Session 9D

Writing a Scientific Paper

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Platform Papers:	9D-1 to 9D-2

Writing a scientific paper

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A crucial part of scientific research is effective communication of results. As scientists we are judged by our peers on the quality of our research and increasingly this is taken to be indicated by the number of publications in refereed journals with a high impact factor. Here we consider what the role of a scientific paper is and discuss approaches to writing one. We anticipate our audience will be mostly postgraduate students and young scientists in early career.

What is a scientific paper?

A scientific paper is not the same as a project report. In a report, the results of an investigation are presented, often at length. Quite often, much of the detailed interpretation is left to the reader. In contrast, a scientific paper presents a digested and carefully analysed set of results in order to highlight for a wide scientific readership not just what the main outcomes were, but also to indicate the wider implications of the work and any possible applications. Choice of the journal depends on the target audience and the typical topic coverage of a journal. Journals have 'house-styles' and provide instructions on the structure of the paper.

In all cases papers will have an Introduction which outlines the background to the work, and justifies doing it, followed by a Materials & Methods section which describes how the work was done in sufficient detail to enable someone else to repeat it. In the Results section, the authors describe what happened and subsequently but sometimes in parallel there is a Discussion section which explains what the results mean and place the findings in a wider context.

Before you start writing

Clarify what you want the reader to learn. Investigate which journal is appropriate for the information you want to provide to the readership (i.e. check the journal's remit). When you have decided an appropriate journal to submit to, check the journal style, i.e. check the structure of papers (the titles and order of the sections), the unit conventions, the statistical conventions, how the journal cites and formats references. Plan the paper by identifying the main message, selecting what tables and figures are needed to illustrate the 'story'. Plan the results section. Cut out anything not relevant to the message.

Writing the paper

Papers should be written in the past tense. Don't start with the Introduction. Often writers start with the Materials and Methods section, because this is the easiest to write and is done in a logical consecutive order.

Next write the 'Results' section. Do not at this stage combine with the 'Discussion'. Present the findings in a logical order (which is not necessarily the same as the order in which things were done). Use appropriate subheadings. It is not necessary to present all the results obtained, be selective and highlight the main points. Next, write the Introduction. This should set out the problem and explain (justify) why you did the work.

Write the Discussion last. Initially have separate Results and Discussion sections. This lets you distinguish what you did from what others have already done i.e. you demonstrate the scientific novelty of your work. If the journal style is for a combined results and discussion, combine them later.

Write the discussion to provide:

1) explanation (how the results came about, reasons for the statistical approach):
2) interpretation (what it means for the science and understanding of the topic):
3) application (how the findings will be used).

The Discussion must not repeat the results. If the target journal requires a combined 'Results and Discussion' section, combine the two sections and use subheadings so the reader can distinguish what you found out from what was already known. Use a different set of subheadings from the results. A common structure is to have headings in Results 'Expt 1', Expt 2' etc but in the Discussion have headings e.g. 'Trends in leaf area', 'Effects of fungicides' etc.

Pay great attention to the references. Check the journal style and ensure you cite correctly, and you cite in the journal style.

Writing style

Shorter sentences are better. Write concisely, the editor and reviewers will judge the submission on scientific quality not quantity. Do not refer to every data point, just make the important contrasts. Do not contrast values and then say they are not significantly different – all you can say is they are the same. Sometimes 'no difference' is an important result. Round data values to at most three significant figures, often two will do and more is spurious accuracy. Give statistical data (SE, SED, SEM, LSD – check journal conventions) to one additional place. Do not plagiarise from other published material.

Tables and figures

Do not present all your results – select those that are central to the message – and never present the same results in a table AND a figure. In figures, make sure the axes, points, lines and legends will be legible when reduced for printing. Generally keep it simple. Check all tables and figures are referred to in the text and are numbered in the order they are referred to in the text.

Other thoughts

If you say 'this confirms someone else's results' throughout your paper, it is unlikely you have novel findings and the submission is likely to be rejected. If you have done a PhD, consider rewriting the literature review with your supervisor and submitting as a review paper to an appropriate journal that publishes reviews.

And finally, enjoy writing as much as researching

Submitting a scientific paper and responding to editors

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A crucial part of scientific research is communicating results. Increasingly scientists are judged on the quality of their research which is taken to be indicated by the number of publications in journals with a high impact factor. Here we describe the steps in submitting a scientific paper, consider the possible decisions by the journal and your responses.

Writing your scientific paper?

When preparing your paper you will have clarified what you want the reader to learn. You will then have (a) investigated which journal is appropriate for the subject matter (i.e. check its remit), and (b) checked the journal style, (i.e. the structure of papers, the titles and order of the sections, the unit conventions, the statistics conventions, how the journal cites and formats references). Your scientific paper will present a digested set of results in order to highlight for a wide scientific readership not just what the main outcomes were, but also to indicate the wider implications of the work and any possible applications. A scientific paper usually starts with an Introduction (which outlines the background to the work, and justifies doing it). There is a Materials & Methods section which describes how the work was done and how the data was collected in sufficient detail to enable someone else to repeat it. In the Results section, you describe what happened. Finally, and crucially there is a Discussion section which explains what the results mean. Sometimes the Discussion is combined with the Results.

Submitting your paper

Many journals now require online submission. Some still ask for paper copies and if so, send the number of copies requested. With online submission upload the paper in the style requested. This may be as a single file containing tables and figures, or the journal may request text, tables and figures to be in separate files. The journal will want you to confirm that ALL the authors have (a) seen the paper, (b) approved the paper. Ensure this is done. The senior or corresponding author will have to certify this.

Journal Responses

You are unlikely to get an immediate acceptance. All reputable journals operate a review or referee process in which your submission is read and assessed by at least one scientist who has knowledge of the field of study. Most referees are active scientists and cannot read your submission and respond as soon as they receive it. However, if you have not heard anything after three months then consider asking the senior editor about progress.

The most usual responses from the editors of a journal are revision (minor or major) or rejection. If your submission is a rejected you may not have submitted to the most appropriate journal. In this case the editors will probably say it is not within the journal remit and may suggest a more appropriate journal. If there are other reasons for rejection, do not be angry with the editors. Editors choose reviewers for the expertise, they are not fools. Think about the comments made and resolve to learn from them so you can improve your performance as a scientist and as a writer.

Minor revision usually means the paper is basically satisfactory but the reviewers think there are some improvements or clarifications to be made and/or it is not in the required format. The amendments should not take too long.

Major revision means the journal still wants a paper on this topic, however, you may need to do some more analyses and re-interpretation. Sometimes this is classed as 'Revise and Resubmit'. Try to modify your paper as quickly as possible. Ensure you respond to ALL the comments. Usually editors will ask you to write your responses to the reviewers comments: ensure you provide these. If clarification is asked for, ensure you put this in the revision not just in the response letter.

Think of a revision as the last chance for you to get the paper accepted. Make sure you do all the amendments required. If there were comments that your original submission did not conform to the journal style, ensure this revision is perfect. Editors do not want a paper which requires further revision: the editor will have other papers which can be accepted in perfect condition. Remember it is up to you as an author to submit a paper that can be accepted. The editor and referees provide guidance on how your paper needs to be revised to make it acceptable to the journal. It is not their job to rewrite your paper for you.

