrol agent factory, able to mass-produce beneficial entomopathogenic nematodes (EPNs), opened at the end of 2015. EPNs that occur naturally in the soil were isolated, and are now being mass-produced in vitro, and then applied to the field to destroy soil insect pests. The lethal impact of EPNs is due to a symbiotic relationship between the nematode and symbiotic bacteria harboured in its gut. Once the nematode has penetrated the insect, bacteria are released into the insect tissues, where they multiply and rapidly kill the insect. The nematode then feeds on the bacteria/host tissue. It is important to distinguish between EPNs and the larger plant-parasitic nematodes, which are root pests and taxonomically distinct. The biocontrol factory is an essential step forward in Rwanda's rising expertise in biological control of agricultural pests, serving as a model for future scale-out, and also as a platform to conduct sound research in cooperation with neighbouring countries in East Africa.[1]

A solution for soil insect control was urgently needed. Serious soil insect outbreaks from about 2011 onwards have been devastating many vegetable and tuber crops, probably due to changes in agronomic practices. We know from our surveys of >1000 soil insects collected in Rwanda in 2014 that at least 40 different soil insect species impact agriculture in the country, but the most troublesome are scarabaeid larvae in the genera *Anomala* and *Hoplochelus* and the tribe Melolonthini, followed by cutworms (*Agrotis* species), bean flies (*Ophiomyia* species) and tuber-attacking weevils (*Cylas* species). Not only do the pests damage crops, but the impact of infestation also filters through the entire value chain. Poor yields mean reduced food for household consumption and, as demand for agricultural products exceeds supply, prices shoot up making food expensive. Additionally, food crops damaged by soil pests are prone to secondary infections, thus reducing their shelf-life and marketable value. Crop yield losses due to soil insects, including total losses in some areas, have heavily impacted on smallholder farmers and their families.

With one of the highest population densities in Africa, over 80% of its population dependent on agriculture for their livelihoods, and an influx of refugees, land and other resources in Rwanda are stretched. Consequently, any threat to agricultural production may have serious and far-reaching consequences.

But controlling soil pests poses a number of challenges. Firstly, soil pests occur below the ground making their detection and control difficult. Secondly, there is a lack of knowledge and skills in soil pest control (in our survey of 110 households, 76% of farmers lacked these). Thirdly, soil pesticides are either not available or costly, are often highly toxic to humans, may have serious other nontarget effects, or are banned from use nationally or internationally.

Against this background, a project was implemented in 2014–2015 that offers Rwandan farmers better options for soil pest control, primarily in the form of EPNs. The project was based on a multipartite collaboration to transfer biocontrol-based crop protection technology from China to Rwanda with the help of European and East African experts and under the supervision of Rwanda's Ministry of Agriculture (MINAGRI). The partnership was led by CABI centres in China and Kenya, together with the primary beneficiary, the Rwanda Agriculture Board (RAB). The project was supported by technology experts from the Guangdong Entomological Institute, China (GEI), the Institute of Plant Protection of the Chinese Academy of Agricultural Sciences (IPP-CAAS) and CABI centres in Switzerland and the UK.

The team came together under a project funded by the Research Challenge Fund of the AgriTT programme of the UK Department for International Development (DFID AgriTT RCF 1301), building on previous work in central Europe, China and the Democratic People's Republic of Korea.[2]

We have made promising progress in four areas:

1. Nine local EPN species/strains were isolated from Rwandan soils during surveys in 22 semi-natural and 17 agricultural habitats across 16 districts of different altitudes in northern, central, eastern and southern Rwanda in 2014 (216 samples in all).[3] Among them five new species/strains were identified using DNA sequence comparisons and morphological examination, i.e. previously unknown strains of *Steinernema carpocapsae* and *Heterorhabditis bacteriophora*, as well as two unknown steinernematids and one unknown heterorhabditid. These are the first records of naturally occurring EPNs in Rwanda. It is also the first record of *S. carpocapsae* from Africa. Subsequently, 12 laboratory bioassay screening tests for nematode virulence and control efficacy revealed that these strains and species are effective against a number of different soil pests, each nematode having a slightly different specificity.

