PESTICIDE USE IN COCOA

Practical Manual – Fourth Edition, 2023

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Preface

At the beginning of this century, both the European Union (EU) and Japan changed and implemented legislation on Sanitary and Phytosanitary Standards (SPS) in response to public concerns about food safety. From 1 September 2008, the EU extended the standards imposed on domestic produce, to imported commodity crops such as cocoa. The first edition of this Guide was an attempt to explain to producers how pesticides used on farms or in storage, might be traced in assessments of cocoa quality imported into the EU and elsewhere. This has undoubtedly ‘concentrated minds’ over crop production in general and pest management practices in particular. Other issues have come to public attention, including the use of child labour in production and, increasingly over recent years, cocoa has been placed on lists of commodities that are linked to deforestation.

It seems too easy to allow "pesticides" to become a proxy for other environmental and social ills, when chainsaws and poverty are also culpable. For example, it is easy for us to implore readers to forbid the use of child labour for pesticide application: something that might seem obvious to policymakers and their electors in consumer countries, but less obvious to impoverished communities that actually grow cocoa. Likewise, organic chocolates have become popular, but when cocoa production is 'organic by default', with no costly inputs and very low productivity (say <500 kg/ha.), the crop can become a driver of deforestation. At the time of writing this 4th edition, it appears that the profile of environmental issues has risen and may continue to rise over the coming years. It is not within the scope of this guide to examine climate change in detail, except to suggest that Good Agricultural Practices (GAP), efficient land use, with reforestation, can be significant components for mitigating the threats.

Insect pest and disease problems remain major constraints to cocoa production. However, pesticide regulations (including the review processes, started by EU directives 91/414/EEC and 396/2005/EC, followed by subsequent directives) have produced real benefits ‘on the ground’. Far from being the “potential disaster to farmers”, predicted by some, the effective removal of some of the most highly hazardous pesticides from the market has been beneficial to cocoa-growing and other rural communities. Examples of products that were reported as being a serious cause of illness include: cyclodienes (high toxicity, high persistence), mercurial fungicides and many of the most hazardous organophosphorus (OPs) and carbamate insecticides, that were still in use at the turn of this century.

Nevertheless cocoa, like other tropical crops, continues to be attacked by insects, diseases and other pests that must be controlled effectively and safely. Pesticide use and the crop residues they potentially create, is something that can be 'policed' and mitigated: via SPS, Maximum Residue Limits (MRL) and implementation of GAP. Reports of residue exceedance continue to be a concern, but supply chain managers should be aware of the concerns and constraints of cocoa farmers. For example, the risk of *Phytophthora megakarya* black pod disease in the most humid parts of Central and Western Africa, may account for treatments near to harvest and high residues in cocoa beans. From the farmers’ point of view, potential crop losses of more than 80% make such decisions appear rational, if costly. A 'lose-lose' situation is created when pesticide sprays have been poorly applied, ill-selected or timed, so we address application techniques as well as the products themselves.

Recently, environmental campaigners have appeared to focus on issues such as insecticides that harm pollinators and herbicides (occasionally missing real harms in place of popular concerns): but what should be recommended, based on evidence? Our general approach is Integrated Pest Management (IPM), but how best to implement and certify GAP? The purpose of this manual is to explain concepts and provide practical guidance:

1. In the first 2 chapters, we examine the broader context of the crop and the societies that grow it, in order to better define the terms "sustainability" and IPM: by doing this, we hope to define what the "green deal" and similar portrayals might actually mean in practice.
2. We summarise important policymaking and certification schemes in **Chapter 3**. **Chapters 4 - 6** will be of particular interest to trainers and practitioners seeking more background information on pesticide science, including technical issues, especially relating to the cocoa crop.
3. Finally, we suggest a 'road map' for establishing good crop pest management, storage and distribution practices for bulk cocoa. A summary of GAP in the field crop is given **Chapter 7**, with drying and storage issues examined in **Chapter 8**. Concluding recommendations relating to pesticide use are made in **Chapter 9**, with various terms and lists of key pesticides included in the **Appendices**.

Our approach, as in previous editions, attempts to provide: (a) a concise overview of the technical issues with 'problems and solutions'; (b) emphasis on practicality; (c) specific reference to compounds that are or may be used on cocoa, but neither naming nor recommending individual commercial products; (d) emphasis on the needs of smallholders and (e) linkages to web-based and other resources including lists of the status of key active ingredients (Appendix 4), which should be updated regularly. The last point is important and readers are encouraged to visit the ICCO site: www.icco.org/SPS/.

Although the manual continues to be a 'dynamic document', it is our intention to increase its impact by translating it into other languages of cocoa-growing countries. We will reiterate that it is for guidance only, written in the spirit of creative commons and has no legal status.

ACKNOWLEDGEMENTS
We are most grateful for all the helpful advice and suggestions received from the large number of colleagues who have provided many valuable comments, insights and constructive criticisms to earlier editions of the manual. For this 4th edition special thanks go to Yunusa Abubakar, Michelle End, Catherine Entzminger, Martin Gilmour, Marc Joncheere and several other anonymous reviewers. Many thanks also to the secretariat and members of the ECA-CAOBISCO Working Group of Pesticides and Contaminants. We would also like to thank Daniel Kadow (Chairman of the Joint Cocoa Research Fund), Katrin Sinderhauf-Gacioch, Pierre Broun and Michiel Kokken; we are also most grateful to Michel Arrion, and the rest of the team at ICCO for their support.

Several diagrams in this manual are courtesy of *CropLife International* - the industry association that places information on PPE, safe use of pesticides, storage, etc. in the public domain (http://www.croplife.org). We also thank Jean-Ponce Assi, Jerry Cooper, Hans Dobson, FERA UK, Marc Joncheere and Graham Matthews for other illustrations.

Our sponsors have provided funds for this work in order to promote international development and cocoa sustainability. The views and recommendations expressed here are given in the spirit of free exchange of information and ideas. Whereas every care has been taken to ensure accuracy throughout, we cannot take any legal responsibility for any errors or omissions in this manual. Any such errors are the sole responsibility of the authors, who continue to welcome comments and suggestions for future revisions.

RB & JC Revision: February 2023

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01 Introduction

1.1 The crop and its origin

Having probably originated in the upper Amazon, the cacao tree *Theobroma cacao* was also extensively cultivated in Central America, with archaeological evidence of cocoa bean processing more than 1,000 years BCE, around Chiapas and Gulf of Veracruz in Mexico. Following its well-known introduction to the Spanish court by the conquistadores in the 1540s, knowledge of cocoa rapidly spread throughout Europe in the following decades. By the 19th century, introductions of the crop had been to scattered tropical locations in other continents, with Tetteh Quashie introducing cocoa to the African mainland from Fernando Po (now Bioko island) in 1876. The wider international trade and the popularity of chocolate products followed during the 20th century.

The cocoa plant itself belongs to the genus *Theobroma* – of which there are about 20 species, all from Southeast Mexico to Tropical South America; it is now placed in the subfamily Byttnerioidea (it was placed previously in the "Sterculiaceae"). These and other taxa have been relegated to subfamilies in the cotton/mallow family Malvaceae: of which there are nearly 250 genera, with a world-wide distribution and an especially high diversity in tropical areas. Modern plant breeders recognise about ten major cocoa clades[1], but traditionally the trade has considered three main types of cocoa, with which most practitioners remain familiar[2]:

Forastero is 'bulk cocoa' or 'mainstream' cocoa, probably accounting for more than 80% of worldwide production and most African production, with relatively high yield and disease resistance. This includes cocoa from planting material developed from Amazonian types and their hybrids.

Criollo or 'native' cocoa, historically the type of cocoa domesticated in MesoAmerica, is cultivated in small quantities, with 10% of the world's production. It includes rare and sought-after varieties, producing the finest grades of chocolate.

Trinitario originally applied to the hybrid of Criollo and Amazonian types occurring in Trinidad, but is now used to describe various hybrid types known for their floral/fruity flavours.

These terms required revision because of long-standing debates about the genetic background of the planting materials, with arguments about the provenance of and strategies for optimising production. For example, 'Nacional' from Ecuador is a well-known, fine flavoured variety but probably an Amazonian (Forastero) type tree. There is controversy as to whether this "national treasure" should be grown in preference to CCN-51, which has a higher production, tolerance of direct sunlight and probably disease resistance.

Fig. 1.1. A plantation of CCN51 growing in Ecuador (left) and 'Nacional' pod (right)

1.2 Cocoa production world-wide

The nature of cocoa production has changed considerably over the last century, with enormous shifts, not only in how the crop is produced, but also where it is grown. Information on the production of the crop is available from online sources such as the International Cocoa Organisation (ICCO)* and the Food and Agriculture Organisation of the United Nations (FAO).

Trends in cocoa bean production

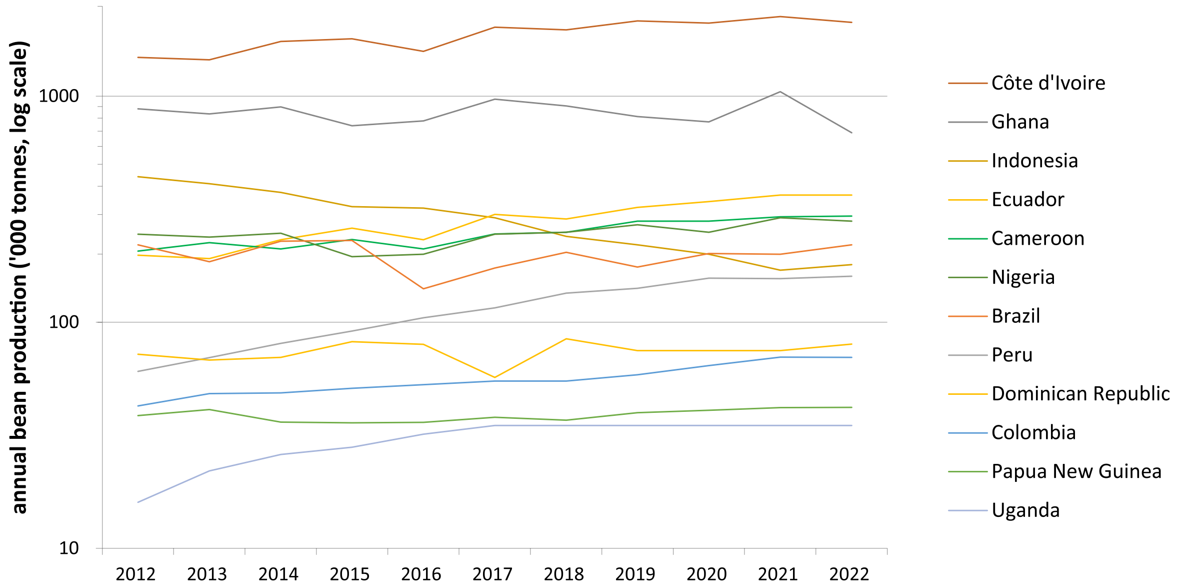


Fig. 1.2. Cocoa bean production by major growing countries (ordered by averages) over the decade ending 2020. Source ICCO.

The chart above (Fig.1.2) indicates trends in bean production in the top 12 cocoa growing countries over the last decade: they account for about 95% of total world production. Over longer periods, dramatic changes have occurred. Having originated in the Americas, the crop was increasingly cultivated there (including the Caribbean), and in 1900 the region still grew some 80% of the world crop. By 1980, the proportion had reduced to approximately 36%, then 12% by 2000 due to many factors, but especially crop disease pressure. In contrast, African production increased from 16% in 1900 to a little over 70% of world production, where it has remained since. Production in the Asia-Pacific region that is currently dominated by Indonesia, increased from approximately 5% to 19% over the 20th century, but is now less than 15%, partly due to insect pests. Current forecasts for the 2020/21 production season put world production at just over 5 million tonnes with Africa accounting for 77% of production, the Americas 17% and Asia and Oceania 6% (Fig. 1.3).