Some other thoughts

Space is at a premium in journals. So write concisely. Do not refer to every data point, just make the important contrasts. Don't contrast values and then say they are not significantly different. Generally, round data values to at most three significant figures, often two will do and more is spurious accuracy. Give statistical data (check journal conventions) to one additional place. Don't present the same results in both a table and a figure.

Although some journals accept a combined 'Results and Discussion' section, you need to be careful to ensure the reader can distinguish what you did and are reporting, and what you are saying has already been done. This is why it is a good idea to write separate 'Results' and 'Discussion' sections initially, even if you later combine them. If you write 'this confirms someone else's results' throughout your paper, it is unlikely you have novel findings and the submission is likely to be rejected.

If you have done a PhD, consider rewriting the literature review with your supervisor and submitting as a review paper to an appropriate journal that publishes reviews. The review from a thesis is rarely in a style which is acceptable for a journal and so will probably need to be rewritten. Alternatively, think ahead and write your thesis review in the style of a journal you target for publication (but check this is acceptable to the University).

When you read scientific papers in journals it is useful to analyse the ones you found easy to understand and the ones you found difficult. Why was this? How did the authors structure their paper? What was their writing style? Learn about writing from reading.

And finally, enjoy publishing the results of your research.

Food security in Africa: public-private partnerships for closing the yield gap

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For the past 30 years, food availability in Africa has failed to meet the demands of a rapidly increasing population. The number of malnourished people has grown from 88 million in 1970 to 200 million in 2000 and the trend is projected to continue. While many causes have been identified for this alarming situation, limited innovation in African agricultural systems is one of the most significant underlying factors. A very large number of farmers are still using varieties inherited from their grandparents; the use of fertilizers is extremely low (about one tenth of the world average); pest and diseases have increased in severity while drought and the absence of irrigation take an increasingly frequent toll on crops that survive other biotic and abiotic challenges. The end result is that Africa has the lowest crop yields amongst all regions of the world, and these have barely increased in the past 40 years. African farmers feed the ever increasing population by expanding the land under cultivation rather than by increasing their productivity per unit of land and labor. This approach is damaging to the environment and is not sustainable because the amount of arable land is very limited.

Increasingly, African governments and regional organizations are recognizing the centrality of agriculture in the economic development of the continent. At their 2003 summit, African Heads of States committed themselves to allocating 10% or their countries' GDP to agricultural development. The Comprehensive African Agricultural Development Program (CAADP) developed by the New Partnership for African Development (NEPAD) calls for a minimum 6% annual growth in agricultural productivity to ensure that Africa meets its development targets.

While yields of most crops in Africa are the lowest in the world, African research institutes have over the years been developing high yielding varieties and soil fertility management techniques that can increase crop yields, sometimes by several fold. There is a significant gap between crop performance and the yields obtained on research plots and those achieved by African farmers. How can this gap be bridged?

In the late 1960s and early 1970s when international agricultural research centers (IARCs) were established, their mission was to use the best scientific talent to seek technological solutions to problems of agriculture in the developing world. It was assumed that national research institutions and extension services would take up and disseminate the findings from IARCs. While this model has been credited with the advent of the *Green Revolution* in Asia and Latin America, it has not worked for Africa. A new model is therefore needed. Although the public sector has not been efficient in distributing seeds, agricultural inputs and best agronomic practices to farming communities, the private sector has been very successfully at distributing Coca-Cola drinks and more recently cell phones to these same communities. Unfortunately, in many African countries, seed regulations and other policies have discouraged the private sector from distributing agricultural inputs. In recent years, however, some countries have introduced and enforced plant breeders' rights and have liberalized the seed sector. In response to this policy change, private sector investment in the seed industry is growing with the participation of both local and foreign investors.

For the foreseeable future however, the capacity to develop technologies and products for African farming conditions will rest with either national and/or international public research institutions (such as IARCs). Private enterprises, on the other hand, will continue to demonstrate an unchallenged ability to distribute products across rural Africa. Harnessing possible synergies to be derived from the capacities and capabilities of the public and private sectors presents a unique opportunity to bring to African smallholder farmers the inputs and knowledge they need to increase agricultural productivity.

The African Agricultural Technology Foundation (AATF) was created four years ago to access proprietary technologies (from within and outside Africa) and to put them in the hands of African smallholder farmers, after adaptation by public research institutes, on-farm testing by NGOs, research institutes and extension services, and dissemination by private entrepreneurs, stockists and agro-dealers.

A good example of this model is the dissemination of Imazapyr-resistant (IR) maize varieties to control *Striga* in maize fields, first in West Kenya, and now in Uganda, Malawi and Tanzania. BASF, a German multinational corporation owns the IR maize germplasm and has made it available to CIMMYT which bred the trait into varieties adapted to eastern and southern Africa. BASF also manufactures and distributes the herbicide imazapyr and had it registered for use in Kenya. The Weizmann Institute of Israel contributed the technology to coat maize seeds with imazapyr. Three Kenyan seed companies obtained breeder's seed from CIMMYT and multiplied it for large scale on-farm testing and field demonstration by NGOs, seed companies and extension services. Over 13,000 farmers were involved in testing the technology. Pictorial brochures, rural radios and newspapers were used by NGOs to reach many more farmers than those involved in field trials. The new maize variety produces high yields in farmers' fields where maize production was no longer possible due to severe *Striga* infestation. Today, this variety is commercially available to farmers in West Kenya, through a local seed company's network of dealers and stockists and through NGOs acting as middlemen. While the research institutes were instrumental in developing the technology, these would not have reached so many farmers so quickly without private sector involvement.

AATF aims to facilitate *agricultural innovation platforms* whereby various institutions are brought together so each can provide timely inputs to the agricultural technology value chain. Public and private organisations play clear roles, from basic research to applied research, field testing and commercialization, including facilitating market access to encourage farmers to produce a surplus. Keeping all the partners engaged in the process is the single most important challenge to bringing technologies to farmers. This model also provides, in our opinion, an efficient approach to ensuring that African farmers will benefit in the future from the products of gene technologies. It makes it possible to address, in an effective manner, issues such as intellectual property management, regulatory compliance and public awareness management for which traditional public research institutes and extension services do not have the comparative advantage.

Closing the yield gap: crop protection for poverty alleviation. Can we help? Should we help?

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The 2006 FAO report on the 'State of World Food Insecurity' (http://www.fao.org/sof/sofi/index_en.htm) tells that we are not on course to meeting the Millennium Development Goal on reducing poverty and hunger. However, this is not because of overall production in the world but a problem of access and availability – poor people are hungry and malnourished, the well-off are obese!

The Millennium Ecosystem Assessment, published by the Island Press in 2006 (http://www.millenniumassessment.org/en/index.aspx) concluded that although agriculture has been very successful in meeting the growing needs of society for food and the other agricultural products, current production systems and land-use practices have damaged many of the world's ecosystems.

Many recent studies predict that the demand for food, agricultural commodities and ecosystem services will increase and could double over the next generation. This demand will be driven by population growth, income increases, urbanisation, regulation, education and global trade.

World leaders are looking to agriculture to reduce poverty, support economic growth, provide worthwhile employment, conserve environments and provide an increasing diversity of environmental services.

Climate change and the rising demand for biofuels have added new challenges and opportunities for agriculture and landscape management.

Consumer concerns and changes in the structure of the agricultural industry are creating increased interest in and scrutiny of the sources and the methods of production used. Farmers are aging and it is increasingly difficult to retain the interest of young people in agriculture as a job.