2. The first-ever biocontrol agent mass-production factory was established and adapted for local conditions at the research centre of RAB's southern zone division in Rubona between 2014 and 2015, making biocontrol products against soil insect pests available for the first time. Four native EPNs (*Steinernema* sp. strain RW14-M-C2a-3, *Steinernema* sp. RW14-M-C2b-1, *S. carpocapsae* RW14-G-R3a-2, *H. bacteriophora* RW14-N-C4a) are currently being produced.[3] The factory also produces four internationally used

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EPNs (*S. longicaudum* X-7, *H. bacteriophora* H06, *H. indica* LN2, *S. carpocapsae* All) for comparative research, largely for use as positive standards. The in-vitro mass-production is based on semi-solid systems using sponges as support materials. The symbiotic bacteria of the specific nematode are subcultured first. Then they are mass-cultured on media-soaked sponges. Once the bacteria have proliferated, nematodes are inoculated on to the media-soaked sponges where they can also proliferate. Once most of the nematodes have reached the infective juvenile stage, each sponge with its nematodes is either cool-stored, or harvested, formulated, distributed and applied. The factory is currently producing about 1–2 billion nematodes per production cycle, but has the capacity of producing up to 10 billion per cycle, thus about 100 billion nematodes per year. The biocontrol products can, depending on the application method (in-soil row or spot sprays), crop and crop stage, be applied on about 50–200 ha of vegetables or tuber crops.

3. The EPNs were tested in six field trials in Irish potato, beans and cabbage to facilitate the successful incorporation of the new technology with local integrated crop management techniques, such as crop rotation and manual hand-picking of insect pests during soil preparation or from damaged crops. In addition EPNs can replace the occasionally used synthetic soil insecticides.

4. Extensive in-country capacity building helped to successfully transfer and adapt the Chinese soil pest control technology to Rwanda, and to lay a solid base to scale out the technology in Rwanda and, potentially, elsewhere in East Africa. A total of 12 Rwandan experts (six men and six women) are now fully trained in EPN production including isolate screening, stock culture maintenance, bacteria and nematode mass-production, product storage and field application. Several demonstration trials and mass-extension events introduced hundreds of smallholder farmers to this new control method by the end of 2015, and further events are following.

In summary, the project, despite its extremely short two-year timeframe, made an environmentally friendly and economically sustainable plant protection technology available in Rwanda. It built in-country capacity to mass-produce and use the country's native EPNs for soil pest control. Field application trials indicated reductions of 20–40% in damage and 5–20% in losses caused by soil insect pests. Thus, soil pest-based losses in smallholder vegetable production can be reduced and the food situation better stabilized. Moreover, adverse health effects of toxic soil pesticides can be eliminated through replacing them with safe, EPN-based biocontrol products. What remains is to include EPNs in the relevant Rwandan legislation, something that has recently been kick-started, as Rwanda had no regulatory framework in place for the use of indigenous macrobial biocontrol agents. This will allow a widespread use of such technologies either as governmental programmes or through commercialization.

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Extraordinary Economic Benefits of Investing in Mole Cricket Biological Control

An economic analysis of the impact on cattle producers in Florida of a 34-year (1979–2012) biological control programme against invasive mole crickets shows a benefit–cost ratio of 52:1.[1] The study is a compelling addition to a growing body of evidence showing that developing and implementing biological control takes time and resources, but ultimately has the potential for huge returns on investment.

Three species of *Neoscapteriscus* mole crickets that were accidentally introduced from South America emerged as pests in the southeastern USA during the first quarter of the 20th century. Between them, they established over an area extending from Florida to North Carolina, and west to Texas. The mole crickets feed primarily on roots and stems at night as they burrow underground. This causes severe and extensive damage to grass, notably pastures and amenity sites such as golf courses, and to cultivated crops. Chemical control with chlordane was effective but rather environmentally hazardous. It was the withdrawal of the persistent organochlorine insecticide for this use that stimulated consideration of a biological control approach, because alternative insecticides were less effective and more expensive.

Under the biological control programme, three biocontrol agents were introduced and established. The tachinid fly *Ormia depleta* from Brazil was released extensively in the late 1980s. The hymenopteran parasitoid *Larra bicolor* was imported several times from Bolivia from the late 1980s and established in Florida. In 2001, *L. bicolor* was released and established in Georgia. It was subsequently found in Alabama and Mississippi, presumably owing to spread from Florida or even Georgia. The nematode *Steinernema scapterisci* was imported from Uruguay in 1985 and later deployed across Florida by extension services, and also as a commercial product (Nematac® S) from 2001.