12 COUNTRIES REPRESENT 96% OF THE WORLD COCOA PRODUCTION

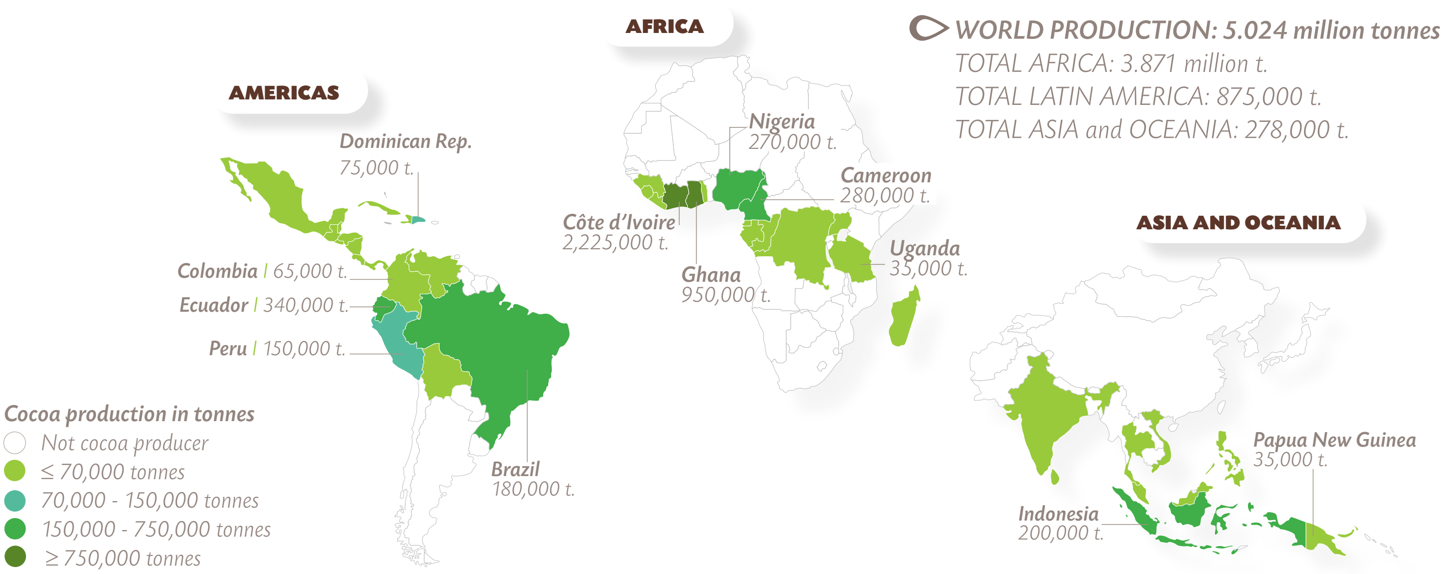


Fig. 1.3. World cocoa production for the 2020/21 season by country and region (ICCO)[3]

* www.icco.org/about-cocoa/growing-cocoa/

Three South American countries: Ecuador, Peru and Colombia have shown production increases over the last decade as has Côte d'Ivoire, the world leader. Statistics for countries recently producing more than 100,000 tonnes of cocoa beans annually are indicated in table 1.1.

Table 1.1 Estimated bean output, growing area and changes in major producing countries. Statistics tend to fluctuate and percentage increase/decrease was calculated from the first and final two years of the decade.

	Production	Production area (ha)		Mean yield kg/ha		% Change over decade	
	2019/2020 (1,000t)	FAO 2020	ICCO est. 2019/2020	FAO (2020)	ICCO	yield	area
Côte d'Ivoire	2130	4,075,644	4,250,951	523	454	-25%	69%
Ghana	806	1,678,504	1,628,493	480	511	-14%	-1%
Indonesia	210	1,656,144	1,642,270	127	131	-50%	-8%
Ecuador	325	476,213	488,518	683	633	35%	29%
Cameroon	280	632,372	642,465	443	440	35%	-3%
Nigeria	260	1,191,877	1,232,443	218	198	2%	2%
Brazil	188	634,557	621,389	297	325	4%	-12%
Peru	146	136,811	135,203	1,068	1,019	43%	64%

The differences may indicate many factors of course including policy and farmer decisions, besides the impact of fertility, crop pests and other agronomic factors. Many cocoa farmers are smallholders, who usually minimise inputs for pest and disease management, and may not be willing or able to invest their time or resources in any pest management when cocoa prices are low. Losses of cocoa to diseases globally is often estimated and reported as 30-40% annually, this estimate does not include the losses due to insect pests. If these estimates are anywhere near accurate, the loss of yield due to pests and diseases has a significant impact on farmer income. In Asia, they are known to have made hard economic decisions, shifting production from cocoa to more profitable crops such as fruit trees. In Indonesia (and Malaysia at the end of the last century), the costs of labour and crop protection have been very significant factors, especially for control of a 'new encounter' pest: the cocoa pod borer. In Central and South America, the spread of the 'co-evolved' *Moniliophthora* diseases - witches' broom and frosty pod rot – resulted in dramatic declines in production, with the latter having the capacity to reduce yields by more than 80%. The diseases caused by *Phytophthora megakarya* (black pod) and cocoa swollen shoot virus (CSSV) have both been major constraints in West Africa with management of the later resulting in massive 'cutting out' campaigns in an attempt to limit the spread of the virus in both Côte d'Ivoire and Ghana.

I.3 The need to understand and address cocoa pest issues and their management

In many cocoa growing areas, major constraints to production include the black pod diseases (*Phytophthora spp.*) and farmers spray on a regular basis, since copper compounds and other fungicides are efficacious[4]. In contrast, two fungus diseases, belonging to the genus *Moniliophthora*, pose a significant threat to the crop in Latin America where they are thought to have co-evolved with cacao and other plants in the tribe *Theobromateae*, making control much more difficult.

The work of the Angiosperm Phylogeny Group (APG4) might appear rather academic, but it can also have practical significance, including importance for cultural control methods. These remain the foundation of IPM strategies for most crops, not least the pest complex associated with the cocoa plant, *Theobroma cacao*. Cultural practices are discussed in more detail elsewhere (national recommendations and general guides***), but minimising pesticide use must inevitably be linked to the cultivation of a healthy crop, with serious attention paid to potential alternative hosts and other phytosanitary measures (Chapter 7). As cacao was introduced to Africa and Asia, a number of 'new encounter' diseases and insects, such as mirids, rapidly became prevalent as countries adopted the crop. Table 1.2 summarises the key pest problems, with *Phytophthora* black pod especially

* www.icco.org/pests-diseases/#toggle-id-38 - * https://www.worldcocoafoundation.org/wp-content/uploads/files_mf/vos2003.pdf
* www.dl-manual.com/doc/trainers-manual-for-sustainable-cocoa-ghana-nv5rddq630z1

important and possibly subject to the most global pesticide use for the crop. *P. megakarya* has only been found to occur in Central and Western Africa and has been isolated from many different plant species but does not appear to cause any significant symptoms, and to date the original forest host has yet to be identified[5]. Cocoa swollen shoot virus disease (CSSVD) is thought to have arisen from *Adansonia, Ceiba*, Cola and Sterculia – all in the Malvaceae; reclassification shows that "potential alternative hosts" may have to be placed at the family level or beyond. The science associated with these key problems is subject to continuous review, from several routes of enquiry. Likewise, it is probably no coincidence that the major cocoa 'capsid' (Miridae) pests, prevalent in different regions, all come from very closely related genera (in the tribe Dicyphini) and usually oligophagous to Malvaceous plants.

Pesticides have now been used on cocoa for more than 60 years, with notable early research carried out independently in the former West African Cocoa Research Institute (now the research institutes of Ghana and Nigeria), Brazil, Ecuador, Cameroon, Costa Rica, Côte d'Ivoire, Indonesia and Malaysia.

By the early 1970s, a number of effective control techniques had become 'established', and there was little incentive for change until environmental awareness increased in the 1990s. Notable amongst these were concerns over the widespread use of lindane for the control of cocoa insect pests; this chemical was eventually phased out but not until the early 21st century in some countries. Many farmers believe that pesticides work, at least against some cocoa pest problems, and continue to use them depending on the pest and country (Table 1.2).

Table 1.2 A guide to cocoa pests against which pesticides may be in current use (based on industry sources and the author's observations).

Cocoa Pest		Region	Use*
Black pod rots	*Phytophthora spp.*	Ubiquitous	1-2
- especially:	*P. megakarya*	C. and W. Africa	1
Witches' broom disease	*Moniliophthora (Crinipellis) perniciosa*	Latin America	2-3
Frosty pod rot	*Moniliophthora roreri*	Latin America	2-3
Capsids (Miridae)	*Sahlbergella singularis* *Distantiella theobromae*	C. and W. Africa C. and W. Africa	1 1
	Helopeltis and related spp.	Africa & Asia	1-2
	Monalonion spp.	Latin America	2-3
Swollen shoot virus (CSSV)	*Vectors: mealybugs such as Planococcoides njalensis*	W. Africa	3
Vertebrates (many spp. depending on region)	*Squirrels, rats, larger mammals, woodpeckers, etc.*	Ubiquitous damage	1-2
Cocoa pod borer	*Conopomorpha cramerella*	SE Asia	1
Vascular streak die-back (VSD)	*Ceratobasidium (=Oncobasidium) theobromae*[6]	SE Asia	2
Other diseases including - root diseases - minor pod diseases	*Several spp. including:* *Ceratocystis & Roselinia spp* *Lasiodiplodia (=Botryodiplodia) theobromae*	Depends on Sp.	3
Insect pests of cocoa trunks, including termites, stemborers, stinkbugs etc.	*Various spp. including:* *Zeuzera sp. (SE Asia)* *Eulophonotus sp. (Africa)* *Bathycoelia thalassina* *Carmenta theobromae*	Locally serious in many cocoa growing areas. W. Africa Latin America	2-3 1-2 2
Pests of young cocoa	*Many spp. - often polyphagous*	Ubiquitous	2
Weeds (especially in young cocoa)	*Many spp.* *(includes mistletoe on mature trees)*	Ubiquitous	2
Insect pests of storage: - Beetles - Warehouse moths	*Many spp. including:* *Cryptolestes ferrugineus, etc.* *Ephestia spp.*	Ubiquitous	1

* Key: 1: Common (although not necessarily ubiquitous) use of pesticides: often dependent on economic circumstances of farmer
2: Localised use of pesticides (may be frequent if cocoa grown commercially)
3: Pesticide use rare, ineffective or experimental: cultural and other control methods recommended.

1.4 Stakeholders

The cocoa industry promotes the use of IPM and cultural methods (removal of diseased plant parts, etc.) are the most proven and cost effective first line of defence against diseases and insects although implementation by farmers of all control methods can often be poor. Pesticides are used on cocoa in certain circumstances (most often category 1 in the table above). The edible part of the bean "nibs" is encased within a shell that covers the bean, which in turn is protected by the pod husk until harvest, making contamination by pesticides less likely unless systemic pesticides are used or beans are contaminated during harvest or drying.

To state the obvious, the two major stakeholders are cocoa producers and the increasing number of consumers. Adapting an observation in Hamilton & Crossly's useful book[7], there are a number of other participants in the debate on pesticides, each with their own agenda:

- **The Agrochemical (now often called Life Sciences~) industry**: principally the half dozen multinational research-based companies which have invested hugely in new technologies (and wish to protect their investments with patents and confidentiality). They provide Governments with regulatory data to show that their products are safe and effective.
- **Companies producing 'generic' products** benefit farmers by pushing down the prices of agrochemical products when patents expire ('off-patent' compounds). In some countries, they are owned / supported by Governments. It is not always appreciated by the general public that their interests (and those of their respective salespeople) may be different to those of research-based companies.
- **Consumer groups and activists**: who voice concerns, which are often shared by the general public, but which may be taken out of context. Their work was pioneered by Rachael Carson, whose book *Silent Spring* (1962) highlighted the hazards, many now undisputed, of the unrestricted use of the older pesticides. It has been argued that they need "regular exposés of unsafe residues in food to maintain their profiles".
- **The Media** are interested in selling newspapers or television time, with priority given to colourful and sensational stories. It is debatable whether it is in their interests to provide a completely objective balance to such stories, but presenters often guide the debate.
- **National Governments (and increasingly, international bodies such as the European Union)** have to balance the various interests and provide an appropriate legislative framework for the various players involved. For example, the UK Health and Safety Executive (HSE, formerly Pesticides Safety Directorate - PSD) disclose documents (on the Web pages and elsewhere) emphasising that this framework must be "evidence based". Governments are also a major source of support to researchers.
- **Research Scientists**: who "seek research grants [and] may try to influence research funding bodies by carefully timed and purpose-designed press releases or may overemphasise a safety concern in order to secure funding".

The cocoa supply and chocolate industries therefore can expect to receive diverse advice on the subject! Nevertheless, decisions must now be made, with minds concentrated by recent regulatory developments, but with incomplete knowledge about the pesticides in question.

02 Risks to sustainable cocoa production

2.1 Overview

This chapter highlights some of the major global issues that threaten the sustainability of cocoa production.

2.1.1 Climate change

In 2021, the Intergovernmental Panel on Climate Change (IPCC) published its sixth assessment report on climate change[8]. The report states that emissions of CO_2 and other greenhouse gasses produced by human activities have warmed the planet at an unprecedented rate. Average global temperatures have already been reported to have risen by 1.1°C, and estimates predict that warming is expected to reach or even exceed 1.5°C in the next twenty years unless there is a strong and sustained reduction in CO2 emissions. With a rise of 1.5°C, the length of dry seasons will increase with shorter cool seasons and heat waves will become more common place. If warming continues to 2°C, critical tolerance levels for health and agriculture may be reached and many of the effects will be irreversible for centuries to come.

Changes in climate have been noted in cocoa growing regions and various climatic models have projected scenarios of climate change and its effects on cocoa (predominantly in West Africa). Changes in climate will cause a shift in cocoa production, with some areas becoming more suitable for cocoa and some less suitable. Predictions by Schroth et al. (2016)[9] show that climate change will significantly reduce the suitability of areas in West Africa for cocoa production due to decreased rainfall and climate drying, this could have the potential of increasing the risk of deforestation in more suitable areas as land is cleared to produce cocoa. These predicted changes in climate and what is currently being observed on the ground have spurred on the search for new climate-smart adaptation strategies including selection of more drought resistant cocoa varieties, revisiting agroforestry systems and reducing carbon emissions through the reduction in the use of synthetic fertilisers and pesticides. If the effect of climate change is uncertain for cocoa production, it also raises uncertainties around how changing weather patterns will affect cocoa pests and diseases let alone their natural enemies - at this point in time, very little is known on the subject.