Since agriculture began there are have been several approaches to enhancing yields – specialised and protected fields; fire; rotations, shifting cultivation and transhumance; better cultivation techniques; irrigation; seed selection; planting in rows; manures and chemical fertiliser; mechanical, biological and chemical crop protection; systematic breeding and genetic engineering. Seldom has a single technology survived for ever and it has been necessary to combine and integrate technologies to cope with rising demands and the capacity of pests and diseases to evolve, mutate or change their behaviour to exploit new opportunities. Bugs get up earlier, breed faster and go to bed later. Their capacity to adapt is a measure of their success and essential to their survival.

These challenges are huge and point in the direction that 'business as usual' or 'more of the same' will not provide sustainable solutions. Innovation and partnerships are needed, but from where will these new ideas and alliances come. Can we help?

There have been numerous studies comparing farmers' field yields with those that are attainable under experimental conditions. The great majority of these studies show that the yields obtained under field conditions are significantly lower. In Africa, the yields of food grains remain obstinately at around one tonne per hectare. Is this a problem of the statistics or are there real barriers to increasing yields?

Some of these studies imply that the technologies available are inappropriate, because they are reliant on unavailable or unaffordable inputs, such as water, credit, fertiliser and pesticides. Others point to a failure of markets, infrastructure, policies, governance or institutions. Others blame environmental factor such as climate change. Many advocate a greater emphasis being given to participatory approaches. Sadly the blame game seems more attractive that the solutions business.

Recent initiatives by Sasakawa, the Millennium Project, Rockefeller and the Gates Foundation have aimed to remove the technology and finance constraints through improved access and advice. They work primarily through the public sector or civil society. They have demonstrated that it is possible to increase yields dramatically – but are these approaches sustainable? Can they be replicated or sustained when the exotic inputs are no longer available – probably not!

It is noticeable that where markets are strong agriculture prospers. However, seasonal fluctuations in the yields from rain-fed agriculture are inevitable.

The Syngenta Foundation's experience has been that one of the main areas of failure has been in access to markets and an absence of small and medium businesses (SMEs) in the rural/urban interface. It is interesting to note that SMEs are responsible for creating a significant proportion of new jobs. However, the greater portion of development assistance is still focused on public sector spending which can encourage the public sector and civil society to engage where it might be more appropriate and sustainable for the private sector to take the lead. But stimulating the private sector requires more thoughtful, analytical and business-like approaches, as well as a commitment to longer time horizons.

Should we help? This raises both practical and ethical issues! By attempting to help are we creating cultures of dependency or pushing inappropriate technologies or approaches? Are we going for simplistic quick fixes when we should be placing greater emphasis on building indigenous capacity – particularly in the private sector? Sadly the development community interested in agricultural development has created a battle ground of ideologies – technofix v. technophobia; small v large; markets v subsidy; public v private goods etc. These ideological disputes do not help and in some cases have reduced investment and hindered the building of partnerships between players in the public and private sectors. We need fora to discuss and resolve these differences.

In conclusion – yes, the international development and scientific community can help but will only do so if we have done sufficient analyses and are prepared to invest adequately to build appropriate and robust indigenous institutions. There are no quick fixes. We must take a longer-term approach.

How relevant is crop protection research to poverty alleviation?

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The estimated rates of return of agricultural research and extension investment, including the development and application of crop protection technologies, are high across countries and commodities and have not declined over time. Some impressive examples have been recorded, for example, in West Africa, where cassava green mite biological control was first achieved, economic returns have reached a hundred fold – US $ 100 in return for each US $ 1 invested in the program (Dixon *et al.* 2003). The growing body of evidence on rates of return should encourage policy makers to invest significantly in the sector, but trends over the last two decades suggest otherwise. Investment in agricultural research and extension is still growing, but only at a decreasing rate (Pardey *et al.*, 2006). In many developed countries, investment has stalled and has become a small proportion in total science and technology spending while in many developing countries, investments are stagnating.

The lack of research and extension investment in many countries of sub-Saharan Africa and S. Asia is of particular concern because the livelihoods of 40-75% of the workforce in these regions are dependent on renewable natural resources including forestry and fisheries. There are a number of reasons for this declining support. Firstly, over four decades there have been significant changes in aid modalities such as the movement away from the green revolution technologies of the 1960s to 1980s and the integrated rural development projects of the 1980s and 1990s, to sector-wide approaches and support to poverty reduction strategies (PRS). Agriculture is featured in many PRS, but investment by national governments is low. Secondly, the international development agenda has focused on targets such as the Millennium Development Goals which, quite rightly, emphasise social sectors such as education and health, but do not mention at all productive sectors such as agriculture which provide opportunities for the poor. Thirdly, international and regional trade agreements and policies fail to support small scale producers and labourers. Finally, the evidence has not convinced policy makers that investment in agricultural research can tackle the multi-dimensional nature of poverty including the lack of equity and voice.

Some of these issues were explored during the implementation of the DFID Renewable Natural Resources Research Strategy between 1995 and 2006. DFID invested over £200 million in the RNRRS, funding over 1600 projects throughout sub-Saharan Africa (56%), South Asia (32%) and Bolivia (12%). The 10 programmes separately addressed crop production and protection, post harvest issues, market access, forestry, fisheries management, aquaculture, soil and water conservation, livestock production and animal health. All focused on improving the livelihoods of the poor through better management of natural resources and by developing new ways of working with and for this constituency. Multidisciplinary research between natural and social scientists became the norm, research initiatives usually included the requirements of stakeholders in the R&D agenda and used new promotional channels to enhance rural and urban livelihoods directly or indirectly.

The Crop Protection Programme (CPP) generated knowledge to improve pest, disease and weed management in systems that are managed by or employ the poor. Activities took place in over 20 countries and new partnerships, including those with NGOs and private sector, grew as the strategy evolved. Unfortunately, impact evidence such as that presented for the cassava mealy bug example does not exist from the RNRRS, but an independent evaluation found that the high quality of research had made significant contributions to scientific knowledge (Spencer *et al.*, 2005). There was clear evidence of positive impacts on the livelihoods of the poor in target developing countries as well as good potential for wider impact on poverty. Some of most valuable CPP lessons stemmed from the participatory processes which attempted to empower and increase the voice of poor communities, the development of new partnerships between researchers and users to improve uptake and the use of new communication channels and policy messages to create livelihood opportunities and benefits, directly or indirectly. Examples from CPP include:

- *Promotion of bean IPM strategies in E and S Africa 1997-2006. (Ward* et al., *in press)*
- *Understanding farmers demands from research in Bolivia (Bentley* et al., *2007)*
- *Policy change in E. African biocontrol legislation (Wabule* et al., *2003)*
- *Cost effective weed management practices for rice systems in S. Asia (Johnson* et al., *2003) Chickpea IPM in Nepal and Potato and groundnut IPM in Uganda*

The contribution of science to pro-poor growth is being increasingly recognised. DFID is doubling investment for agriculture, fisheries and forestry research in poor countries to £80 million a year by 2010 and its programme 'Research into Use' aims to put the best of the RNRRS into use across Africa and South Asia. A third of the budget is allocated to monitoring, impact and learning so this initiative will not only scale out research, but will identify essential actors in agricultural innovation systems, will explore the flow of information between the actors and how and why research is taken up or dropped. It should also capture qualitative as well as quantitative impacts of research. Lessons will inform managers and policy makers when considering future agricultural research investments.