The analysis of the costs and benefits followed careful methodology to provide robust results. Costs for all work associated with developing and implementing the Mole Cricket Biological Control Program in the period 1979–2012 were derived from records of the University of Florida/Institute of Food and Agricultural Sciences. Operating funds (cost of equipment, supplies and project staff/students) were separated from state-funded faculty salary costs.

Benefits due to the programme were calculated by collecting and analysing farm-level data obtained from 577 valid responses to a questionnaire sent to 3030 members of the Florida Cattlemen's Association. Information elicited included type of cattle operation, area lost to mole crickets, and costs of control before and after the biological control programme. North, central and south Florida have different areas of pasture and experiences of mole cricket infestation and biological control. The data for the three regions were analysed separately and are discussed in depth in the paper.

Total costs of the biological control programme, adjusted to 2013 US dollars, were calculated as $4.46 million operational costs, plus $4.15 million state-funded faculty costs (faculty who would have been paid by the state anyway). Benefits in mole cricket control costs for cattle producers were calculated by comparing costs associated with mole cricket management in 2013 with annual costs before biological control (again adjusted to 2013 dollars). These benefits equated to $4.21 million, $7.39 million and $2.01 million for north, central and south Florida, respectively, i.e. a total benefit of biological control of c. $13.6 million for Florida cattle producers in 2013. The authors also calculated from the data supplied by cattle producers that 18% of pasture infested with mole crickets had been recovered (106,000 ha) and control costs had been reduced on another 20.6% of infested pasture (almost 118,000 ha), while the need for supplementary feeding or pasture renovation to maintain stocking rates had diminished.

The biological control programme ended in 2012. The three biocontrol agents have established and have been shown to spread naturally to maintain biological control of the mole crickets. Commercial production of the nematode ceased because it became unprofitable as demand fell. As is evident above, though, biological control is not complete, and in addition outbreaks can occur after events such as flooding, cultivation and pesticide application that disrupt biological control. Throughout the life of the programme, biological control was part of an integrated pest management system involving also cultural and chemical control. The biological control element is now focused on conservation, for example sowing nectar plants for *L. bicolor*, to ensure that current levels of biological control are maintained or restored if disrupted.

The authors calculated that the benefit–cost ratio the biological control programme had achieved by 2013, the first year after it finished, was 3:1 on the basis of total programme operational costs only, and 1.6:1 if the relevant proportion of salaries of permanent faculty are included. Thus all the costs were more than recovered within a single year (benefits accrued during the programme years were ignored). Yet this economic benefit to Florida's cattle producers will continue indefinitely because classical biological control has permanent impact. A benefit–cost ratio under these circumstances commonly relies on a social discount rate to estimate permanent benefit. Using a discount rate of 3% for the calculated benefit of $13.6 million for 2013, the authors determined the perpetual benefit of the biological control programme for cattle producers in Florida as $453 million, a benefit–cost ratio of 52:1.

The large 52-fold benefit is itself an underestimate, partly because the authors restricted the study to costs of mole cricket control in cattle production in Florida, yet the producers received other benefits as described above. Other sectors also benefitted from the biological control – turf producers, golf courses and other turf-based amenities, vegetable growers, home-owners with lawns – and the programme covered a large area of the southeastern USA beyond Florida, which benefitted from the Florida-funded research. But probably the largest economic gain came from the role the biocontrol agents played in limiting the spread of the invasive mole crickets. In Florida alone, they had the potential to infest 2 million hectares, with associated potential annual control costs of perhaps $18 million, yet their distribution may have been limited by biological control to 29% of this area.

Some 35 years ago now, decision makers in Florida were tasked with deciding how best to use public funding to tackle the mole cricket problem. Fortunately for the cattle producers and many others, they were far-sighted and chose to invest in biological control. The authors hope that rigorous economic analyses of successful biological control programmes, like this one, will help increase understanding and support for biological control as a long-term investment with the potential to deliver outstandingly cost-effective solutions to invasive species problems.

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Incorporating the Risk of Doing Nothing into Weed Biocontrol Release Applications

A paper in *BioControl* describes a matrix-based framework that allows the risks of nontarget effects from a prospective biocontrol agent and its target plant to be assessed on a like-for-like basis.[1] The tool has been developed for managers, decision makers and regulatory authorities tasked with deciding whether biocontrol releases should go ahead. The aim is to redress the imbalance in the weighting given to risks from biocontrol agents and invasive plants when making decisions about classical biological control releases. By considering both the risk of damage to native species from the biocontrol agent and the risk to native species from the target alien invasive plant, a better assessment of the overall risk of a release can be made.