2.1.2 Deforestation

Agricultural expansion is the main driver for deforestation, with large scale commercial agriculture (cattle ranching, soy and oil palm production) accounting for 40% of deforestation in the tropics between 2000-2010 and subsistence agriculture accounting for 33%*. Between 2015 and 2020, the rate of deforestation was estimated at 10 million hectares per year, down from 16 million hectares per year in the 1990s. The impacts of deforestation include: soil erosion, increased flooding, biodiversity loss, increase greenhouse gas emissions and therefore a driver for climate change.

It has long been acknowledged that cocoa is a driver for deforestation, forests have been cleared to provide more productive land when farmers are faced with aging unproductive cocoa trees, soil degradation, or increased pest and disease pressures. Rates of deforestation in West Africa have risen over the last decade and led to government and private sector commitments to try to end cocoa driven deforestation. Public-private initiatives led by the World Cocoa Foundation (WCF) in Colombia, Côte d'Ivoire and Ghana and IDH-The Sustainable Trade Initiative in Cameroon aim to prevent further deforestation and introduce more sustainable, climate smart approaches to cocoa. During the recent COP26 meeting in Glasgow, the leaders from more than 100 nations committed to stop or reverse the effects of deforestation by 2030.

The picture below, of a felled tree and young cocoa plants in a leading cocoa producing area, illustrates another perspective: "The loss of tropical rain forest is more profound than merely destruction of beautiful areas. If the current rate of deforestation continues, the world's rain forests will vanish within 100 years causing unknown effects on global climate and eliminating the majority of plant and animal species on the planet"[10].

* *https://www.fao.org/3/ca8642en/ca8642en.pdf*

2.1.3 Child Labour

Child labour in West Africa has become a very serious issue within the cocoa sector, and concern expressed by consumers has put pressure on the industry and country governments to take steps to eradicate child labour. The International Labour Organization (ILO) defines child labour as 'a violation of fundamental human rights and has been shown to hinder children's development, potentially leading to lifelong physical or psychological damage'. Child labour can be divided into three different categories:

- Light work: when a child helps out on a family cocoa farm, the work is not hazardous, does not interfere with the child's education and should be done under adult supervision;
- Child labour: ILO Convention 138, sets the minimum age a child can be to engage in employment as 15 years;
- Worst forms of child labour: ILO Convention 182, prohibits forced labour (trafficking/slavery) and protects children under the age of 18 years from engaging in hazardous forms of work.

In cocoa production, the worst forms of child labour are defined as: **i) land clearing, ii) carrying heavy loads, iii) exposure to pesticides, iv) the use of sharp tools, v) long working hours, vi) night working.**

During the 2018/2019 cocoa season, the National Opinion Research Centre (NORC) carried out a survey to assess child labour practices in cocoa growing regions in Côte d'Ivoire and Ghana. The study also intended to compare, where possible, finding from previous surveys carried out in the 2008/2009 and 2013/2014 growing seasons by Tulane University but the difference in the methodologies made this difficult. Some of the main findings from the NORC Report (2020)[11], especially those relating to pesticide use, are summarised below*:

- Approximately **1.56 million** children were engaged in child labour in cocoa production, of those, an estimated **95% (1.48 million children)** carried out some form of hazardous child labour.
- Among all agricultural households in cocoa-growing areas, the percentage of children aged **5-17 years** working in cocoa has **increased in the past decade**, from 31% in 2008/2009 to 45% in 2018/2019 (Côte d'Ivoire increased from 23-38% and Ghana from 44-55%).

* www.cocoainitiative.org/knowledge-hub/resources/ici-technical-summary-norc-report-assessing-progress-reducing-child-labour

- The proportion of children in cocoa-related child labour and hazardous child labour has remained consistently higher in Ghana than in Côte d'Ivoire.
- In cocoa-growing households, rather than all agricultural households in cocoa-growing areas, the prevalence of child labour and hazardous child labour has remained stable since 2013/2014 in both countries.
- Of children aged **5-17 years** from agricultural households in cocoa growing regions, **45%** were engaged in child labour in cocoa production (38% in Côte d'Ivoire and 55% in Ghana).
- **43%** of children aged **5-17** years were engaged in **hazardous work** in cocoa production (37% in Côte d'Ivoire and 51% in Ghana).
- Among children working in cocoa in agricultural households, the proportion **not** exposed to any hazard has increased from 4% in 2008/2009 to 11% in 2018/2019, but the proportion of children working in cocoa doing four or more types of hazardous tasks has **increased** from 7% in 2008/2009 to 22% in 2018/2019.
- Children's exposure to agrochemicals, which **increased on aggregate from 5% to 24%**, was most often linked to carrying water for spraying and being present on the farm during or after spraying. The proportion of children directly applying agrochemicals increased by 50% but at a lower level (4% to 8%).

The cocoa industry has responded to the cocoa child labour crisis through the 'Industry Intervention Package' led by WCF to identify, monitor and support households with vulnerable children in certain communities through awareness raising, improving educational infrastructure, formation of community protection committees and women's livelihood support programs. The findings from a second study by NORC published in 2020[12] show some improvements but continued stakeholder engagement is essential.

The International Cocoa Initiative (ICI) developed a cocoa specific CLMRS (Child Labour Monitoring and Remediation System) to set key indicators for child labour and to monitor progress in the sector, several industry partners have adopted this system. Many certification schemes (e.g. Rainforest Alliance and Fairtrade) are also trying to address the issue and include child labour certification criteria as part of their social requirements. The 'Chocolate Scorecard*, which provides an annual summary of companies' performance relating to several sustainability criteria, includes a section on child labour (and agrochemical use as a separate topic).

In a blog recently published by WCF**, the author suggests that child labour does not occur in a social vacuum but is symptomatic of a much wider set of issues relating to child welfare and which must be considered if the problem is to be resolved.

An example of awareness raising material for preventing/reducing children's exposure to pesticides developed by FAO and ILO (2015)***

* www.chocolatescorecard.com/
** www.worldcocoafoundation.org/blog/should-we-stop-talking-about-child-labor-in-chocolate-an-anthropologists-critique/
*** www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1260531/

2.1.4 Crop production, protection and SPS standards

The long-standing debate on pesticide-related issues shows no sign of diminishing, matched only by the need for increased production of cocoa and other foods and is therefore about a balance between effective and sustainable production.

This manual focuses on appropriate pesticide use for sustained maximisation of yields, within a GAP/IPM context that might be used in the farm, or in storage of bulk cocoa. IPM previously perceived by some as a nicety has become a necessity: no longer can it mean "Incredibly Popular Mantra". It is a rigorous, multi-disciplinary approach for crop production and serious political pressure is now applied for its implementation. Over the coming decade, there will be an increasing demand for new, but practical and effective, IPM techniques for growers of cocoa and other crops.

2.2 Risk and Hazard

Pesticides are often described as "hazardous" or "risky", but these terms are sometimes used loosely. They have specific meanings:

RISK = (INTRINSIC) HAZARD x EXPOSURE

Exposure may have two elements: time and level of contact with the hazard. This is an important concept and has been (mis)used in the past to suggest that "there are no hazardous substances, just dangerous ways of using them".

An analogy may be useful here. Motor vehicles are intrinsically **hazardous**, and we note that far greater numbers of people die in motor accidents every year than from all forms of pesticide poisoning. We only take a **risk** when we are exposed to vehicles (as drivers, passengers or other road users) - and most people are prepared to take on that risk. Some cars are less hazardous than others (e.g. those with many safety features and that do not go fast) and roads have speed limits (**risk reduction**). When a person is a long way from any motor vehicle (exposure = zero), the risk is zero. Since for most people economic life must continue, the concept of reducing the risk to levels that are **As Low as Reasonably Achievable** (ALARA) is more practical than eliminating the risk - which can be considered impossible in practice. Of course, the criteria set for ALARA can be both political and subjective.

Readers are also reminded that there are also risks to the cocoa crop itself. For example, an analysis of the crop in Ghana[13] revealed that key pests (such as black pod) collectively constitute the greatest risk to cocoa supply: either as existing sources of crop loss or the existential threat of invasive alien species. Other risks to cocoa production include ageing trees, price fluctuations and attractiveness of other crops and sources of income.

2.2.1 Risks with chemical pest control

Chemical pest control methods have been, at different times, places and for the various analysts, considered as:

- crucial for sustaining a healthy crop, or
- expensive and of limited cost efficacy, or
- environmentally unsound in the complex cocoa agroecosystem.

Improved crop varieties and various alternative biology-based control techniques may eventually offer sustainable long-term solutions. The major overarching issues with pesticide use include:

- **Safety** aspects including real and potential risks to growers and consumers (see Chapter 5).
- **Cost-effectiveness**: perhaps of greatest interest to many farmers.
- **Technical problems** with pesticide applications: sometimes called the 'three Rs' including development of resistance by pests (resulting in loss of effectiveness) which may cause farmers to increase dosages and thus add to the risk of high **residues**. **Resurgence** where insecticides can actually make minor pest problems worse (see Chapter 4).
- Other sustainability concerns including general **impact on the environment** and non-target organisms (e.g. the build-up of copper in the soil after long-term use for disease control).

Safety aspects are of course by far the greatest concerns for the general public and thus regulators, but pesticides can be important tools for farmers and cannot simply be wished away. Consumers do not always appreciate the high levels of disease and insect pressure that occur in tropical countries, and solving pest control problems for growers remains a crucial part of the "package".

2.2.2 Other SPS Risks

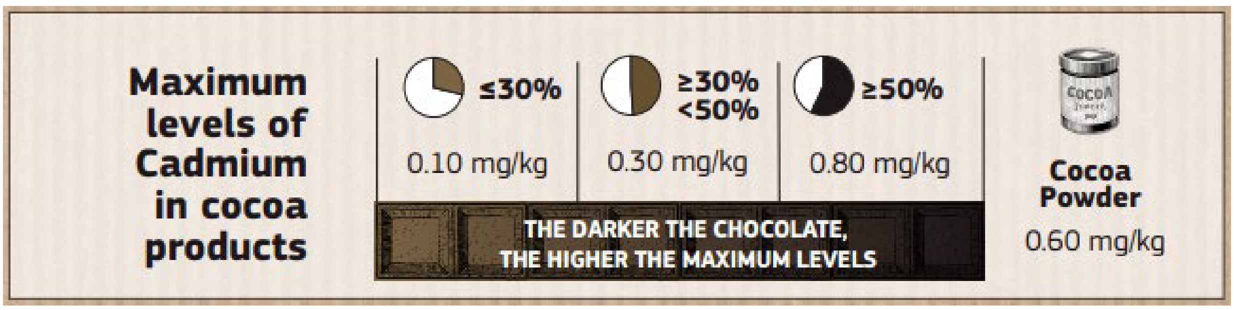
Consumer concerns on food safety and the threat of contaminants to human health have caused tightening of regulations in consuming countries. This increases the risk of disruption to cocoa trade, so poor **Sanitary and Phyto-Sanitary (SPS)** standards have the potential to harm the welfare of farmers in a number of cocoa-growing countries.

Although not the subject of this manual, readers should be aware that in addition to pesticide residues, food safety and cocoa quality concerns include:

- Mycotoxins: especially Ochratoxin A (OTA), often due to poor crop drying – potential damage to DNA (mutagens)
- FFA (Free/trans Fatty Acid): also an indicator of poor cocoa quality – risk of exacerbating diabetes
- PAHs (Polycyclic Aromatic Hydrocarbons): usually due to smoke from badly designed crop dryers – are often carcinogens (risk of causing cancer)
- Mineral oil hydrocarbons (MOH) contain MOSH (mineral oil saturated hydrocarbons) and MOAH (mineral oil aromatic hydrocarbons, including PAH): exposure through packing materials, food additives, lubricants and fuel – MOAH may be mutagenic and carcinogenic
- Acrylamide: formed in starchy foods when cooked at high temperatures (frying, roasting and baking) - carcinogens (risk of causing cancer)
- Heavy/toxic metals, often associated with crops grown on volcanic or polluted soils, include:
    - o Aluminium (Al) – potential neurotoxin
    - o Cadmium (Cd) – highly toxic and carcinogenic
    - o Hexavalent chromium (Cr(VI)) – toxin and carcinogen
    - o Lead (Pb) – carcinogen can cause miscarriages and infertility in males
    - o Mercury (Hg) – damages the nervous system

The levels of heavy/toxic metals are routinely monitored in a variety of different foodstuff to enforce regulatory standards and protect the health of consumers, especially that of young children. In recent years, focus has fallen on cadmium and in 2014 the EU announced the setting of maximum permissible levels in various food stuffs including cocoa and chocolate products*. To allow cocoa producers and processors time to prepare, a 4-year implementation period was granted and on 1 January 2019, the new legislation came into force. From that point forward, cocoa and chocolate products exceeding the maximum permissible levels cannot be marketed in the EU (Source: European Commission**).

The European Commission operates a Rapid Alert System for Food and Feed (RASFF). This is a notification system to exchange information on identified hazards between Member States on food, food contact materials and animal feed. In 2014, the RASFF consumers' portal was launched, a free internet tool to allow the public to access the latest information on food recall notices. It includes public health warnings issued by food safety authorities and food companies***.