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The benefits of rational pest control practices in Indian cotton

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In the late 1990s, some 40% of the variable costs of cotton production in Asia were for control of key pests, in particular caterpillars of the cotton bollworm, *Helicoverpa armigera*. Insecticide resistance, particularly to pyrethroids, was a major cause of the large and growing overuse of chemical pesticides. A series of research programmes from 1992 to 2005, supported initially by the Indian Council for Agricultural Research (ICAR) and the UK Dept. for International Development (DFID), later with support from the Common Fund for Commodities (CFC) and the International Insecticide Resistance Action Committee (IRAC), undertook detailed examinations of the genetic and biochemical bases of these resistances to the four common groups of chemistry used in the region (endosulfan, organophosphates, carbamates and pyrethroids.) (Kranthi *et al.* 2001a and b). Table 1 summarises the findings of this work.

Table 1. Distribution of resistance mechanisms in Asian *H. armigera*

	Metabolic				Target site		Penetration reduction
Mechanism	Oxidases	Esterases	GST	Ache	Nerve Insens	rdl	
Chemicals affected	Pyre.	OP/carb endo/pyre. h.	Pyre.	OP/ carb	Pyre.	End	Pyrethroid (others?)
India	***	**	*	*	**	*	?
China	***	**	*	*	*	*	*
Pakistan	**	**	*	*	*	*	*

GST – Glutathione-S-transferases; Ache – Acetylcholine esterase; rdl – dieldrin resistance mutation

Study of the cross resistance patterns relevant to these mechanisms gave potential rotation groups for use in reducing the impact of insecticide resistance in *H. armigera* control. Taking into account the need to control other pests, a 'window' strategy was adopted and trialled on an increasing scale to 1999 when 255 farmers in three states were using the methodology (Russell *et al* 2000). The Indian Council for Agricultural Research then adopted the practices in a series of programmes from 2000-2002 when a much larger, national programme was set up under funding from the Cotton Technology Mission funds. Simultaneously, the research base was strengthened and the programme rolled out into India and Pakistan with funding from the Common Fund for Commodities (2002-2005).

Working within a full IPM context and with the support of field staff in each village and a resistance monitoring laboratory in each district, the insecticide rotation programme shown in Table 2 was implemented (with minor regional variations) across all 11 cotton states in the 26 cotton growing districts where insecticide use was the biggest concern (Kranthi *et al.* 2005). Results have been spectacular. Table 3 shows the increasing scale of operations from 2004-2007, with close to 90,000 growers now actively enrolled in the programme in over 1,000 villages spread across India.

Table 2. Simplified IRM programme recommendations for Central India 2002-5

Sucking pests	Bollworm window 1	Bollworm window 2	Bollworm Window 3	Bollworm window 4
0 - 60 days* Zero sprays	60-90 days endosulfan (neem/HaNPV)	90-105 days spinosad/ indoxacarb	105-120 days organophosphate / carbamate	120-140 days pyrethroid

Note: Windows 2 and 3 are commonly run together, using only OP/carbamates, by resource-poor growers.

Figures are weighted averages of the 11 state averages and compare results with neighbouring villages which are not in the programme. Average insecticide use reductions, yield increases and increased net profit were seen in all 11 participating states.

Table 3. Recent progress in the IRM village programme

	No of villages	No of farmers	% reduction of sprays	% Yield increase	Net profit increase $US/ha	Total benefit to farmers	Benefit to cost ratio
2004-5	444	20,525	-46%	11%	$193	$11.5 mill	28:1
2005-6	565	46,400	-48%	12%	$183	$24.6 mill	32:1
2006-7	1,023	89,000	-52%	10-15%	$174	$33 mill	44:1

Insecticide use continues to be approximately halved, while significant yield increases contribute to the $US170-200/ha average profit increase, more than doubling cotton profitability for these farmers. The Indian government is committed to expanding this programme in the current five year plan to 2011, having attained a >40:1 benefit to cost ratio for the programme with expenditure of less than $US4/ha. Insecticide resistance to all four classes of chemistry has fallen in the programme areas and more widely as the success of the programme has been publicised though village level plays, >1,000 farmer meetings, broadcasts, newspapers and extension systems. The use of these older chemistries is now falling nationally with only modest increases in the use of newer chemicals e.g. spinosad and indoxacarb. This programme contributed to the sharp increase in national cotton production from 15 million bales in 2002 to over 25 million bales in 2006, starting well before any significant impact from the planting of Bt cotton. The programme team, led from the Central Institute for Cotton Research in Nagpur, won the 2006 ICAR Award for Team Science.

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Semiochemicals – the future for crop health

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Semiochemical-mediated communication affects a myriad of interactions between organisms. The best studied and most commercially exploited are pheromones and kairomones. Employed to manipulate the behaviour of economically important pest species, technologies have been developed to monitor and control populations that impact on crops providing the basis for a global $150 million per annum industry. Yet semiochemicals are by no means restricted to moderating interactions within and between species and their hosts, but also act at a tritrophic level enabling, for example, plants to alert parasitoids to the presence of herbivorous insects. The distinction between hormones and semiochemicals has become blurred with the isolation of a phytohormone, jasmonic acid, in insect eggs and demonstration of gravid female moths modifying their behaviour in response to phytoecdysteroids.

In principle, this knowledge and associated technology can be utilized to alleviate the poverty of resource-poor farmers in threshold countries. Indeed early success was achieved in Egypt with the female sex pheromone of the pink bollworm, *Pectinophora gossypiella*, being controlled by mating disruption. By 1997, almost the entire 400,000 ha crop was treated with pheromone, saving between $5.1 and $9.5 million per annum and reducing national insecticide consumption by 40%. In India, cotton sustains the livelihoods of 60 million people and accounts for 20% of Indian exports. The pest complex is quite different from Egypt, with *Helicoverpa armigera* being the main pest species and not amenable to control by mating disruption. Yet IPM is promoted through the Government sponsored 'Technology Mission on Cotton'. Introduced in 2000, the Mission provides a mechanism for Government tenders to procure pheromone traps and lures for use by cotton farmers; accounting for 90% of the two million sold in India. This initiative has seen improvements in quality and yields almost doubled to over 500 kg/ha. However, since 2002 the area under *Bt* cotton officially increased from 0.03 m ha to 1.6 m ha in 2005, 18% of the total crop area and in some states unofficially estimated to account for over 90%.

The economic importance of Government tenders to SMEs and their dependence on pheromone blend importers has stifled competition. Tenders are price and not quality sensitive, resulting in farmers receiving poor quality products that undermine the IPM message promoted by NGOs and extension functionaries. Others question the motives of SMEs and espouse the virtues of empowering farmers to use home-produced crop management solutions. Nevertheless, without an efficient private sector to produce and promote environmentally-acceptable, cost-effective and sustainable crop protection technologies in threshold countries, technology transfer will not be sustained and opportunities to alleviate poverty lost. SMEs, by their nature, are innovative and flexible, but lack access to knowledge and finance. Increased interest in pesticide-free crop produce has encouraged SMEs to develop and promote packages of technologies for control of key crop pests and diseases. This process has been greatly assisted by donor funds made available to support the development and promotion of semiochemical technologies such as lure-and-kill for control of fruitfly, *Bactrocera cucurbitae* and mass trapping for eggplant fruit and shoot borer, *Leucinodes orbonalis*; pests of critical economic importance to vegetable producers in the sub-continent. Control of the latter pest can account for up to 40% of production costs, \$1,200/ha/annum in Bangladesh. Mass trapping is promoted as part of a package including the egg parasitoid, *Bracon hebetor*, and use of grafted plants with root stock resistant to bacterial wilt. To compliment these initiatives, donor-funded technical assistance was provided to companies in South Asia to improve the efficacy of their technology enabling several to develop new products for control of palm weevils, sugarcane borers and coffee white stem borer, *Xylotrechus quadripes*.