In a weed biological control programme, biocontrol agent testing specifically looks for occurrence and severity of attack on nontarget plants (usually native species and also species of economic importance). The results are presented in a risk assessment which forms the core of an application to release the biocontrol agent. The nontarget risk that the target plant itself poses to these native species is not addressed in the same rigorous manner, although the threat the target plant poses to invaded ecosystems is generally used as a justification for the proposed biocontrol agent introduction. This discrepancy feeds through to decision making, where risk to nontarget species is treated as coming only from the potential agent, and not from the target plant as well.

Risk as a term is used in various ways, but for this framework it is defined as the *consequences* of an event and the *likelihood* of the event happening. The first two steps of the framework estimate the risk of (i) nontarget damage by the biocontrol agent and (ii) impacts on native species by the target plant.

Similar matrices are used for biocontrol agents and target plants; the difference is that for biocontrol agents, consequences and likelihood are 'of nontarget damage from the agent', while for target plants they are of 'impact to native species'. This reflects a greater certainty for biocontrol agent predictions, which are based on stringent testing. In both matrices, the consequences of the damage/impact from the agent/target are categorized on a four-point scale (catastrophic, pervasive, negligible, benign), and the likelihood of damage/impact on another four-point scale (very likely, likely, unlikely, very unlikely). This creates a 16-cell matrix. An indicative description of what each category should encompass and the criteria for selecting it are provided to minimize subjectivity. These are based on information from the literature on real-world situations of typical introductions, and by using selected worst-case examples as benchmarks (*Rhinocyllus conicus* and *Lantana camara* for agent and target, respectively, where damage/impact is very likely and will be catastrophic). Using this guidance, the consequences and likelihood of damage/impact from a proposed biocontrol agent/target plant can be decided, and the species assigned to the appropriate cell of the relevant matrix. Each cell has a pre-assigned risk (four levels: high, medium, low, miniscule), and a descriptive summary of how it equates to likelihood and impact. For example, 'Likely' (under likelihood) and 'Pervasive' (under consequences) damage/impact to nontarget/native species from the biocontrol agent/target plant is given a 'Medium' risk category in both matrices, with a brief descriptor of the damage/impact as 'likely and will be damaging').

The third step is to derive an overall risk status for the biocontrol agent/target plant combination. The four possible risk categories for each of them is used to create another 16-cell matrix. But in this combined risk matrix, each cell is assigned one of three risk ratings (coded by letter) that corresponds to an overall level of risk expressed in terms of nontarget damage if the biocontrol agent were released against the target plant: A = risk is considered low and it is appropriate to permit a release; B = further information is needed to ensure the risk is appropriate before release is permitted; C = risk is unacceptable and the release should not be permitted. The risk statuses derived from steps 1 and 2 determine which cell the agent/target combination is placed in. For example, if the risk of nontarget damage by the biocontrol agent is categorized from step 1 as 'Low', and the risk of impact on native species by the target plant is categorized from step 2 as 'High', the overall risk of releasing this biocontrol agent against this target plant, as shown in step 3, is A – release is appropriate. Yet if risk of nontarget damage from the biocontrol agent is 'Low' again, but risk of impact on native species from the target plant is also 'Low', the overall risk is B – further assessment necessary. Thus the risk of impact by the target plant on native species modifies the overall risk assigned to the introduction. (The authors emphasize that a 'B' rating does not necessarily indicate further host-specificity testing, which has been dealt with under the testing protocol, but that the supplied information is insufficient to make a judgement.)

The overall risk is the endpoint of the framework; it brings the focus back to the biocontrol agent and the decision about whether it should be released. But unlike conventional approaches to determining the risk of an agent release, the risk emerging from this matrix-based framework has taken equal account of target plant and biocontrol agent in deciding the overall risk to native species of making the release.

The authors illustrate how the framework would work in practice by using six historical examples where sufficient information on nontarget impacts of target plant and biocontrol agent are available to assign them to cells in steps 1 and 2. The biocontrol agents came in medium and low risk categories, as expected because they were subjected to testing and risk assessment, while the target plants came in the high or medium risk categories almost by default, because their obvious impact had made them targets of biological control programmes. Four of the biocontrol agent/target plant examples were placed in the low overall risk category in step 3, so would pass the criteria for release today. The other two were in category B, so would be suggested for more stringent assessment, but not immediate rejection. In these latter cases, the actual nontarget effects were transient in one case and minimal in the other, while biological control has been beneficial if patchy.