* Source: www.eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32014R0488
** Source: www.ec.europa.eu/food/system/files/2019-03/cs_contaminants_catalogue_cadmium_chocolate_en.pdf
*** www.webgate.ec.europa.eu/rasff-window/screen/search

Limits for cadmium in chocolate have since been put in place in other countries including: Australia, Indonesia, New Zealand, Russia and the USA (California), as well as standards being introduced by the *Codex Alimentarius*. Smallholder producers are most affected from some parts of Latin American and the Caribbean where levels of cadmium in cocoa beans can be high. Although the levels for cadmium are not set on unprocessed raw cocoa beans, buyers are placing arbitrary limits to ensure the final chocolate products do not exceed the maximum permissible levels[14]. Research efforts are continuing in the region to find solutions to prevent and reduce cadmium contamination in cocoa beans.

More information on food safety and cocoa quality can be found in the CAOBISCO/ECA/FCC Chocolate and Cocoa Industry Quality Requirements Manual*.

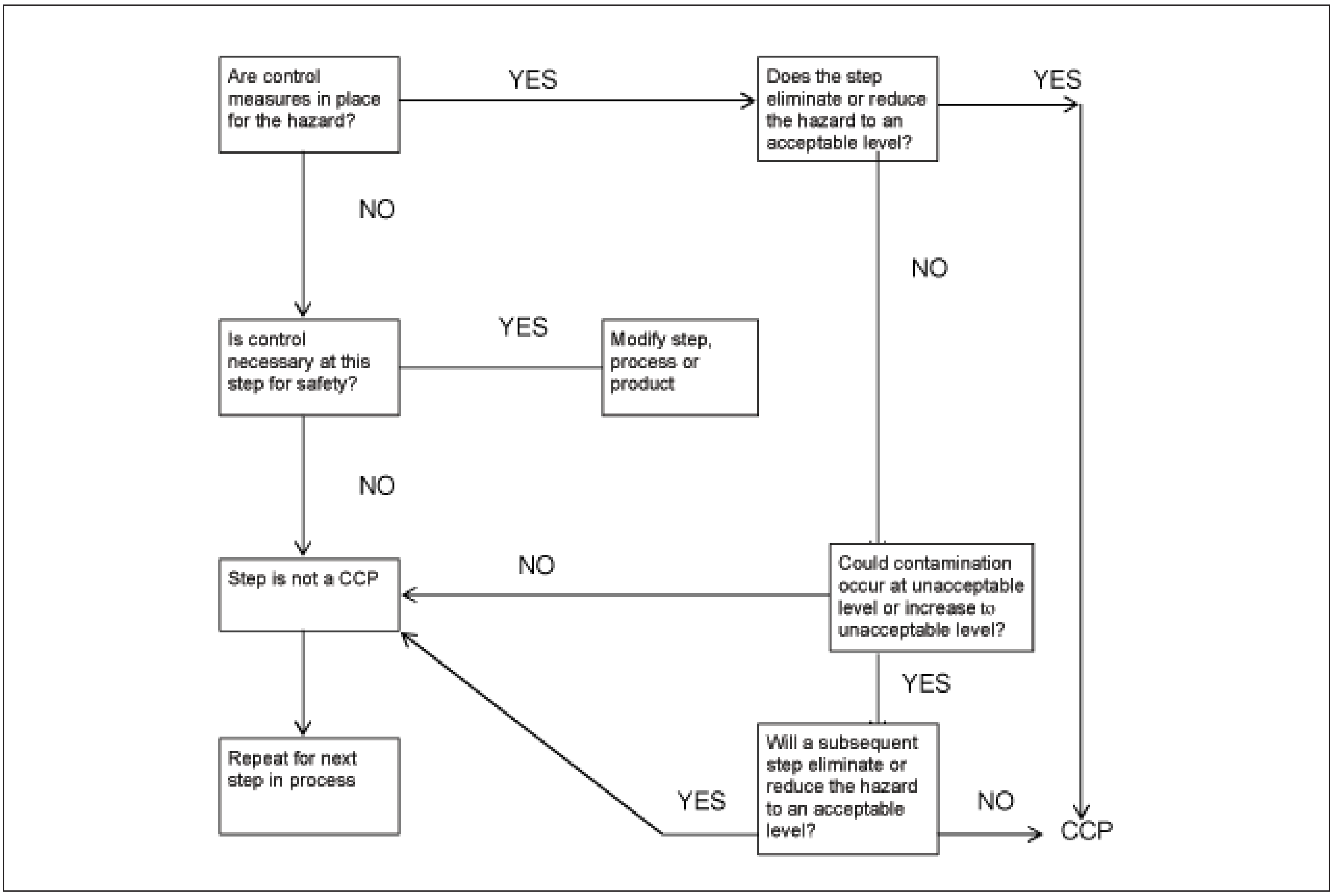
2.3 Hazard Analysis and Critical Control Points (HACCP)

HACCP is a systematic approach to administering safety in production processes, which emphasises the prevention of hazards rather than product inspection. HACCP is thought to have originated in World War II armaments manufacture, but is now also associated with the various stages of food production and distribution.

There is now general agreement that there should be seven HACCP procedures or 'principles', included in the international standard ISO 22000 FSMS 2005, which may form an organization's 'Total Quality Management' system:

1. List all hazards associated with each step and think through suitable **preventative measures to control the hazard**: these may be microbiological, chemical or physical in nature and, at each step, describe the preventative measures that can be used to control these hazards. More than one preventative measure may be required to control a specific hazard.

2. Identify the Critical Control Points (CCP): identification of a CCP in the system can be facilitated by the following flow chart**.



* https://www.cocoaquality.eu/data/Cocoa%20Beans%20Industry%20Quality%20Requirements 20Apr%202016_En.pdf (accessed 21/5/2022)
** Source: http://www.eden.gov.uk (accessed 24/1/2012)

If a hazard has been identified at a step where control is necessary for safety and no preventative measure exists at that step, or any other steps, then the product or process must be modified at that step, or an earlier or later stage, to include a preventative measure.

3. **Establish Critical Limits for each CCP**: these limits depend on the hazard assessed and should be specified for each preventative measure. For pesticides and other contaminants, these are MRLs.

4. **Establish a Monitoring System for each CCP**: monitoring procedures must be able to detect any loss of control at a CCP. Data derived from monitoring must be evaluated by designated people or organisations, with knowledge and authority to carry out corrective actions when necessary.

5. **Establish corrective action**: specific actions must be developed for each CCP in order to correct noncompliance. Such actions must ensure the CCP is brought under control and include details of what to do with affected product.

6. **Validate the HACCP System**: in order to maintain confidence in the system, ensure the HACCP system is working as intended and identify any areas for improvement.

7. **Establish and maintain Record Keeping** and documentation: in order to be effective, the keeping of records is essential.

03 Pesticides, SPS standards and their implementation

3.1 International pesticide regulation

3.1.1 National regulations

The Food and Agriculture Organisation (FAO) of the United Nations and other international bodies have consistently encouraged national pesticide registration schemes, which have now been implemented in most countries. However, it is not always easy to implement regulations (especially those that are technical in nature) in remote rural areas, and products may also pass through 'porous national borders'. The farmer therefore may be faced with a bewildering array of products, with little advice provided on their appropriate use.

In all countries, the primary role of registration is to protect human health. FAO codes of conduct on matters such as the importation of chemicals are based on the principle of *prior informed consent* (see below), where importing countries have a right to know about pesticides (and other substances) that have been banned or restricted in other countries. It is the responsibility of Governments to provide appropriate guidance on the use of hazardous compounds, ranging from easily comprehensible labelling to outright banning of the most toxic products.

The FAO published a Code of Conduct in 2016 outlining guidelines on Highly Hazardous Pesticides (HHP –see Box 1). It is designed to "provide guidance to countries on how to interpret and apply these articles effectively in order to reduce risks posed by HHPs. Countries are encouraged to identify the HHPs in use, to assess the risks involved and to decide upon appropriate measures to mitigate these risks. These guidelines apply to all pesticides, including agricultural, public health, household, amenity and industrial pesticides"*. In order to mitigate risks "while effective, less hazardous, alternatives are available; the most effective option to mitigate such risks will often be to end its use through regulatory action. This can be done through banning or through cancelling or withdrawing registration, or not extending registration".

3.1.2 Prior Informed Consent: pesticides

Prior Informed Consent (PIC) is a convention that was finalised by 50 Governments at a Diplomatic Conference in Rotterdam in September 1998. This '**Rotterdam Convention' creates legally binding obligations** for countries to implement PIC procedures. It was initially built on a voluntary PIC code of conduct, initiated by the United Nations Environment Programme (UNEP) and FAO. The Convention entered into force on 24 February 2004 with two major objectives:

- to promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm;

- to contribute to the environmentally sound use of those hazardous chemicals, by facilitating information exchange about their characteristics, by providing for a national decision-making process on their import and export and by disseminating these decisions to Parties.

* PDF at http://www.fao.org/3/i5566e/i5566e.pdf (retrieved Sept. 2021)

Box 1 - Endocrine Disruptors (ED) and Highly Hazardous Pesticides (HHP): impacts on cocoa

Approvals for substances may be withdrawn within the EU and elsewhere based on several indicators, including 'Endocrine disruption' (ED). The current definition in the EU of an ED is "**an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub)populations**".

The UK Chemicals Regulation Directorate (CRD) report on the possible impact of hazard-based assessments included reference to the EC 1107/2009 stricture: "substances regarded as having endocrine disrupting properties that may be harmful to humans or non-target organisms cannot be authorised". Several observers have pointed-out that no definition was included during the adoption of these regulations. ED effects are disputed among scientists and a functional definition of the term has been agreed in the EU. A public consultation was launched in 2014 (all stakeholders were encouraged to take part) and resolved in 2016.

Dictionary definitions of 'disrupt' are wide ranging: from causing "confusion or disorder" to alteration or interruption of a process. It could be argued that, since an animal's endocrine functions are signalling mechanisms and are known to be influenced by a wide range of naturally occurring and permitted synthetic substances, any attempt to assess ED on a hazard rather than a risk basis is untenable. The removal of smallholder farmers' exposure to HHP (clearly definable by toxicity class) resulting from the 91/414/EEC and 396/2005/EC processes has been beneficial, but further reduction of active ingredients' (AI) diversity could be deleterious to cocoa productivity (which could have environmental consequences, since farmers would need to cultivate more land to obtain the same yields). Every effort should be made to inform the relevant authorities of the potential consequences for crop production and farmer livelihoods before any decisions are made on the status of 'strategic AI' (e.g. as in Appendix 3A), without suitable alternatives having been identified.

Whereas pesticide registration constitutes sovereign national decisions, categorisation of substances as ED in consumer countries may eventually result in the reduction of MRLs to the default 0.01 mg/kg for cocoa and other food crops: a consequence described in one African country as 'banned by the market'. There has been much speculation on the potential consequences of further withdrawal of AI to cocoa and other imported commodity crops and initial approaches have been similar to that taken with HHP, i.e. identify the substances under threat and ask what the alternative pest management measures would be. We here suggest that:

- For sustainable pest management of a given pest, more than 2 modes of action (MoA) are needed, with competing AI and products within each MoA (here used in its broadest sense to include proven-effective, biological control).
- Restriction of AI to only 1-2 MoA could become a significant problem for management of key cocoa pests and proposed changes have to be taken in the round. For example, withdrawing all organophosphorous (OP) insecticides and most pyrethroids on suspected ED problems, together with pyrethroid and neonicotinoid insecticides (NNI) for bee toxicity could result in serious difficulties with mirids and other key insect pests. This may already be an issue for control of storage pests (see chapter 8).
- If an AI is to be banned, 2-3 years are needed for disposal of old stocks of products containing that AI. If AI withdrawal removes a whole MoA and there are not at least 2 alternatives, at least 5 years will be needed (probably more) for the necessary research, development and registration of substitutes.
- To summarise: a 'precautionary approach' should also apply to our ability to protect crops.

Section 7.3 shows some of the new hazard labelling signs to be included on pesticide labels. In this process, a new hazard category "Serious health hazard" has been added, meaning:

- May be fatal if swallowed or enters airways
- Causes damage to organs or may cause damage to organs
- May damage fertility or the unborn child
- Suspected of damaging fertility or the unborn child
- May cause cancer or suspected of causing cancer
- May cause or suspected of causing genetic defects
- May cause allergy or asthma symptoms or breathing difficulties if inhaled

The pictogram will be used for everyday substances such as turpentine, petrol and lamp oil and presumably could, once defined, include ED pesticide substances (even if only suspected). Would the use of such signs on pesticide products give the user sufficient prior informed consent? In household situations, the answer is clearly thought to be yes.

With pressure on global agriculture to increase production, developing countries frequently provide a market for older, cheaper and more hazardous pesticides. They often include generic compounds from producers in expanding economies, which seek less controlled markets. Furthermore, in some countries, locally-produced generic products are actively promoted in the interests of industrial development and low prices for farmers.

PIC is a process which identifies and shares government decisions to ban or severely restrict pesticides, and includes dissemination of decisions to importing countries where information may be difficult to obtain. While promoting shared responsibility between importers and exporters, the exporting countries must ensure their industries comply with importing country decisions. Pesticides currently in the PIC Convention include (amongst other substances): 2,4,5-T, aldrin, captafol, chlorobenzilate, chlordane, chlordimeform, DDT, dieldrin, dinoseb, 1,2-dibromoethane (EDB), endosulfan, fluoroacetamide, HCH (lindane), heptachlor, hexachlorobenzene, mercury compounds, and certain formulations of parathion, methamidophos, monocrotophos, and phosphamidon. Other pesticides will be included in the PIC Convention if they:

- have been banned or severely restricted on the basis of a science-based risk/hazard evaluation in two regions;
- are "severely hazardous pesticide formulations" which cause health or environmental problems under conditions of use in developing countries. These may be included following a verified incident in a developing country.