In related work, considerable efforts were expended to control the yellow rice stem borer, *Scirpophaga incertulas*, by mating disruption in India, and while efficacious the technology was not cost-effective. In contrast, mass trapping of *S. incertulas* proved to be both efficacious and cost-effective, but is only slowly being adopted in the absence of external support. Current efforts are focused on development of auto-confusion which holds considerable promise as an environmentally-acceptable alternative to insecticides. Formulated in a biodegradable wax the technology is hand-applied without the need for expensive spray equipment. The fact that auto-confusion does not require traps or water for application suggests it would be appropriate for use by resource-poor farmers in semi-arid crops such as millet, sorghum, pigeonpea, groundnut and maize.

In South America, pheromones are used on large acreages for control of tomato pinworm, *Keiferia lycosicella* allowing growers to earn an additional \$3,500/ha compared to those who use conventional insecticides. Codling moth, *Cydia pomonella* is controlled by pheromones in apples on an estimated 100,000 ha worldwide, with 10,000 ha in South America and 14,000 ha in South Africa. Aggregation pheromones of Coleoptera have also been exploited by resource-poor farmers to control cotton bollworm, *Anthonomus grandis* in South America, with over 350,000 ha treated in Colombia, Paraguay, Brazil, Bolivia and Argentina, reducing populations by 85% and damage typically from 40% to a minimal level. Similarly, sweet potato weevil, *Cylas formicarius* is controlled by sex pheromone traps as part of an IPM programme in Cuba on an area of 35,000 ha, eliminating the need for between 12 to 15 applications of organophosphates used previously.

Many of the pheromones of economically important African crop pests have been identified and yet their impact at the farmer level has been disappointing. In South America and South Asia, semiochemicals compete with insecticides in the market-place, and while it is important to understand the issues that motivate farmers' choices of crop protection, they are primarily driven by economics and availability, as exemplified by the rapid adoption of *Bt* cotton in India. For resource-poor farmers in sub-Saharan Africa to benefit from semiochemicals in crop protection it will require the creation of an enabling framework that can deliver quality products in the absence of donor finance and in the face of competition from conventional crop protection technologies. SMEs are best placed to manufacture and market this technology but they will inevitably focus on farmers producing high value, export oriented crops. As in South Asia, semiochemicals are best introduced as part of technology packages that eliminate the need for pesticides, but to develop and validate these strategies has cost implications that will inevitably be dependent on increasingly scarce donor finance.

Biological pesticides for Africa: why has so little research led to new products to help Africa's poor?

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For many years there has been a sizeable body of research focused on developing biological control agents (BCA) for use in Africa. Microbial entomopathogens, such as bacteria, viruses, fungi and nematodes, have been seen as the source of new crop protection products to tackle the myriad pests and diseases that contribute so much to limiting yields in the less developed countries, particularly in Africa. However, much of the research effort has failed to lead to new products or had any direct impact on the ground. This raises serious questions: what are the issues and factors that have impeded the research from being brought into use. Recently there have been a number of public sector led initiatives to promote biological pesticides. Study of these cases can provide much information about the issues that may be impeding the development of these agents.

The focus on BCAs as crop protection solutions in Africa has a number of diverse drivers. There is the perception that these agents are 'natural' and safer than synthetic chemical products, this has been a major plus for some funders, but its evidential basis is questionable and as a force for driving farmer adoption of BCAs it is weak. A significant sector of the research and development community seems ideologically opposed to the use of chemical pesticides, or indeed any commercially sourced synthetic agro-inputs, and promoting BCAs can reflect this agenda. Thus, major drivers of research into the development of BCAs have not necessarily selected them because they are the 'most fit for purpose' in tackling specific crop problems or because meet genuine farmer needs. A more realistic approach would be for projects to include stronger end user input in the process of selecting, developing and implementing BCA projects.

The limited R&D capacity for BCAs in Africa is also a serious constraint. International research centres and collaborative north-south projects have helped by augmenting the very limited local capacity in the research stages. However, without an indigenous industrial expertise in scaling-up, in production and in commercialization, the research efforts frequently progress no further than promising small scale field trials. Commercialization of BCAs needs industry involvement for their expertise in product development with a rationale use of resources. To achieve this however the cultural differences between research and commercial organisations need to be bridged with new ways of working and trust developed. Issues such as unrealistic valuation of intellectual property rights have tended to inhibit development of good relationships.

Historically, failure to recognize the health drawbacks of the indiscriminate use of pesticide on food crops has restrained demand for safer production that might create the market for BCAs. Recent concerns about safety for the consumer and the environment have driven commercial growers to adopt an Integrated Pest Management (IPM) approach to crop protection. BCA can be successfully incorporated into IPM systems where farmers have adequate knowledge, resources and supply systems, but apart from in the intensive high value horticultural 'hot spots' in Kenya and South Africa, most African farmers lack the expertise, resources or infrastructure into which BCAs can fit. The high cost of BCAs can be a very significant factor for most farmers in Africa. The majority can only afford the minimum of inputs, and broad spectrum chemicals are for them a far more appropriate solution than pest-specific BCAs. BCAs have the advantage that they can be produced locally, perhaps at lower cost, by a range of methods each requiring different economic and technical resourcing. To implement the appropriate approach successfully, however, engagement by researchers with policy makers and industry is vital. There is considered to be potential for some BCAs to be produced at village level with a relatively simple technological base; an attraction for some NGOs who see this as a means to empower resource poor farmers. However, issues of registration, quality control and economics in particular mean that this model is far from proven as a sustainable model of large-scale delivery.

Market size and value is a key consideration in developing new commercial biopesticides. The African market is small in world terms and highly fragmented. In China and India, development of new BCAs has been rapid in recent years, but they represent two extremely large and diverse markets providing many product niches within a single registration system. Market size has important implications in registration; efforts are now underway to simplify, harmonise and standardize registration of BCAs in Africa, but the need to register in multiple countries through systems that lacked expertise in BCAs has been a significant deterrent to many initiatives. Another constraint has been the attitude of some regulatory agencies that perceive bio-security problems in the importation of exotic BCA, even from neighbouring countries sharing identical, even contiguous pest-crop systems. This in turn has reflected an absence of any coherent government policy to promote BCA use or production. Lack of awareness of BCAs by policy makers and opinion formers means there has been little policy action to support the research. Research funders have until recently failed to address this, but there are now some examples of capacity building: DFID and the COLEACP Pesticide Initiative Programme have provided capacity building expertise in Kenya for BCA registration, mass production and commercial development.

Given these weaknesses in market and infrastructure, it would make sense to focus efforts where the pest-crop system are least challenging for BCAs. The high value export horticulture sector is one where higher farmer resources and familiarity with IPM make it promising. It is also here that MRL legislation and consumer preference for 'low pesticide produce' might provide the market driver for their adoption, and indeed Kenya and South Africa have been a focus BCA research. Another promising entry point for BCAs is control of migratory pests such as locust and armyworm where outbreaks can involve environmentally sensitive national parks. Here national or regional co-ordination of control programmes may ensure both a sizable market and sufficient expertise to use BCAs successfully.