The authors stress that the framework outcome is not a traffic-light system for biocontrol agent releases. Instead, it presents like-for-like risks as an extra tool for decision makers to think about the level of risk they are prepared to accept. It highlights the risk of impact of the target plants on the same species that the decision makers are tasked to protect from errant biocontrol agents, and gets away from a sole focus on the risk from the biocontrol agent. Once the notion of risk to native species from the target plant is accepted, there may be a willingness to be less risk-averse with regard to the biocontrol agent.

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Biological Control of Old World *Vespula* Wasps in New Zealand

New Zealand has no native social wasps, but exotic *Vespula* wasps (*V. germanica* and *V. vulgaris*) have become widespread in the country since their introduction in 1945 and 1978 respectively. Absence of natural enemies and abundance of food sources such as honeydew have allowed them to flourish. In some habitats they are among the most commonly encountered insects, and the beech forests at the top of South Island have the highest densities of *Vespula* wasps in the world (10,000/ha on average).

The wasps have significant impacts on biodiversity and industry in New Zealand. Wasp densities may reach 30 nests per hectare in the beech forests of South Island, where they are now the dominant honeydew feeders and consume 70% of the honeydew.[1] By directly competing with native fauna for access to the honeydew resource and feeding on invertebrates the wasps, together with other introduced predators, have restructured the food web in these forests.[2] A recent economic evaluation showed that the wasps cost the country's economy some NZ$ 130 million per year. Largest impacts are in pastoral farming, where they disrupt bee pollination and hence reduce clover swards and increase fertilizer costs, and in apiculture, where they attack honeybees, steal honey and destroy hives – and by monopolizing honeydew in beech forests, they reduce honey yields. Wasp-related traffic accidents and health costs from wasp stings add to the toll.[3]

Vespula wasps are also a familiar feature of summers in their native range in the temperate Old World, not least because of their penchant for disrupting human outdoor eating in late summer in their search for sugar and protein. Earlier in the season, they perform a useful role in natural pest regulation because they forage for protein to supply the queen and growing larval brood, and pest insects are among their prey. The need for food becomes constant to maintain the rapidly growing colony. Late summer to early autumn, as the nest matures, is when they become more apparent – and a nuisance – to humans. Their nuisance status has led to a good deal of research, but so far no sustainable control methods have been developed.

The discovery in New Zealand of a previously unknown mite species may herald a breakthrough. First collected in 2011 from *V. germanica* wasps in nests in South Island, it was recently described as the new species *Pneumolaelaps niutirani*. This is the first time the genus has been found associated with vespid wasps. There are some 60 species of *Pneumolaelaps* worldwide, mostly associated with bumblebees. Adult female mites hitch-hike on bumblebee queens as the nests collapse in autumn, and overwinter with them in their hibernation sites.[4]

Pneumolaelaps niutirani has now been recovered from nests of the invasive *Vespula* spp. and also from honeybee hives in New Zealand. Systematic surveys indicated that the mite is widespread on both invasive species throughout the South Island and North Island. Mite-infested wasp nests are 50–70% smaller than uninfested nests, and preliminary observations suggest that worker wasps from mite-infested nests may be less aggressive than those from uninfested nests. Surveys also found immature life-stages of the mite present inside wasp nests, in cells containing wasp eggs or larvae, alongside adult mites. This indicates a strong link between mites and wasps, with the mites spending a significant part of their life history inside the nest. They aggregate in large numbers on the virgin wasp queen before it leaves the nest to mate and later hibernate, which indicates how they disperse and colonize new wasp nests. Taken together, phoresy and the mites' ability to evade the wasps' meticulous hygiene behaviour suggest a close, coevolved relationship, which merits further investigation and has been taken up by another initiative.

The discovery of the mite in association with poorly performing wasp nests suggests it could have potential for development as a biocontrol agent. But there was a potential roadblock. While the origin of the mite is a mystery, it seems likely that it is not a native New Zealand species. The mite has been investigated under the Hazardous Substances and New Organisms Act, 1996 to determine its legal status. This act requires that organisms not present in the country before 29 July 1998 are considered new organisms, and as such require approval to be brought into the country and before allowing intentional propagation and/or distribution. Fortunately, the Bee Surveillance Programme of the Ministry for Primary Industries, which began in the 1990s, had relevant sticky board traps dating back to 2003.