3.1.3 The Codex Alimentarius

The Joint FAO/WHO Food Standards Programme and the *Codex Alimentarius* Commission (often shortened to *Codex*) was set up to provide internationally recognised standards for protection of consumers' health and to ensure fair practices in the food trade. It was initially believed that, if all countries harmonized their food laws and adopted internationally agreed standards, "such issues would be dealt with naturally". Through harmonization, the founders envisaged fewer barriers to trade and more freedom of movement among countries, which would be to the benefit of farmers and their families and would also help to reduce hunger and poverty. The Codex commission adheres to a code of ethics for international trade in food, with the following general principles:

1. International trade in food should be conducted on the principle that all consumers are entitled to safe, sound and wholesome food and to protection from unfair trade practices.

2. No food should be in international trade which:

(a) has in it or upon it any substance in an amount which renders it poisonous, harmful or otherwise injurious to health; or

(b) consists in whole or in part of any filthy, putrid, rotten, decomposed or diseased substance or foreign matter, or is otherwise unfit for human consumption; or

(c) is adulterated; or

(d) is labelled, or presented in a manner that is false, misleading or is deceptive; or

(e) is sold, prepared, packaged, stored or transported for sale under unsanitary conditions.

The *Codex Alimentarius* has always been a science-based activity. Experts and specialists in a wide range of disciplines have contributed to every aspect of the code to ensure that its standards withstand the most rigorous scientific scrutiny. The Codex operates through a number of specialist committees*, which include Contaminants in Foods and Pesticide Residues.

One scientific committee is the **Joint FAO/WHO Meeting on Pesticide Residues (JMPR)**. The JMPR was established in 1963 following a decision by the FAO Conference that the *Codex Alimentarius Commission* should recommend maximum residue limits (MRLs) for pesticide and environmental contaminants in specific food products to ensure the safety of foods containing residues. It was also decided that the JMPR should recommend methods of sampling and analysis.

* https://www.fao.org/fao-who-codexalimentarius/about-codex/en/

- JMPR members are independent scientists who are expert in aspects of pesticides, environmental chemicals and their residues and who are appointed in their own right and not as government representatives.
- The JMPR is independent of the Commission.
- The FAO appointees draft MRLs for substances under evaluation, based on field trials that are conducted worldwide. WHO appointees conduct toxicological evaluations of the pesticides.
- Reports of evaluations are published.
- There is close cooperation between the JMPR and the *Codex* Committee on Pesticide Residues (CCPR). The CCPR identifies those substances requiring priority evaluation. After the JMPR evaluation, the CCPR discusses the recommended MRLs and, if they are acceptable, forwards them to the Commission for adoption as *Codex* MRLs.

The following table is derived from the *Codex* Alimentarius pesticide database and lists the current *Codex* MRLs that apply to cocoa beans*. The *Codex* MRLs for deltamethrin, fenitrothion and lindane were revoked in 2003. At the time of access (May. 2022), the database includes "Codex Maximum Residue Limits for Pesticides and Extraneous Maximum Residue Limits adopted by the Codex Alimentarius Commission up to and including its 42nd Session (July 2019)".

Maximum Residue Limits for Cocoa beans (commodity code SB 0715)

Pesticide	MRL	Year of Adoption	
Hydrogen Phosphide	0.01 mg/Kg		Po
Clothianidin	0.02 mg/Kg	2011	(*)
Endosulfan	0.2 mg/Kg	2007	
Mandipropamid	0.06 mg/Kg	2019	
Metalaxyl	0.2 mg/Kg	1991	
Methyl Bromide	5 mg/Kg	1999	Po
Pyraclostrobin	0.01 mg/Kg	2019	
Thiamethoxam	0.02 mg/Kg	2011	(*)

(*): At or about the limit of determination.
Po: The MRL accommodates post-harvest treatment of the commodity.

* https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/commodities-detail/en/?lang=en&c_id=239 (accessed Nov. 2021)

3.2 Global trade and cocoa SPS regulations

The following Sankey diagram (Fig 1.4) graphically illustrates the flow complexity of global trade in cocoa beans with European countries importing over 60% of cocoa beans traded, this goes some way to explain why emphasis has been placed on European import tolerances. However, the USA - and increasingly Asia - are also major importers of cocoa beans for processing and consumption.

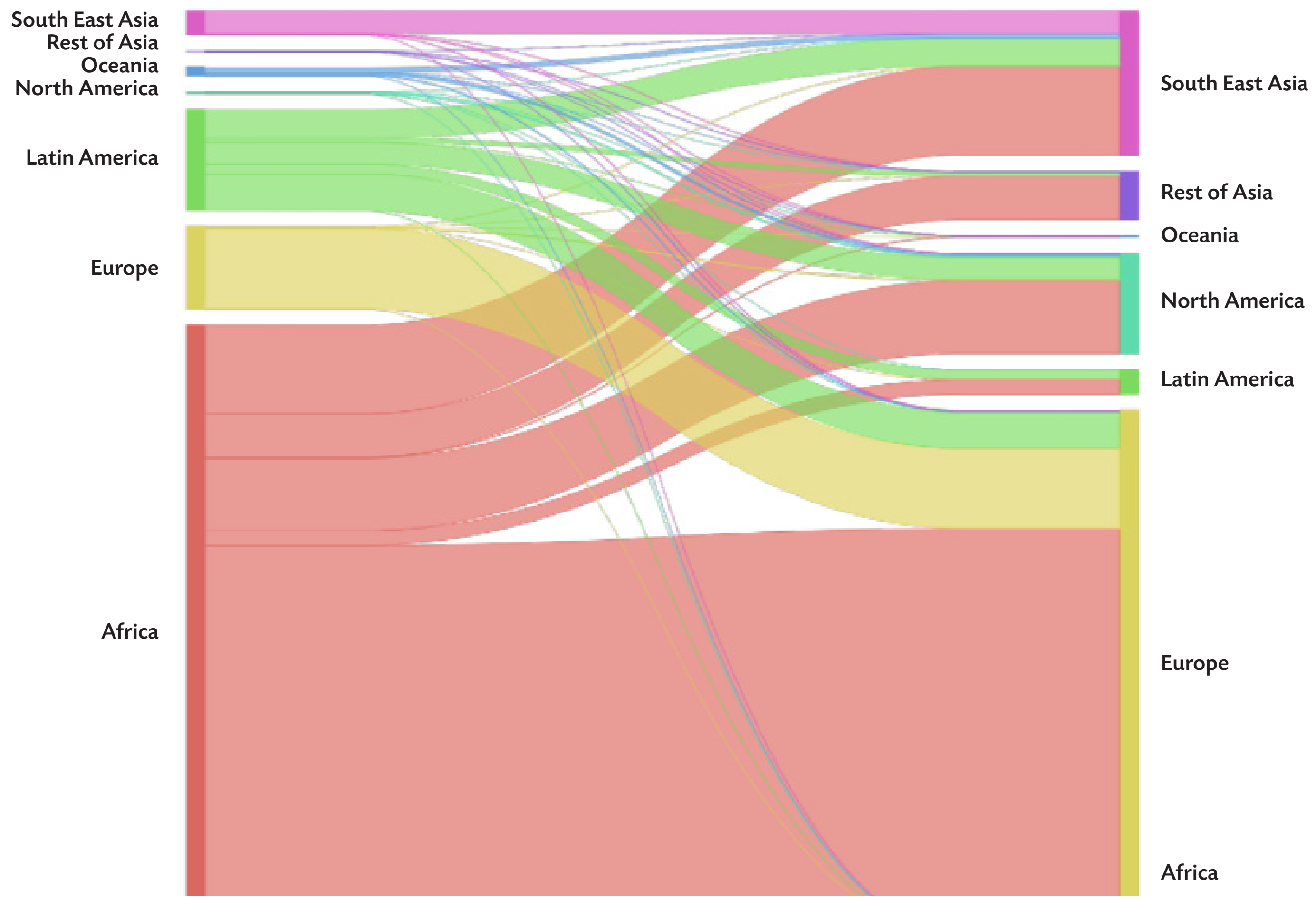


Figure 1.4 Export flow of cocoa beans and recipient importing regions during the 2019/2020 season. Source: ICCO

The International Plant Protection Convention (IPPC), under the auspices of FAO, maintains a database on country legislation for phytosanitary requirements, restrictions and prohibitions here: **https://www.ippc.int/en/countries/all/legislation/**

3.2.1 EU regulations for pesticides and commodities

In 1991, the European Commission started a community-wide review process for all **active ingredients** (AI - also known as **active substances**) used in plant protection products within the EU. A defining moment for the use of pest control products in Europe was the introduction of **Directive 91/414/EEC**. The process involved evaluation of substances, followed by recommendation on their acceptability to the European Commission. Acceptable substances were included in a positive list of AI known as "Annex I", if the risk to consumers, workers and the environment was considered acceptable. The original Directive made a distinction between "existing" (on the market before July 1993) and "new" compounds (introduced to the market afterwards). If the compound could not be included in Annex I, authorisation for products containing that substance was withdrawn within a period specified in the Commission Directive. This review programme effectively resulted in a very substantial reduction (>50%) of pesticides available for use in EU countries. Directive 91/414/EEC was seen from the outset as a continuing review process in which "... based on scientific assessments, each applicant [has] to prove that a substance could be used safely regarding human health, the environment, ecotoxicology and residues in the food chain."

Regulation EC 1107/2009* replaced Directive 91/414/EEC, which was repealed on 14 June 2011 and provides even stricter controls on AI, with a shift in emphasis from risk to hazard-based assessment of pesticides[15]. In addition, fumigants, rodenticides and other pest control products used in stores, are subject to the **Biocides Regulation EU/528/2012** (see section 6.5).

From the end of 2003, the European Food Safety Authority (EFSA) was set up to deal with risk assessment issues, with the European Commission retaining risk management decisions. The standards of this assessment and the policy of their use are constantly improved in a number of expert groups and documented in guidance documents. The UK Chemicals Regulation Directorate (CRD) of the Health & Safety Executive (HSE)** examined the 286 substances previously included in Annex 1 to Directive 91/414/EEC and under review for EC 1107/2009, in light of possible practical consequences to EU farmers16. They considered that criteria **might** consist of:

- no cat 1 or 2 CMR (substances that are carcinogenic, mutagenic or toxic to reproduction) unless exposure is negligible
- no endocrine disruptors (ED: see Box 1 &***) unless exposure is negligible
- no POPs (persistent organic pollutants)
- no PBT (persistent Bioaccumulative Toxic) chemicals
- no vPvB (very persistent, very bioaccumulative) chemicals
- withdrawal of substances with an ADI (acceptable daily intake), ARfD (acute reference dose) or AOEL (acceptable operator exposure level) which is significantly lower than those for the majority of approved substances
- no substances considered to cause a risk of developmental neurotoxic or immuno-toxic properties
- no substances with a high hazard quotient for bees
- no substances which cause concerns and/or can leach easily into groundwater.

Regulation 396/2005/EC came into force on 1 September 2008 and sets MRLs for pesticide residues in food and animal feed produced, or being imported into, the EU. MRLs were first published as Regulation 149/2008/EC in March 2008 in the form of Annexes to 396/2005/EC; these were updated before they came into force and continue to be subject to review (see section 3.2). All cocoa beans imported into the EU must conform to the new Regulation, although temporary MRLs (tMRL) may apply to certain AI for a transitional period.

Information is on **www.ec.europa.eu/food/plant/protection/evaluation/index_en.htm** - the DG SANCO site which aims to "maximise transparency on the decision-making procedure".

The European Commission has recently announced the implementation of the European Green Deal, which is a series of policy initiatives which aim to make the EU climate neutral, making Europe the world's first climate-neutral continent by 2050. These policies will affect many different sectors including energy, construction, transport, industry, food and agriculture****. The Farm to Fork Strategy at the heart of the European Green Deal aims to make food systems more sustainable*****. To achieve this, the programme includes targets to:

- have 25% of total EU farmland under organic agriculture by 2030
- reduce by 50% the use and risk of chemical pesticides by 2030
- reduce by 50% the use of more hazardous pesticides by 2030
- reduce soil nutrient loss by at least 50%
- reduce the use of fertilizers by 20% by 2030
- reduce the use of antimicrobials in agriculture and aquaculture by 50% by 2030
- create sustainable food labelling
- reduce food waste by 50% by 2030

* http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:309:0001:0050:EN:PDF
** Formerly Pesticide Safety Directorate (PSD) UK (December 2008): Revised assessment of the impact on crop protection in the UK of the 'cut-off criteria' and substitution provisions in the proposed Regulation of the European Parliament and of the Council concerning the placing of plant protection products on the market.
*** http://ec.europa.eu/environment/chemicals/endocrine/definitions/endodis_en.htm (accessed Nov. 2021)
**** See: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
***** See: https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en

With the planned reduction in pesticide use and risk in the EU under the Farm to Fork Strategy there is increased scrutiny on the current authorization of pesticide active ingredients, with those that are considered to be more hazardous being reviewed and withdrawn from use. The knock-on effects of this for cocoa exporting countries is that increased numbers of active ingredients currently used for pest and disease management in cocoa are being withdrawn from use in the EU. Staying informed of proposed changes in the status of plant protection products in cocoa importing is essential for producing countries to be able to identify less hazardous replacement products for pest management in cocoa.