In conclusion, the relatively slow progress in promoting the use and adoption of BCA in Africa is the product of many factors beyond the simple issues of product effectiveness or suitability. Successful development of BPs to meet Africa's needs lie in focusing efforts on the best fit cases where the situation is already favourable. Then, through the development of a few successful products this process may in itself build new capacity and embed approaches that will facilitate further developments.

The protection of farmers' health is key to ensuring optimal agricultural production

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Background

The promotion of agriculture in the medium and least developed countries is a potent means of helping to address extreme poverty in its many dimensions (income poverty, hunger, disease among others) as spelled out in the UN Millennium Declaration. The declaration, signed in September 2000, commits the 192 UN member states to achieving eight goals. The success of initiatives aimed at promoting agriculture is contingent on the promotion of health of the farmers. Among the diseases endemic in Cameroon's rich forest and savannah regions are vector borne diseases. The most notorious of these are malaria and filariasis. We present data obtained from two regions of Cameroon where agriculture is predominant.

Methods

This study was carried out in the Sanaga Maritime division (Littoral province) and Fako division (South West province) of Cameroon. We visited five villages in the first and seven in the second. We sought to find out from the villagers what they considered to be the greatest impediment to their agricultural endeavours. We equally inquired from the health services and the villagers what they considered to be their common health problems. In the Sanaga Maritime division, we proceeded to test blood samples and skin snips from selected consenting subjects in order to look for the presence of malaria parasites and *Loa loa* microfilariae (from blood) and *Onchocerca volvulus* microfilariae (from the skin snips). These studies were approved by the faculty's Ethics Committee.

Findings

In the two divisions studied, the over-riding impediment to successful farming was ill-health. This was closely followed by the presence of insects. With regard to ill-health, malaria was the number one culprit. Among the insects incriminated as impediments to successful farming were mosquitoes.

However, another common nuisance is the *Simulium damnosum* (black fly), vector for onchocerciasis (river blindness). Thus, farmers were unable to farm either because they were ill from malaria or onchocerciasis or because of the nuisance caused by the biting insects. There were 428 persons who consented to being examined. Of these 21% had *Plasmodium falciparum* in their blood, 51% had *O. volvulus* microfilariae in their skin and 5% had *L. loa* microfilariae in their blood.

Discussion

Our study has highlighted two issues that we need to address as we engage in the promotion of agriculture within the context of alleviating poverty and disease through wealth creation and the increase of food production to address issues of malnutrition and famine in a continent laden with natural and man-made disasters. First, we need to address the issue of vector control. Vectors, such as mosquitoes and black flies are a nuisance for farmers.

They hum and drone close to the ears of farmers and bite them in their exposed parts. Whole villages have been known to vacate arable land because of the presence of vectors. These vectors also transmit disease causing agents: plasmodia which cause malaria and microfilariae which may result in blindness. Although malaria generally tends to make adults sick and therefore take time off work, it is a leading cause of deaths in children and of abortions in pregnant women. Further, sick children need to be looked after, thereby reducing the number of hands available for field work. In certain farm areas where irrigation is used such as in rice fields in the savannah regions, the use of cattle as a bait to divert mosquitoes away from humans is being investigated.

The second issue which arises from this study is the reinforcement of the underlying relationship between health and development. Agriculture in most of Africa is practiced by the poor. They tend to be particularly vulnerable to all kinds of prevailing diseases, but have a chronic problem of access to health care. Agricultural development or extension programmes must look into integrating health promotive, preventative and curative activities within their packages.

In Cameroon, the Yaounde Initiative Foundation (YIF) has started a programme aimed at improving the livelihoods of people along the Sanaga river valley by implementing integrated vector management. Vector Intervention Teams (VIT) will be responsible for vector management within their villages for both the anopheline mosquitoes and the black flies. The fact that they will be using insecticides for their work in mosquito control (insecticide treated nets, ITN, and indoor residual spraying, IRS) will raise issues of development of resistance to these insecticides.

Within the context of its social obligations to communities, the Faculty of Health Sciences of the University of Buea is working closely with the YIF to learn from their experiences and apply the positive lessons in its communities.

Weed management in Africa: experiences, challenges and opportunities

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Weeds continue to undermine efforts to improve farm productivity in sub-Saharran Africa (SSA). Seven of the ten 'world's worst weeds' (*Cyperus rotundus*, *Cynodon dactylon*, *Echinochloa crus-galli*, *E. colonum*, *Eleusine indica*, *Sorghum halepense* and *Imperata cylindrica*) are widely distributed in Africa (Holm et al. 1977). Other problem weeds include *Striga* spp., *Rottboellia cochinchinensis*, *Commelina* spp., and *Euphorbia heterophylla*. These are both competitive and difficult to control. For example *I. cylindrica* is ranked as the most troublesome weed in cassava, maize, and yams in West Africa. *C. dactylon* is serious weed of cereal crops in Southern Africa. *Echinochloa* spp are serious weeds of rice. *Striga* is a parasitic weed that thrives under conditions of low soil fertility. In West Africa, *I. cylindrica* competition caused an estimated 50% loss in cassava and 20-80% in maize. Upland rice yields with farmers' weed control methods were 44% lower than on researcher weeded plots. Losses from *Striga* can be 100%.

Weeding by hand hoeing is common in SSA, using 50 to 70% of the labour needed to grow a crop (Chikoye *et al.*, 2001). Smallholders are generally aware of the detrimental effects of weeds but delayed weeding is caused by labour shortages due to the migration of younger people to urban areas, while HIV/AIDS and malaria exacerbate labour bottlenecks by reducing labour productivity. Farmers, particularly women and children who provide over 50% of agricultural labour, would benefit greatly from low-cost, labour saving weed control practices. These must be matched to the socio-economic circumstances of communities if adoption is to be widespread. Herbicide use can be a pro-poor technology where labour is expensive and in short supply if products are sold in appropriate size packs, training on application is provided and there is a ready market for produce. Mechanization reduces the drudgery associated with manual weeding. To improve access to mechanization, greater focus is needed to design appropriate tools and implements requiring less energy; to promote ox-drawn implements, low horsepower tractors and to design more affordable sprayers.

Successful attempts to promote improved weed management in SSA include:

1) *Imperata* in West Africa: Participatory Research and Extension approaches were used to promote *I. cylindrica* management practices in Nigeria. Researchers and extension agents provided potential solutions (tillage practices, herbicides, cover crops and improved

agronomic practices) for farmer groups to evaluate. Trial monitoring and evaluation allowed farmers to share experiences and provide feedback to researchers. Labour use decreased by 54-96% as farmers switched from hoe weeding to chemical control in cassava, yams, or soybean. Chemical control reduced speargrass density by 88-97%, gave 38-55% higher crop yields and had a 28-50% lower cost than farmer control methods. Adoption depended on the availability of improved seed, fertilizers, herbicides, and output markets. The benefits of improved technologies included were increased incomes, reduced drudgery, improved food security and nutrition and improved soil fertility. These benefits accrued to women, young people, and the very poor, who often bear the brunt of weeding.