Examination of these indicated that *P. niutirani* was present from at least 2003 onwards on both islands, but had not been formally identified. As mites are poor dispersers, it was argued that they must have been present in the country for some if not many years before 2003 in order to reach such a wide distribution. This argument was accepted and the mite was deemed a non-new organism in a decision by the Environmental Protection Authority in December 2014.

Rearing the mites in captivity is a challenge that has not so far been overcome. The project application had stipulated the ability to mass rear the mite as a make-or-break point. This was because it was anticipated that large numbers of mites were going to be needed for safety and impact testing, and at that time the mite was not known to be so widely present or abundant. Since then, a method has been found for extracting live mites from nests, which means large numbers of mites can be retrieved quickly, so mass rearing may not be necessary – and the 'stop' on the project was avoided. Efforts continue to develop rearing methods, however, as they may be needed for some of the programme.

One puzzle recently solved is how the mites interact with the wasps, because mite gut analysis had found no evidence of wasp DNA. Worker wasps bring prey to the nest to feed the larvae, but they are unable to digest it themselves. Larvae digest the prey, and while they use the digested matter as a growth resource, they also regurgitate some of it, which is fed on to the rest of the colony by the workers. Filming the mites close up in a nest showed that they also feed on this regurgitated protein-rich material, thus reducing food resources for wasp workers.

Competition for food is not thought sufficient explanation for the observed reduction in wasp nest size and worker aggressiveness, and researchers believe that disease transmission is probably involved. As indicated above, the mite has been recovered from honeybee hives, albeit in low numbers, but the potential threat needs to be assessed. While the mites may have arrived accidentally as 'hitch-hikers' on raiding wasps, potential interactions with honeybees, and native Hymenoptera including bumblebees, are being investigated.

Current thinking is that the mite is probably best suited for an augmentative approach. The goal of the project, though, was to make more progress towards a long-term, landscape-scale biological control. So the remainder of the project will be focused on another wasp natural enemy: *Sphecophaga* parasitoids. Three species/subspecies were introduced to New Zealand in the 1980s–1990s, but according to B.J. Donovan, only one subspecies has established. Given the paucity of knowledge of this genus (most research has been done in New Zealand), it is possible there are undiscovered species in *Vespula*'s area of origin. To this end, surveys are planned for Europe in 2016, both to collect additional material of the established parasitoid (*S. vesparum vesparum*) to provide new genetic stock, and to survey for other natural enemies.

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Seeing is Believing: Rice Farmers' Experiences with Biological Control in Southern India

In their paper on farmers' attitudes toward the use of biological control agents (BCAs) in strawberry production in Italy, Israel and Germany, Moser *et al.*[1] indicate that the socioeconomic environment in which they are applied and the farmers' attitudes affect the use of BCAs. The authors also identify media coverage and the positives of BCAs as the most significant factors affecting growers' confidence in biological control. Though such large-scale studies on farmers' perceptions of biological control are lacking in India, the time has come to undertake extensive investigations on factors other than 'performance' of BCAs. It is all the more so considering the recent experiences with farmers implementing biological control in the south Indian states of Kerala and Andhra Pradesh.

In the predominantly rice-growing Kerala, the area under this staple cereal has fallen by 70% in the last four decades. The ever-increasing cost of cultivation together with the persistent pest and disease problems are often cited as reasons for this downward trend. Bucking the trend, however, Palakkad district still boasts high rice production despite the existence of similar hurdles.

In the Vadakkencherry panchayat of the district, where the crop is predominantly grown in about 700 ha during September–January, the 1500-odd rice farmers have shown the way to others by enthusiastically following biointensive integrated pest management (BIPM). The cost of production there was high until recently, chiefly because of the extensive and indiscriminate use of synthetic fertilizers and chemical pesticides. Change came in 2015/16 when the Kerala Agricultural University centre of the All-India Coordinated Research Project on Biological Control (AICRP-BC) at Thrissur initiated an extensive programme to implement BIPM in 10 ha of rice at Anakkappara padasekharam. The Vadakkencherry Krishi Bhavan and ATMA (Agriculture Technology Management Agency) under Kerala's Department of Agriculture partnered the initiative.