NOTE

1. It is important to differentiate between the MRLs on produce, which are regulated by the annexes of EC 396/2005 and approvals for pesticide use in EU which is currently regulated by EC 1107/2009. However, the two regulations are linked by common issues described here.

2. Cocoa bean supply chains are complex and largely administered by international companies: at time of writing, the UK remains aligned with EU SPS standards after Brexit with "Regulation (EC) 1107/2009 as it has effect in Great Britain" and "by virtue of the Protocol on Ireland/Northern Ireland in the EU withdrawal".[17]

Chapter 5 includes a number of issues that might appear to be not directly related to residue tolerances. One of the main objectives of this manual is to guide staff in the cocoa industry through the various, multi-disciplinary aspects of pest management: specifically, to 'stay ahead of the game' with pesticides and not just try to keep up with existing legislation. To a certain extent, many were taken by surprise by EU regulation EC 396/2005, which itself continues to undergo amendment (i.e. to its Annexes).

The details of the proposed legislation have taken several years to be agreed. Research institutes in cocoa producing countries should now be considering how best to manage key pest species, if substances possibly 'under threat' (e.g. certain pyrethroids and neonicotinoids) were to be deemed unsuitable for use with food crops.

3.2.2 Regulations in the United States of America

In the **USA**, the **Environmental Protection Agency (EPA)** regulates pesticides with two federal statutes (see www.epa.gov/opp00001/regulating/laws/fqpa/backgrnd.htm) under the Food Quality Protection Act (FQPA) of 1996. The Federal Food, Drug, and Cosmetic Act (FFDCA), establishes the amount of pesticide residues permitted on food for consumption. The EPA produces fact sheets, prepared as part of EPA Registration and Re-registration programmes. Where a fact sheet has been issued for a 'new' active ingredient, this is noted. The EPA also requires that all approved pesticides are clearly labelled with instructions for proper use, handling, storage and disposal: regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

In addition, the **Food and Drug Administration (FDA)** provides guidance on food commodities and pesticides on: http://www.fda.gov/Food/FoodborneIllnessContaminants/Pesticides/ (but at the time of writing, reports appear to be 3 years in arrears).

3.2.3 Regulations in Japan

On 29 May 2006, the Ministry of Health, Labour and Welfare (MHLW) established a positive list system for agricultural chemicals remaining in foods, including cocoa, as part of the implementation of its Food Sanitation Law. The MRL list is available on http://www.mhlw.go.jp/english/topics/foodsafety/positivelist060228/dl/index-1a.pdf. A number of samples were found to have excessive residue levels and shipments have been rejected over the years. The high rejection rate has been attributed to the method of analysis used, which was different to that used by other importing countries, but is now being harmonised (see section 3.5).

3.2.4 Proposed Regulation in the PR China

Concerns about food quality and health have become a major issue in China, with specific proposals for enhanced regulation of cocoa products*: "Supervision over the use of imported cocoa shells as well as manufacturers of cocoa products and foodstuff containing cocoa powder as an ingredient will be intensified, according to a circular jointly released by China Food and Drug Administration and the General Administration of Quality Supervision, Inspection and Quarantine."

* Xinhua News Agency, Beijing, 29 Oct. 2013

The circular called for strict labelling of products, in Chinese and "checks on production permits of cocoa product manufacturers, as well as supervision of manufacturers of cocoa-related food products. The circular also urged local food, product quality and quarantine authorities to jointly check cocoa products and related food companies for safety risks and alert superior departments of any issues."

3.3 GAP, IPM and RPU/RU in practice

There is a commonly held view that pest control is best achieved within a framework of **Integrated Pest Management** (IPM) - or more generally **Integrated Crop Management** (ICM). The practical implementation of 'IPM', a term first coined in 1967 by R.F. Smith and R. van den Bosch, has been a matter of considerable debate: especially in relation to the use of pesticides. The definition that has been agreed by the UN Food and Agricultural Organisation (FAO), and supported by agrochemical bodies, several NGOs, and the International Farmers Organization is that:

*"Integrated Pest Management (IPM) means the careful consideration of all available pest control methods and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimise risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms" *.*

3.3.1 Sustainable Use Directive 2209/128/EC

IPM is also a requirement reflected in the European Directive on the Sustainable Use of Pesticides. In 2009, the European Parliament established a framework for Community action to achieve: "National Action Plans aimed at setting quantitative objectives, targets, measures, timetables and indicators to reduce risks and impacts of pesticide use on human health and the environment, and at encouraging the development and introduction of integrated pest management and of alternative approaches or techniques in order to reduce dependency on the use of pesticides, should be used by Member States in order to facilitate the implementation of this Directive. Member States should monitor the use of plant protection products containing active substances of particular concern and establish timetables and targets for the reduction of their use, in particular when it is an appropriate means to achieve risk reduction targets. National Action Plans should be coordinated with implementation plans under other relevant Community legislation and could be used for grouping together objectives to be achieved under other Community legislation related to pesticides".

Under the Sustainable Use Directive, pesticide use in EU countries, from the beginning of 2014, should only take place within the general principles of IPM. Member States are now obliged to implement true 'integration': establishing an optimal mix of pest management techniques including:

- Cultural methods, such as: attention to potential alternative pest host plants, removal and burning of diseased plant parts, pruning, removal of infected/infested pods and regular complete harvesting.
- Clonal selection and other genetic methods that confer resistance to pests; these are long-term measures (much of the research currently taking place is unlikely to be implemented at the farmer level for several years to come).
- The conservation and/or manipulation of biological agents (e.g. biopesticides and insect predators such as ants).
- Application of chemical pesticides, but only on the basis of rational and responsible use.

How best to implement IPM in cocoa growing countries? In a recent article**, Dr Rob Jacobson suggested a number of key messages for both policymakers and practitioners, including:

- Do not under-estimate the complexity of IPM
- Seek input from experienced practitioners
- Apply sensible time frames for implementation
- Training is vital

* Internal Code of Conduct on the Distribution and Use of pesticides, FAO, November 2002
** Newsletter of the Association of Applied Biologists: issue 79, Autumn 2013

- Understand the crop and work on customers' expectations for quality and cost of produce
- Provide adequate resources for R&D to develop alternative control measures
- Target specific pesticides which will still be required
- Include 'safety nets' in the form of second lines of defence against key pests
- Never relax – always be prepared for the next challenge.

3.3.2 A Farmer's Perspective?

Legislators in cocoa growing countries must be guided by the requirements of the consumer, but it is imperative that any measures taken are appropriate for farmers' needs. Many of the latter are smallholders who, when faced with pest problems, seek effective solutions and continue to turn to the use of pesticides to provide remedies. From the farmer's point of view, (s)he might:

- wish to buy pesticide products for other crops or domestic use, that may be unsuitable for cocoa and leave harmful residues;
- be presented with a bewildering array of products, not to mention sales persuasion, when visiting the agricultural supply store;
- be offered **illegal or counterfeit products**: this is a major concern of responsible suppliers. To find out more, go to www.croplife.org/crop-protection/anti-counterfeiting/.

Which product to choose? Is it effective? Is it safe? Is it genuine? Is it affordable?

3.3.3 Responsible/Rational Pesticide Use as a component of GAP

An international meeting - the **Round Table for a Sustainable Cocoa Economy** (RSCE I), held in Ghana during October 2007, included cocoa farmers, cooperatives, traders, exporters, processors, chocolate manufacturers, wholesalers, governmental and non-governmental organizations, financial institutions as well as donor agencies. A consensus was reached on a number of action points for maintaining sustainable cocoa, often called the "Accra Agenda". Pest management issues featured highly in the list of priorities, with the following key needs (amongst several others) identified:

- Remunerative prices and increased income for cocoa farmers, including consideration of the impact of fiscal policies;

- Development and promotion of **Good Agricultural Practices (GAP)** to increase productivity and quality in a manner that respects both the environment and social standards;
- Reduction of losses due to pests and diseases by introduction of **Integrated Pest Management** (IPM);
- Promotion and support of local services providing improved planting materials, fertilizers, pesticides, etc. and provision of related training;
- Mechanization of farm operations to reduce costs where possible;
- Increased labour efficiency through better management practices;
- Sustainable commercialization includes the development of efficient supply chains to increase the margin received by farmers, while maintaining cocoa quality and improving traceability in the value chain.

As its name suggests, GAP encompasses a large number of crop production procedures that must be safe, effective, recommended and enforced, either on a national or crop basis. The objective of using a pesticide is to achieve effective pest control, while leaving a minimum amount of pesticide residue on the crop (within practical limits). These limits are regulated, but established principally by the agrochemical company wishing to register its products, having carried out a number of trials that conform to agreed and rigorous protocols.

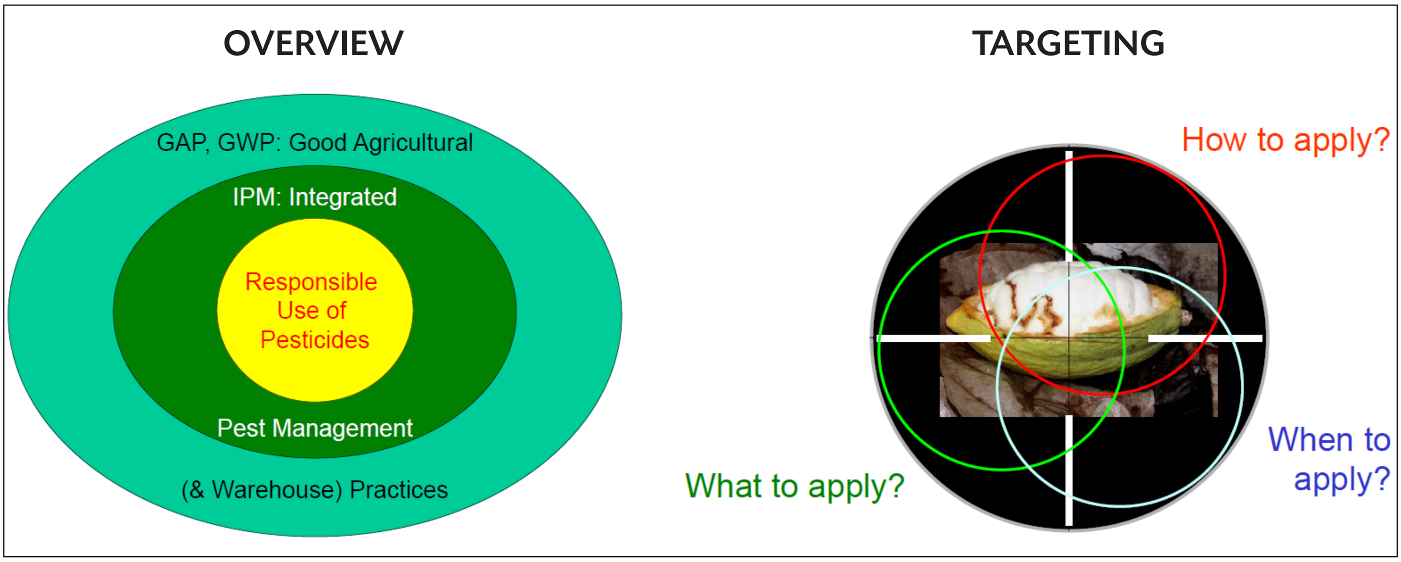
Insect pest and disease control strategies that rely on the application of a limited number of pesticides are almost certainly not sustainable. A research and extension 'vacuum' in appropriate pesticide research since the late 1980s has combined with years of poor returns for cocoa crops. In consequence, most smallholder farmers are unaware of recent control agents and techniques for pest management, and often apply older, often more hazardous, products.

There is now an urgent need for implementation programmes that transfer rational pesticide techniques in each of the major cocoa growing regions, firstly addressing questions such as:

- What are the true levels of pest control and operational costs (over large areas)?
- Can we replace all the currently used and hazardous (WHO/EPA class I and II) products in the near future?
- Why are older pesticides so popular?
- Are there other control techniques that have a minimal environmental impact, yet effectively control target pests?

The term responsible (or rational) pesticide use (RPU[41], or RU is used in *CropLife* literature) describes the targeted and safe use of pesticides as part of a pest management strategy. Three key elements to mitigate the adverse effects of pesticides are improvements in the selectivity of the products themselves and the precision of their application in both space and time. Other potential benefits include: reduction of costs (for both pesticides and labour), improved safety and reduced environmental impact. RPU therefore is about the tactics and tools for managing issues such as residues within an IPM strategy, which in turn is a component of Good Agricultural Practices. Subsequent chapters attempt to provide essential background information, leading to a practical description of ways in which pesticides should be used; namely:

- 1. **Diagnosis** of the problem
- 2. Product **selection**
- 3. Safe and efficient **application** techniques
- 4. **Timing** of application - not only for better pest control, but specifically for residue management communicated to the user via the **Pre-Harvest Interval** (**PHI** - which is the minimum permitted time between the last spray and harvest).



In practice, RPU can only really be achieved with **accuracy and understanding** about pesticides themselves, their properties and application techniques; this will be the subject of Chapter 4.