2) Wild rice in Tanzania: The perennial wild rice *Oryza longistaminata* and the annual *O. punctata* are constraints to lowland rice production in Tanzania. Because of the labour needed to manually remove wild rice from the rice crop farmers tend to avoid infested areas although these are on fertile soils with a good depth of water. Pre-planting applications of glyphosate to reduce wild rice populations have enabled farmers to sow their crop after one plough pass instead of two, to reduce labour for in-crop weed control by 50% and increase average yield by 65%. As there is a ready market for rice, farmers view glyphosate use as highly profitable particularly as herbicide use allows them to plant a recently introduced high yielding rice cultivar that has a "short straw" type that is not competitive with weeds.

3) Tillage for cotton in Uganda: Farmers plough twice to prepare land for cotton in NE Uganda. Timely tillage and planting is difficult for households who do not own draught animals and need to borrow a plough team. By killing weed re-growth with glyphosate after only one plough pass farmers can plant into a weed-free seed bed when soil moisture is optimum. Subsequent labour requirement for weeding the cotton crop is also reduced. Use of the herbicide is particularly effective where perennial grasses (*C. dactylon* and *I. cylindrica*) and sedges (*C. rotundus*) are a problem.

4) Animal-drawn weeders: Farmers in east and southern Africa use animal-drawn weeders because they reduce drudgery and save labour and time spent on weeding by 20-70% compared to hand-hoeing (Chatizwa and Vorage, 2000). Usage is being promoted through giving farmers loans to buy draught animals, training local fabricators and blacksmiths to service the weeders, training of agricultural extension officers and farmers, and encouraging farmers plant their crops in rows. Use of animal-drawn weeders has contributed to increased labour productivity, and increased education opportunities for among young people who often lose time for school due weeding activities.

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GM crops – their role in less developed countries

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Biotechnology has introduced a new dimension to agricultural innovation, offering efficient and cost-effective means to produce a diverse array of novel, value-added products and tools. It has the potential to improve qualitative and quantitative aspects of food, feed, fibre and biofuel production, reduce the dependency of agriculture on chemicals and fossil fuels, diminish over-cultivation and erosion, improve nutrition and functionality of foods and feeds and lower the cost of raw materials, all in an environmentally-sustainable manner. Agricultural biotechnology has helped farmers around the world boost their productivity and grow crops in more ecologically healthy fields while allowing much more efficient use of resources. This technology allows reduced tillage, which cuts down on greenhouse gas emissions, water runoff, machinery and fossil fuel use and soil erosion. Meanwhile, the benefits experienced by larger-scale farmers in both industrialized nations and lesser developed countries are already considerable. A recent study (Marvier *et al* 2007) indicates that biotech crops may contribute to increased productivity in sustainable agriculture. The study analyzes, for the first time, environmental impact data from field experiments all over the world, involving Bt corn and cotton. In an analysis of 42 field experiments, they found that Bt crops can have an environmental benefit because large-scale insecticide spraying can be avoided. Organisms such as ladybirds, earthworms, and bees in locales with 'Bt crops' fared better in field trials than those treated with insecticides.

An economic analysis (Brookes & Barfoot, 2005) shows that in the first nine years of GM crop cultivation, global net farm income increased by $27 billion; the environmental footprint associated with pesticide use was reduced by 14%; there was a reduction in carbon dioxide emissions in 2004 equivalent to taking nearly five million cars off the road for a year. Reduced-till agriculture means healthier soil, with reduced erosion and far less carbon dioxide release. In general, cultivation is not a sustainable practice. It is energy intensive, exposes soil to wind and water erosion. It allows rain to compact the soil, increases the oxygen content of the soil, allowing organic matter to oxidize away. In turn, lower organic matter in the soil allows more compaction and more nutrient loss. Pesticide use fell by over 170,000 tonnes. In 2004 alone this was over 40,000 tonnes, equivalent to more than 30% of total active ingredients used on crops. Less spraying means fewer tractor passes, contributing to lower CO_2 emissions. Insect resistant maize also has a collateral effect - less insect damage results in much less infection by fungal moulds which reduces mycotoxins that are known health risks causing such problems as liver cancer to humans and animals. The only 'natural' way to control those fungi is the use of copper sulfate which has one of the highest toxic hazard ratings of acceptable pesticides and selects for antibiotic resistant bacteria in the soil.

Green *et al* (2005) suggest that intensive high-yield farming on less land is better for wildlife than 'wildlife friendly' less efficient farming. They provide convincing evidence that without yield increase, land use will double by 2050 and that this effect will be especially significant in developing countries where, without greater productivity, China and India will need four times the land area to support their expanding populations. They show that in Latin America, where increased productivity was achieved, there was a significant decrease in deforestation; those producers with greatest yield increase had lower land use.

Of the 10.3 million farmers in 22 countries who grew biotech crops on 102 million hectares in 2006, 90% (9.3 million) were in developing countries (James, 2007). India, the largest cotton growing country in the world, registered the highest proportional increase with a gain that almost tripled its Bt cotton area to 3.8 million hectares. In China, use of genetically engineered cotton eliminated the use of 71 million kg of pesticides, an amount approximately equal to all of the pesticides used annually in California. In addition, because of the primitive method of back-pack applications, significant reduction in pesticide use literally saved lives. A World Health Organization (WHO, 2005) report noted that indirect benefits of agricultural biotechnology include reduction in chemical usage, enhanced farm income, crop sustainability and food security, particularly in developing countries. The report concludes that GMOs offers the potential of increased agricultural productivity and improved nutritional values that can contribute directly to enhancing human health and development. Agricultural research of all forms holds an important key to meeting LDC needs, the FAO said, adding that biotechnology can speed up conventional breeding programs and may offer solutions where conventional methods fail. That is good for growers, consumers, and anybody who cares about the environment.

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Emerging technologies for Striga control in Africa

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Introduction

The root-parasitic witchweeds (*Striga* spp.) remain a severe problem in semi-arid areas of sub-Saharan Africa infesting nearly 100 million hectares of maize, sorghum, pearl millet, cowpeas and upland rice. *Striga* is a poor farmer's problem as infested areas coincide with where the poor farm and hunger prevails (Ejeta, 2007). Farmers abandon lands heavily infested with *Striga*, leading to greater land pressure and exacerbating the natural resource crisis. Eradication and control of *Striga* have been formidable challenges and beyond the knowledge base and the economic reach of subsistence farmers. Decades of research has now generated a better understanding of the nature of the parasite and its association with its hosts, finding that have more recently led to the development of appropriate and cost effective practices for *Striga* control. Two control practices, validated by farmers and officially launched in eastern Africa for wide scale commercial application and adoption, are briefly described below.

Multi-genic *Striga* resistant cultivars

Significant gains have been made in breeding sorghum cultivars with multi-genic resistance to *Striga*. A paradigm was developed upon which the complex trait of *Striga* resistance was dissected into simpler components based on *Striga*'s interactive points with its hosts. This paradigm was based on the hypothesis that genetic variants could be found in nature or induced through mutagenesis for each of the key signals involved in successful parasitism. For each stage of the host/parasitic interaction, the particular signal involved was characterized, laboratory assays were developed, and genetic populations were evaluated using these assays to establish mode of inheritance, and to combine unique recombination. The assays were also useful to describe specific mechanisms of *Striga* resistance that were based on low germination stimulant (*lgs*) production, low haustorial factor (*lhf*) production, the hypersensistive response (*HR*), and the incompatible response (*IR*) induction following infection. Using this approach, sorghum germplasm with superior *Striga* resistance were identified. The inheritance of each of these sources were studied, molecular markers linked with genes for resistance were identified, and new sorghum cultivars were developed and released for wide cultivation in several countries. Adaptive tests were conducted in each country to assess agronomic merit of these cultivars. Three *Striga* resistant cultivars, P9401, P9403, and PSL85061 were recommended for commercial cultivation in Ethiopia under the local names of Gobiye, Abshir, and Brhan respectively.