The required nucleus cultures of the biocontrol agents were supplied by the Indian Council of Agricultural Research's National Bureau of Agricultural Insect Resources (ICAR–NBAIR, Bengaluru). As anticipated, the BIPM programme was a resounding success. Rice yields increased, cost of production decreased dramatically, and, more than anything else, the farmers developed a better understanding of BIPM principles. The farmers could save Rs 4000–5000/ha just by giving up the customary 4–5 rounds of insecticide sprays. Consequently, the sale of insecticides has registered a 10–20% decline in the region. Farmers themselves are now taking up mass production of trichogrammatid parasitoids, a key component in BIPM. This involves mass rearing *Trichogramma* and producing farmer-friendly 'tricho-cards', containing parasitized eggs of a laboratory host-insect, ready for deployment. The BIPM experience has also unleashed a lot of energy among the agriculture department officials, who are now proud of their intervention in rice production at the right time.

In the picturesque Araku Valley near Visakhapatnam in Andhra Pradesh, rice-growing tribal farmers have benefitted from the Tribal Sub-Plan (TSP) programme of ICAR. The biocontrol-centred programme was run by the Anakapalle-based AICRP-BC centre at the Acharya N.G. Ranga Agricultural University (ANGRAU) with support from ICAR–NBAIR. The programme was particularly aimed at increasing the net incomes of small-scale and marginal women tribal farmers with landholdings of 0.2–0.4 ha.

During *kharif* (monsoon) and *rabi* (winter) of 2015/16, frontline demonstrations were conducted in 16 ha of rice in two villages, Kothavalasa and Gunjariguda. Apart from training the field staff on production of 'tricho-cards', ICAR–NBAIR also supplied the cards for direct field releases. It despatched back-up cultures of the host insect and *Trichogramma* species for further production and distribution to farmers. For its part, the Anakapalle centre trained 50 tribal farmers in organic farming techniques and provided inputs, including seeds of a high-yielding paddy variety (MTU 1010), a biopesticide (*Pseudomonas fluorescens*), liquid biofertilizers (*Azospirillum* and phosphobacteria), 'tricho-cards' and knapsack sprayers.

There were more productive tillers (8–10/hill) in the biocontrol-managed crop than in the traditionally raised crop (4/hill). Unlike in the traditional crop, there was neither zinc deficiency nor incidence of stem borer/leaf folder in the biocontrol crop. The farmers practising biological control recorded a higher yield (4025 kg/ha) than those practising traditional cultivation (2100 kg/ha). These motivated tribal farmers now want further dissemination of the organic farming techniques to reap higher yields and thus enjoy better livelihoods.

[1] Moser, R., Pertot, I., Elad, Y. and Raffaelli, R. (2008) Farmers' attitudes toward the use of biocontrol agents in IPM strawberry production in three countries. *Biological Control* 47, 125–132.

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Predator Refuges in Bioenergy Forests: Source or Sink?

Establishing a new crop can throw up unexpected problems. In a blog post[1], Anna-Sara Liman of the Swedish University of Agricultural Sciences, Uppsala, explains how 'energy forests' of fast-growing willows (*Salix* spp.) were established in Sweden in the 1990s as an early step in developing a bioenergy sector. These are managed by intense short-rotation coppicing every 3–5 years, when willow stems are harvested while the ground is still frozen in late winter. Willows in Sweden are attacked by three chrysomelid leaf beetle species that can reach outbreak levels. An increasing number of outbreaks was recorded in the energy forests, causing a substantial reduction in biomass production and posing a significant economic threat. The leaf beetles are preyed on by a guild of heteropteran plant and flower bugs, whose mode of feeding allows them to be omnivorous, feeding on plant cell sap and insect eggs and larvae. While the predators could potentially provide biological control, this has not proved an easy system to work with.

Leaf beetles hibernate as adults away from the trees: two species survive the Swedish winter in large aggregations under loose bark, or in cracks in fence posts or similar shelters, while the third overwinters in the soil. Adult beetles re-emerge in mid-May and re-invade the stand from the edges. The predatory bugs are more closely associated with the willows. One anthocorid species hibernates as an adult in cracks in bark crevices or litter, and lays eggs in leaf tissue; two mirid species survive winter in the egg stage, which females insert into willow bark. While this behaviour facilitates phenological synchrony between insect and tree, coppicing in late winter removes the predator population – which gives an explanation for the leaf beetle outbreaks in these forests. Providing refuges for the predators seemed a promising approach for managing the outbreaks, which led to a four-year field experiment whose results have been published in an open-access paper in *Journal of Applied Ecology*.[2]