3.4 Certification

Many of the major chocolate manufacturers now emphasise the need for traceability along supply chains and collaborate with various certification organisations, three of which are described below. Early experience revealed how difficult it can be to even maintain labour standards (let alone less 'visible' SPS standards) in remote areas, with often complex cocoa supply chains, leaving some to question whether certification is positive for farmers or not. The ICCO commissioned a study* on the merits, possible disadvantages and costs of certification to farmers with a review of research into its contribution to the 'sustainability' of the industry. It was noted that "An average of 89% yield increase in Ghana and 101% in Côte d'Ivoire - which are a consequence of several interventions by certification, such as increased access to pesticide, fertilizer, training and as a consequence good agricultural practices - and a premium [price] per ton, are the strongest levers for the business case." However, farmers often have to commit themselves to an initial outlay (in both money and effort) and concerns have also been raised about the equitability of distribution of premiums – especially to smallholders. Larger farmers and cooperatives may benefit from the activities (with somewhat contrasting emphases) of the certification schemes:

CEN-ISO Certification: In 2019/2020 the European Committee for Standardisation (CEN) and International Organization for Standardization (ISO) published the ISO 34101 standard series for sustainable and traceable cocoa to encourage the professionalisation of cocoa farming**. There are four parts to the standard. Part 1: Requirements for cocoa sustainability management systems, focuses on assisting users to implement effective practices to allow them to continually improve their business. Part 2 is concerned with performance requirements relating to economic, social and environmental criteria. Parts 3 and 4 outline requirements for traceability and certification schemes***.

* www.icco.org/about-us/international-cocoa-agreements/302-study-on-the-costs-advantages-and-disadvantages-of-cocoa-certification-october-2012.html
** www.standards.cencenelec.eu/dyn/www/f?p=205:32:0::::FSP_ORG_ID,FSP_LANG_ID:915650,25&cs=186971D7DCA57FB8AA001D0108ED514CD
*** www.cencenelec.eu/news-and-events/news/2020/briefnews/2020-10-23-standardization-impact-sustainable-development/

The web site (https://www.cen.eu/) states: "CEN's activities in relation to food safety are in line with the European Union's objective to achieve the highest possible level of health protection for the consumers of Europe's food. EU food safety legislation establishes a cascade of methods that shall be used for official control purposes. Preference is given to methods that comply with internationally recognized rules or protocols, like those described in CEN publications. Therefore, a majority of European Standards and other deliverables developed by CEN in the area of Food and Feed are supported by Mandates from the European Commission requesting development of validated methods of analysis of food and feed". Under their 'Vienna Agreement' (1991), CEN and ISO aim to avoid duplication of standards.

Fairtrade International (FLO) (http://www.fairtrade.net): is a non-profit, multi-stakeholder association involving 28 member and associate member organizations. It sets labour and economic as well as environmental and phytosanitary standards. "Fairtrade Standards include requirements for environmentally sound agricultural practices. The focus areas are: minimized and safe use of agrochemicals, proper and safe management of waste, maintenance of soil fertility and water resources and no use of genetically modified organisms. Fairtrade Standards do not require organic certification as part of its standards. However, organic production is promoted and is rewarded by higher Fairtrade Minimum Prices for organically grown products". They emphasise IPM and the use of pesticides with lower toxicity in their Document for Small Producer Organizations *.

The **Rainforest Alliance** (www.rainforest-alliance.org) is an international non-governmental organisation (NGO) founded in 1987 "building an alliance to protect forests, improve the livelihoods of farmers and forest communities, promote their human rights, and help them mitigate and adapt to the climate crisis"**. Working with a network of environmental groups, farmers must comply with appropriate standards for protecting wildlife, wild lands, workers' rights and local communities in order to be awarded the certified seal (as illustrated). Already linked to the Sustainable Agriculture Network (SAN: www.sanstandards.org), Rainforest Alliance merged with UTZ in 2018 and released their 2020 Sustainable Agriculture Standard. There are three types of farm requirements for enabling and measuring improvement: core, mandatory improvement and self-selected for each focus area including management, traceability, income, farming, social and environment. Agrochemical management predominantly falls under the farming category. As part of this standard, Rainforest Alliance also produces a Pesticide Management document listing prohibited and risk mitigation pesticides***.

3.4.1 Criteria of certifiers

The precautionary principle is an especially strong concept in Europe (as opposed to the *caveat emptor* approach often found elsewhere) and often has been used as a guiding principle to constrain the use of pesticides. There is no reason why the precautionary principle cannot be consistent with GAP, and leading proponents in Europe for this approach (as opposed to organic agriculture) are a group of national organisations linked by the European Initiative for Sustainable development in Agriculture (EISA - www.sustainable-agriculture.org).

Potential users should understand the criteria by which GAP – and particularly SPS standards – are evaluated by certification schemes. Decision-making may have been influenced by other organisations and pressure groups such as the ISEAL Alliance (www.isealalliance.org) and the Pesticide Action Network (PAN: www.pan-europe.info, www.panna.org), who contribute to the compilation of "prohibited" or "banned" pesticide lists. Unfortunately, certain lists have recently included substances that are actually permitted for use in both cocoa-producing and OECD countries, and conflate controversial (but permitted) products with obsolete and other highly hazardous pesticides.

Certifiers therefore risk sending 'mixed messages' to growers, with recent cases of efforts to "ban" important MoA groups, without identifying effective, viable, alternative pest management techniques. The ECA/CAOBISCO Pesticides Working Group has argued that it is crucial to coordinate with and strengthen the activities of relevant Regulatory Authorities – which are the only competent and legal entities actually able to ban harmful substances.

* www.fairtrade.net/fileadmin/user_upload/content/2009/standards/documents/2013-02-12_EN_SPO_Explan_Doc_3_.pdf
** www.rainforest-alliance.org/about/
*** www.rainforest-alliance.org/resource-item/annex-s7-pesticides-management/

3.4.2 Organic Cocoa

Following a number of "food scares" and consumer concern over food safety, organic cocoa production has enjoyed substantial growth since the beginning of the century*, but tempered perhaps by the post 2008 recession. Where certification is successfully implemented, the farmer benefits from elevated crop prices, although some argue that production may include cocoa that is "organic by default" - where farmers simply don't use inputs such as fertilisers and pesticides (often with low productivity) – rather than adhering to the principles of organic farming.

At present, there are several interpretations of organic agriculture in use in different regions of the world, reflecting different approaches (agricultural/technical, economic or scientific and philosophical). A general definition was formulated by the *Codex Alimentarius* in 1999: "*Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system*". Most certifiers are affiliated to the International Foundation of Organic Agriculture Movements (IFOAM: www.ifoam.org). IFOAM promotes four principles of organic agriculture: (i) health: of soil, plant, animal, human and planet; (ii) ecology: working with systems and cycles; (iii) fairness: characterized by equity, respect, justice and stewardship; (iv) care: working in a precautionary and responsible manner.

Organic production is not uncontroversial, with arguments against[18] including the damage done by extensive (land use) agriculture to whole ecosystems: rather than the "sustainable intensification"[19] needed to feed a growing human population and limited remaining agricultural land. In addition, organic agriculture is only rarely 'pesticide-free', even though proponents state that they are concerned about substances which are 'bio-accumulative' or 'very persistent in the environment'. Notoriously, copper fungicides continue to be permitted, and in areas where cocoa diseases such as *Phytophthora megakarya* predominate, crop loss could be very severe for organic producers that rely solely on cultural controls alone. Being elemental, copper is not degradable and builds up in the soil with continued use[20]. Limited studies to date have not identified deleterious effects of medium-term exposure to soil organisms,[21] although a Brazilian study indicated that high concentrations of this element might adversely affect the important leguminous shade cover tree *Erythrina fusca*. It can be argued that, in contrast, some synthetic chemicals used by conventional producers are safer to apply (copper compounds vary in toxicity between class I to III) and degradable in the environment**. In the EU, it was proposed that the use of copper should be below 8 kg/ha/year after 2002, and the IFOAM suggested that it should be withdrawn altogether after 2010. However, 'organic' farmers still spray copper, but now usually to a limit of 6 kg/ha/year. This probably represents a maximum of 4 sprays per season at normal application rates; the use of copper fungicides is discussed further in section 4.5.2.

Cocoa that is certified as being 'organic' carries a substantial price premium. Worldwide, there are several systems and marks for certifying organic produce, for example:

Examples of organic certification marks

* www.icco.org/about-us/international-cocoa-agreements/doc_download/114-a-study-on-the-market-for-organic-cocoa-september-2006.html
** At registration, pesticide manufacturers must declare the breakdown pathways of AI and their metabolites.

The 'Euro-leaf' logo (bottom right) became compulsory from 1 July 2009 for pre-packaged organic food produced in any of the 27 EU Member States. Within the EU, the logo bearing the words "Organic Farming" or translations thereof (bottom left and centre) can be used on a voluntary basis by producers whose systems and products have been found to be satisfactory. EU Regulation No 889/2008 lays down detailed rules for implementation of Council Regulation (EC) No 834/2007 – which repeals and replaces Regulation (EC) No 2092/91, in order to define more explicitly the objectives, principles and rules applicable to organic production, and in order to contribute to transparency and consumer confidence, as well as to a harmonised perception of the concept of organic production*.

3.4.3 Striving for 'sustainable intensification'

This manual focuses on appropriate pesticide use for sustained maximisation of yields, within a GAP/IPM context that might be used in the farm, or in storage of bulk cocoa. IPM - previously perceived by some as a nicety - has become a necessity: no longer can it mean "Incredibly Popular Mantra". It is a rigorous, multi-disciplinary approach for crop production and serious political pressure is now applied for its implementation. Over the coming decade, there will be an increasing demand for new, but practical and effective, IPM techniques for growers of cocoa and other crops.

The long-standing debate on pesticide-related issues shows no sign of diminishing, matched only by the need for increased production of all foods, including cocoa, but must also be seen within broader contexts including habitat loss and climate change.

* www.eur-lex.europa.eu/LexUriServ/site/en/oj/2007/l_189/l_18920070720en00010023.pdf

04 Pesticides and their Properties

4.1 What is a pesticide?

The term "pesticide" can be defined simply as any substance which is used to control a pest at any stage in crop production, storage or transport. It is now generally agreed that the term "pest" applies to any organisms that harm crops, be they insects, diseases, weeds, etc. In the past, there has been some confusion with the term "pesticide" - which has at times been applied specifically to insect control agents - and weed-killers (herbicides) that have been managed separately as an agronomy issue.

The main pesticide groups include:

- Fungicides - for crop diseases such as black pod
- Herbicides - kill weeds
- Insecticides: control insect pests, but they may also be
  - acaricides: controlling mites
  - nematicides: controlling nematodes (eelworms)

  (Note: not all insecticides kill mites and nematodes; on the other hand, many insecticidal products are sold mainly as acaricides and nematicides).
- Rodenticides - kill rats and mice (they are often much less effective against squirrels)
- Other pesticide types include molluscicides (that kill slugs and snails) and bacteriacides, but they are not usually used on cocoa. Occasionally, some substances have multiple action (e.g. metam is a fungicide, herbicide and nematicide).

Each of these main groups are further classified: either according to their chemical type or by their biological **mode of action (MoA)** - see section 4.5.

Unfortunately, the term "pesticide" is often translated into words that also mean "medicine" or similar. Once again, it is important to be accurate and specific: there is a common misconception amongst farmers that all pesticides do some good, whatever their properties, yet they may actually be harmful.

4.2 Names and composition of pesticides

From a legal point of view, one of the main methods of communication between an agrochemical company and the user is the **product label**. The most noticeable words on the label will usually be the **trade name (or brand)**, and of course it is in the chemical company's interest to promote its particular **brand** of pesticide. However, it is the **active ingredient** (**AI**: also called the **active substance**) and its concentration that is of most interest from the point of view of efficacy, safety and residue tolerances.

Routine use of brand names can cause confusion because:

- Often (and increasingly) the brand name represents a product containing a mixture of active ingredients;
- Different brand names may be used for the same product in different countries and languages;
- Active ingredients - especially of successful products - may be changed over time;
- The formulation names (and numbers used in the name) may not conform to international standards.

Labels should also give the **chemical name** - which follows rules of nomenclature set by the International Union of Pure and Applied Chemistry (IUPAC) as adapted for indexing in *Chemical Abstracts*. In practice, the **common names** (for which there are ISO standards) are generally used for describing active ingredients. For example, a commonly used pyrethroid insecticide, used on cocoa is:

Common Name (ISO) - lambda-cyhalothrin - which is easier to remember than the ...

Chemical Name - of two stereoisomers: (S)-α-cyano-3-phenoxybenzyl (Z)-(1R,3R)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate and (R)-α-cyano-3-phenoxy-benzyl (Z)-(1S,3S)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate

Trade names are numerous (especially now that the patent for the compound has expired) but they include 'Karate', 'Kung Fu' and 'Matador (as used by the same company in different countries)*.

Fig. 4.1 A pesticide label: the active ingredient and its concentration (in this case a 200 g/l imidacloprid SL formulation) are often in very small writing. Precautions are often described in the form of pictograms (pictures at the bottom right of this label)*

4.2.1 Active ingredients (AI), composition, formulation

For the purposes of toxicology, residue analysis and efficacy, it is the **AI**, as described by its ISO common name that will be the focus of scientific analysis. However, pesticide products very rarely consist of pure **technical material**. The AI is usually **formulated** with other materials and this is the product as sold, but it may be further diluted in use. **Formulation** improves the properties of a chemical for: handling, storage, application and may substantially influence effectiveness and safety.