In Tanzania, two other cultivars P9405 and P9406 were recommended for wide cultivation under the local names of Hakika and Wahi. Large scale adoption and diffusion of these cultivars as components of integrated *Striga* management (ISM) was facilitated by national programs and NGOs in Tanzania, Eritrea, and Ethiopia that encouraged entrepreneurial seed production, and linked farmers to markets. Where packaged along with soil moisture conservation and soil fertility management practices in an ISM program, these cultivars effectively suppressed *Striga* and dramatically increased sorghum grain yields after several years of testing. *Striga* count from the ISM package plots were 10 to 15 times lower, while sorghum yields were two to three times higher than plots planted to local cultivars. In

Ethiopia where the ISM technology was tested over four consecutive crop seasons (Tesso *et al.*, 2007), adoption was high with estimates of over 100, 000 families using the practice and increasing demand for seed. ISM was officially recommended and launched in early 2007 by the government of Ethiopia as an essential practice in *Striga* control in areas of the country where the parasite is endemic. In Tanzania, inclusion of the two cultivars in a well organized participatory regional ISM pilot test (Mbwaga *et al.*, 2007) with the use of animal manure and/or inorganic fertilizers planted in tied-ridges to ensure soil moisture conservation, gave effective control of *Striga* and increased sorghum yields significantly. Demand for seed of the new cultivars is increasing as farmers respond to market opportunities in the brewing and animal feed sectors.

Herbicide seed treatment of imidazolinone resistant maize

This technology, developed through the collaboration between the international maize and wheat research centre (CIMMYT), the Weizmann Institute of Science, and the company BASF, combines low doses of imazapyr (<30 g/ha) herbicide applied as a seed coating to non-transgenic Imidazolinone Resistant (IR) maize seed giving early *Striga* control before or during attachment to the maize roots. Kanampiu *et al.*, (2007) reported that imazapyr can reduce the *Striga* seed bank by 80-100% in the 0-30 cm soil top layer. There are no effects on intercropped legumes, if they are sown at least 12 cm away from the treated maize seed. Since the herbicide can be added to a standard seed treatment, the extra cost of this technology is limited to the cost of the herbicide, estimated at about 4 US$/ha, which corresponds to an increase of 8% of the seed cost.

From 1996 to 2004, the herbicide resistance gene was bred into newly developed stress tolerant tropical maize varieties. During 2004, several new IR-maize open pollinated varieties (OPVs) were tested on-station and on-farm in several countries. Following proof of concept in the field, imazapyr was registered as a seed treatment by BASF and was trademarked as the ‘Strigaway’ technology. The technology and hybrid varieties were later extensively tested and received their first regulatory approval in Kenya, after results showed effective *Striga* control and significant increase of maize yields. The technology was commercially launched in Kenya in July 2005 after extensive pre-release demonstrations of the technology throughout western Kenya. The first new commercialized maize hybrid is marketed under the name of Ua Kayongo (*Striga* killer). Six early OPVs, five late OPVs and two hybrids have also been allocated to seed companies and national programmes (NARS) for further testing and to generate data required by regulatory agencies for registration and commercialization. Wide scale participatory field testing of elite IR-maize material is also being carried out by NARS and seed companies in several African countries to encourage selection of varieties with specific adaptation and quality attributes for each respective country.

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Improving cocoa crop protection techniques for sustaining rural livelihoods in West Africa

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Approximately 70% of the world's cocoa comes from West Africa, with small family farmers producing the vast majority of the world's supply. In this region, the most important disease is black pod (especially the invasive *Phytophthora megakarya*) and cocoa mirids (*Sahlbergella* & *Distantiella* spp.) are the most important insect pests. In addition, the need to manage cocoa swollen shoot virus has recently become more apparent in Ghana and Côte d'Ivoire. Mealybugs (*Planococcoides* spp.) are known to act as vectors, which in turn are tended by black ants, but the disease has proved difficult to control by conventional methods so emphasis has been placed on the development of resistant cocoa varieties.

In contrast, Integrated Pest Management (IPM) measures continue to be the principal method for managing black pod diseases and mirids. Current IPM strategies rely on cultural methods (especially sanitary harvesting) together with sporadic use of fungicides and insecticides. Furthermore, implementation of control techniques by smallholder farmers may be erratic and poorly performed. Farmers have limited access to finance to buy chemical inputs, and when they can, often prefer to apply cheaper, older compounds without appropriate or personal protective equipment (PPE).

Application practices may be inefficient in terms of dose transfer and untimely. When used too near to harvest or inappropriately in stores, pesticide residues may ensue which are, or will shortly be, subject to increased controls in Japan and the EU. The diminution of available active substances in Europe resulting from Directive 91/414/EEC is well known by the crop protection community, but the introduction of EC/396/2005 extends the reach of the former to residue tolerances of compounds for imported commodity crops such as cocoa.

Whereas it has been stated specifically that the purpose of the latter is not to create barriers to trade, it has raised concerns amongst producing countries and highlighted the need for:

(i) better agricultural practices;
(ii) enhancing research into substitutes for obsolete pest control methods.

Certain Farmer Field Schools have agreed that WHO/EPA Class I and II products are inappropriate for smallholder farmers with little access to PPE. With the development of a substantial number of new molecules since the 1980s it should now be possible to find alternatives to class I pesticides and the most toxic products in class II.

In response to this need, we describe recent research initiatives, supported by Cocoa Research UK, Mars Inc and the US Department of Agriculture, that provide better understanding of crop-pest interactions and the use of biology-based control agents as possible chemical substitutes that are cost-effective and safe to both farmers and consumers. Outputs include:

(1) Development of better screening methods and laboratory-to-field procedures for assessing conventional and more environmentally friendly techniques which are compatible with IPM practices.

(2) Introduction of more efficient, safer pesticide application practices. Two approaches to improving application seem appropriate:
   (i) optimised nozzle selection for manual hydraulic sprayers used by the majority of smallholders;
   (ii) better selection and use of motorised mistblowers for collaborative, commercial or centralised control operations (such as area-wide spraying of cocoa pests with approved fungicides and insecticides in Ghana by the National Cocoa Disease and Pest Control Committee: CODAPEC).

(3) Identification and proof of concept of biologically-based methods; these currently include laboratory and field evaluations of *Trichoderma asperellum* against black pod disease and *Beauveria bassiana* against cocoa mirids

(4) Use of pheromones to monitor and possibly control mirid populations.

(5) Technology transfer once the proof of concept has been established in pilot trials.

Cocoa trees in West Africa are often allowed to grow rather tall (>4 m) and in theory, IPM measures such as efficient spraying and sanitary harvesting, would greatly benefit from better control of tree height. We argue that, on a world-wide scale, better management of tree architecture remains one of the most important and tangible precursors to successful pest management. There is also perhaps less of a division between research and implementation/extension than in OECD countries, with scientists regularly being invited to carry out trials on smallholder farmers' cocoa. This requires an especially rigorous approach to safety and sustainability of pest management techniques - which may be very different from the methods originally used to establish fungicide and insecticide application to the crop.