The study looked at the effects of providing predator refuges by asynchronous coppicing: half of each treatment stand was left uncoppiced to provide a predator refuge, and was then coppiced 2–3 years later when the other half of the stand had regenerated sufficiently to provide a refuge instead. Counter-intuitively, the team found that predator populations were lower and leaf beetle populations higher in stands with refuges than in stands without, so refuges increased rather than decreased the risk of outbreaks. The authors suggest that coppicing in winter, which removes the dormant buds so the regenerating trees shoot later and leaves are smaller, may introduce phenological asynchrony. Leaf feeders may be attracted to the older uncoppiced growth, and their aggregations act in turn as a sink for the predators, which do not disperse to the new growth. They say good understanding of the ecology of interacting species is needed for conservation biological control, in this case to design a system with an appropriate trade-off between providing predator refuges and increasing attractive leaf herbivore habitat.

[1]Liman, A-S. (2016) The rise and fall of a simple solution.
Web: https://jappliedecologyblog.wordpress.com/2016/06/16/the-rise-and-fall-of-a-simple-solution/

[2]Liman, A-S., Eklund, K. and Björkman, C. (2016) Predator refuges for conservation biological control in an intermediately disturbed system: the rise and fall of a simple solution. *Journal of Applied Ecology*. DOI:10.1111/1365-2664.12709.

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Field Insectaries: Legacy of a Biological Control Project

A paper in *Biocontrol Science and Technology* describes how a concerted extension effort ensured the sustainability of a biological control project.[1] The Eurasian cereal leaf beetle (*Oulema melanopus*) was first recorded in North America in the 1960s. Biological control was established in midwestern US states with introduced natural enemies: the mymarid egg parasitoid (*Anaphes flavipes*) and the eulophid larval parasitoid (*Tetrastichus julis*). The pest continued its spread, and a multi-agency project was set up to control it in seven western US states and two Canadian provinces. In Washington, *O. melanopus* was first recorded in 1999, and prompt action meant the two agents were introduced from 2000. While *A. flavipes* did not establish, *T. julis* established at all sites and, within five years of surviving its first Washington winter, it had spread across the state and was effectively suppressing the leaf beetle.

Release methods were key to its success. Parasitoids were released into 'field insectaries', a technique developed for the project. Most field insectaries in the state were on farms (typically exceeding 1000 ha in this area of the USA) where pest populations were high and the farmer was willing to dedicate at least 1.4 ha, which was chosen and maintained per project protocol as a favourable habitat for the pest. An insectary comprised two halves, each planted and fallow in alternate years, together with adjacent habitat for overwintering *O. melanopus*. One half was planted in autumn/fall with a strip of winter wheat, and in spring with three successive plantings of oats at two-week intervals. Holding and managing a field insectary was covered by signed agreement and cash compensation. Adult *O. melanopus* overwintered away from the plant and emerged in spring to feed on the winter wheat. As the spring crops grew, it moved into the preferred host, oats, with the successive plantings ensuring high pest populations when the parasitoids were released. Crops were harvested normally, but strips were not tilled at that time – left instead until the following June to allow any parasitoids to emerge.

With the project coming to a close, the team looked for ways to ensure its sustainability through extension activities. In 2007, they set up demonstration plots to show how a simplified field insectary, comprising a strip of oats about 10-m wide located between commercial fields of winter and spring wheat and seeded two weeks after the spring wheat, could increase parasitoid populations on-farm. Beetles moved from winter wheat into the oats, and remained there rather than moving on to spring wheat. An extension bulletin on the topic ensured that farmers had the information to implement this and maximize biological control. Seven years after the project formally finished, occurrence of the leaf beetle in Washington State remains mostly low.

[1] Roberts, D.E. (2016) Classical biological control of the cereal leaf beetle, *Oulema melanopus* (Coleoptera: Chrysomelidae), in Washington State and rôle of field insectaries, a review. *Biocontrol Science and Technology* 26, 877–893.

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Mark Jervis Memorial Issue

The May 2016 issue of *Entomologia Experimentalis et Applicata*, 159(2), is an open-access special memorial issue to commemorate the contribution made to the understanding of insect and parasitoid science by Mark Jervis of Cardiff University in the UK, who died on 11 March 2014. The issue includes contributions from leading researchers who knew him, which celebrate and build on his research, and provide in-depth analysis of how the field has developed, and current understanding and challenges.

Web: http://onlinelibrary.wiley.com/doi/10.1111/eea.2016.159.issue-2/issuetoc