Formulation terminology should follow a 2-letter convention, *e.g.* GR: granules, listed by *CropLife International* (formerly GIFAP then GCPF) in the *Catalogue of Pesticide Formulation Types* (Monograph 2[22]), also recognised by FAO. Some manufacturers still fail to follow these industry standards, which can cause confusion for users.

By far, the most frequently used products are formulations for mixing with water, then applying as sprays. Water miscible, older formulations include:

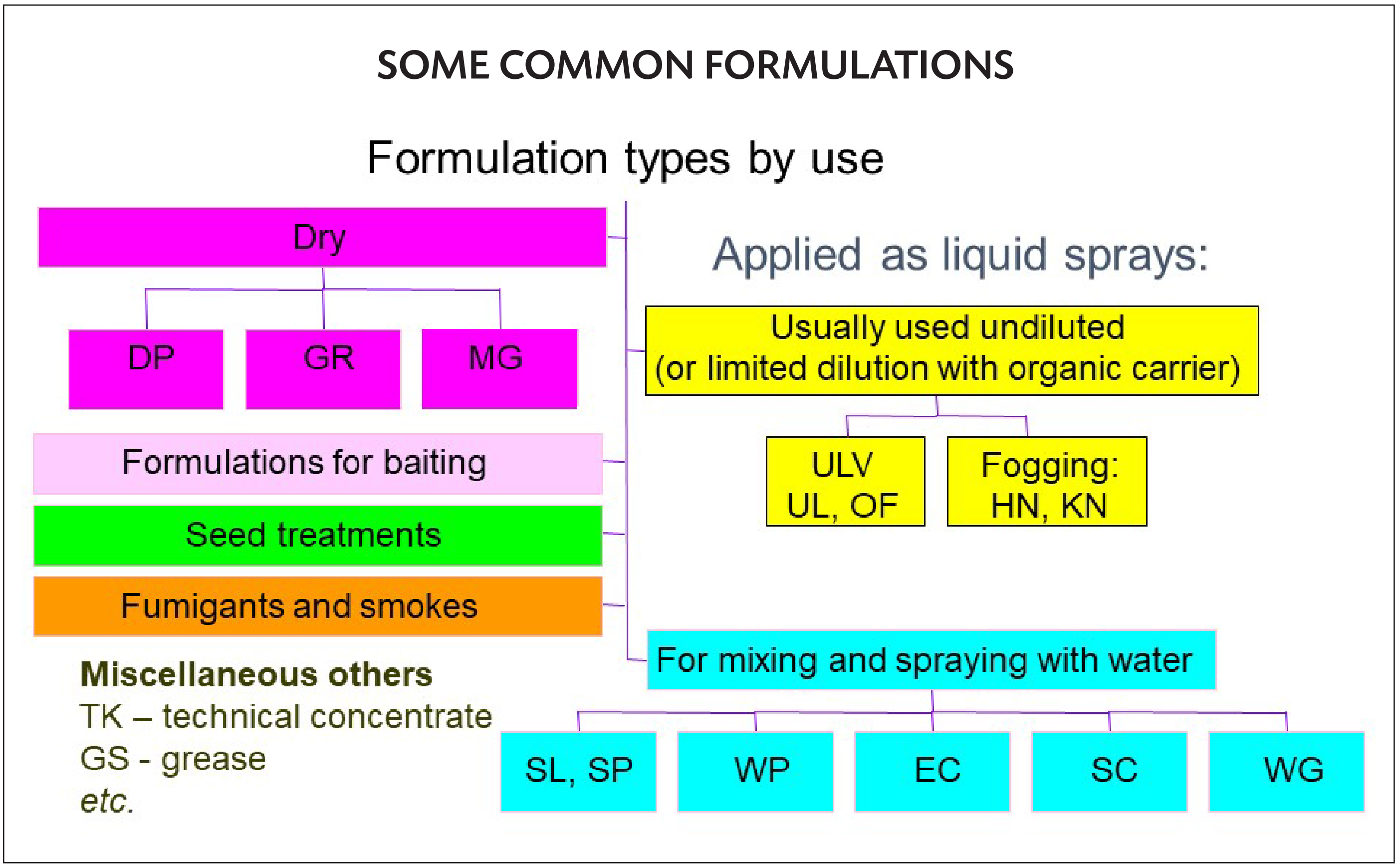
- Emulsifiable concentrate EC
- Wettable powder WP
- Soluble (liquid) concentrate SL
- Soluble powder SP

* Inclusion of compounds or products are for illustration only and does not imply recommendation or otherwise.

Newer, non-powdery formulations with reduced or no use of hazardous solvents and improved stability include:

- Suspension concentrate SC
- Capsule suspensions CS
- Water dispersible granules WG

Fig. 4.2 The major groups of pesticide formulations can be illustrated as follows:



Very occasionally, some pesticides (e.g. malathion) may be sold as technical material (TC - which is mostly AI, but also contains small quantities of, usually non-active, by-products of the manufacturing process). Ultra-Low Volume (ULV) techniques that use oil-based solution (UL) or suspension (OF) formulations have yet to be extensively tested in cocoa, although fogging techniques were used in certain countries having large cocoa plantations. Dusts (DP) are now rarely used and known to be inefficient and hazardous (replaced with micro-granules or MG for other crops such as rice).

In the EU, formulation materials are now covered by new regulations called REACH[23] (EC 1907/2006), designed to promote the use of alternative methods for the assessment of the hazardous properties of substances; several chemical groups previously used in pesticide formulations (e.g. Alkyl Phenol Ethoxylate or APE surfactants) have been dis-allowed.

4.3 Biological activity of pesticides

The purpose of applying a pesticide is to achieve a biological effect on the target pest. This effect is often described by scientists as a **response** and it is **dose dependent** - which usually means that the higher the dose, the more individuals in a **population** of organisms will be affected (and ultimately killed). The population in question could be the **target pests**, but also unintentionally exposed human beings or other **non-target organisms** (beneficial or harmless animals and plants). This is assessed in laboratory experiments called **bioassays**, where response is measured over a range of doses (different quantities of pesticide [AI] delivered individually to target organisms).

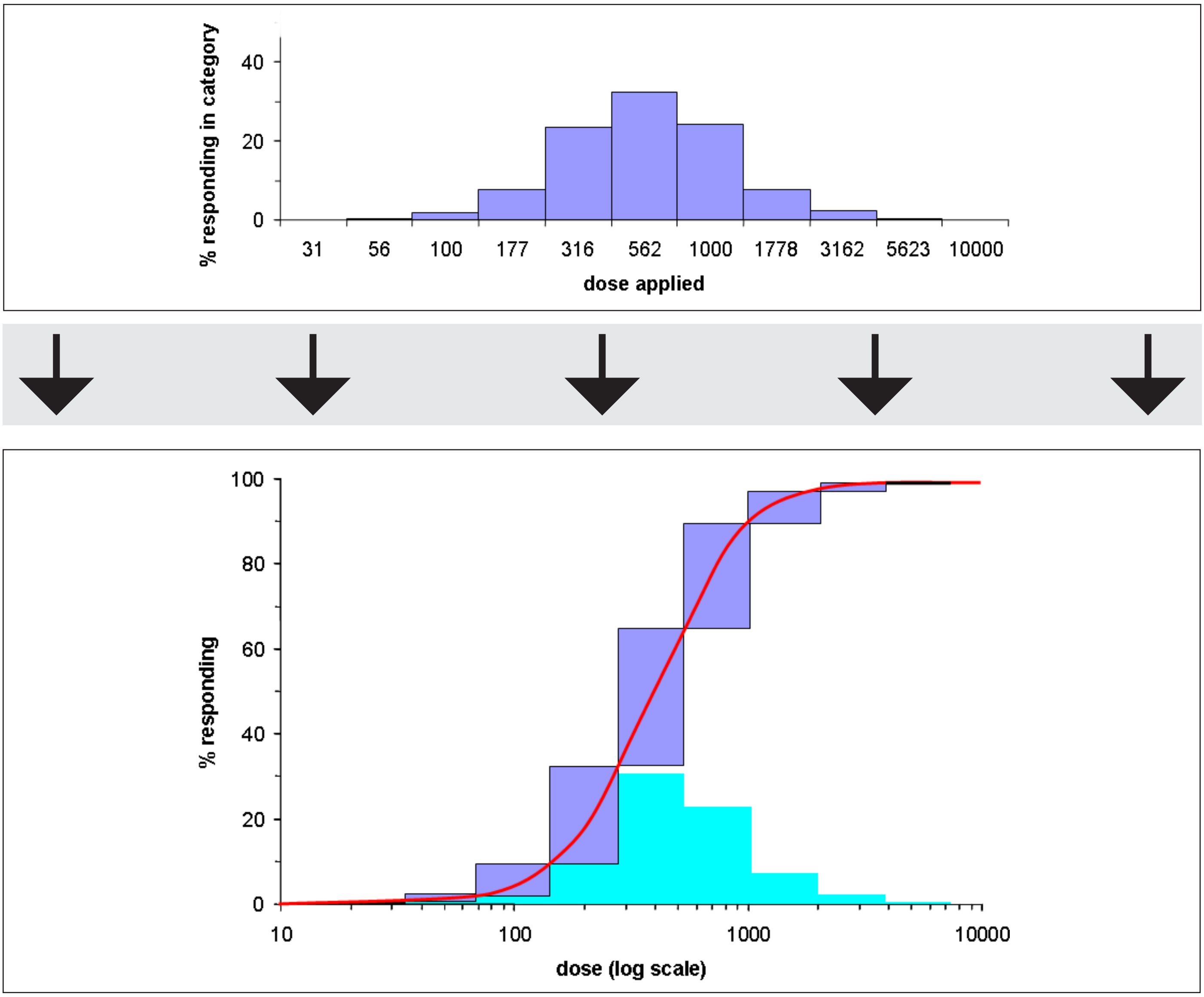
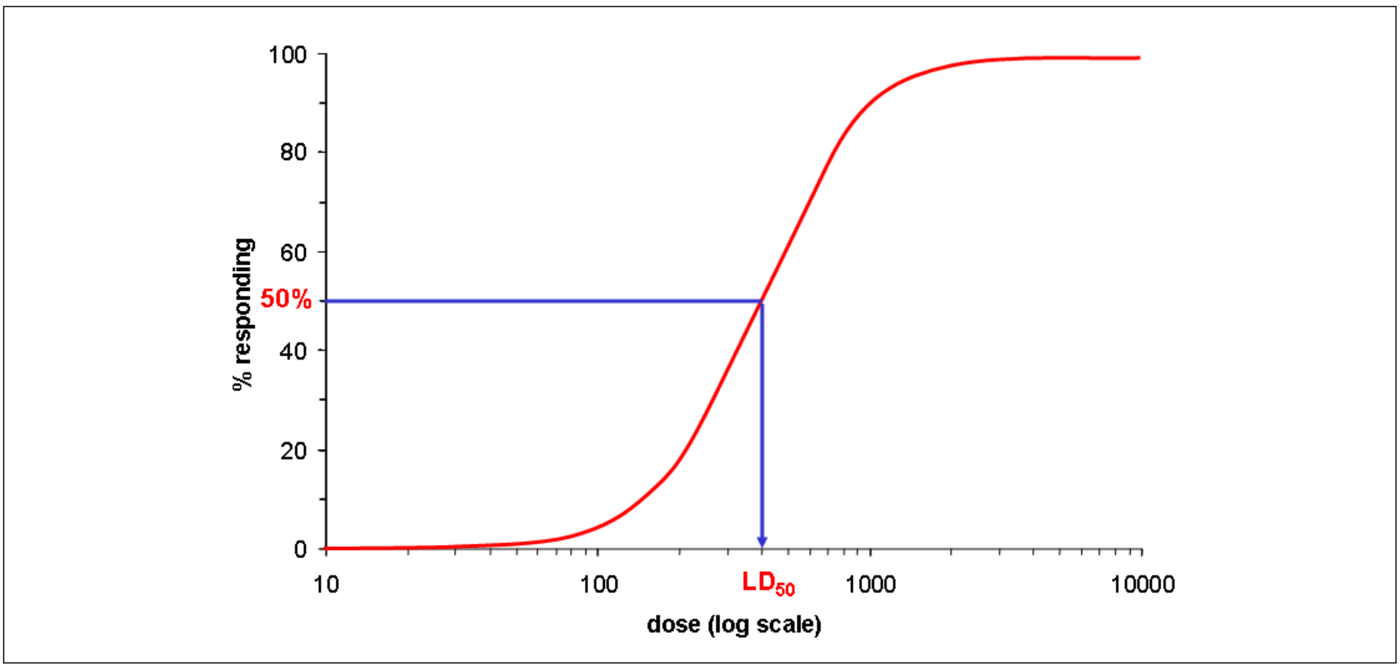


*Fig. 4.3. Origin of the sigmoid dose-response curve from the normal distribution curve (**above**) accumulated on a 0-100% scale. The doses are on a logarithmic scale (without which the 'S' curve would be highly asymmetrical). From this relationship, statistics such as the LD_{50} can be derived (**below**).*



Described on a graph, the response is **non-linear** (i.e. not in a straight line), but usually in the form of a **sigmoid** ('S' shaped) curve - see Fig.4.2. The first diagram shows that this sigmoid curve has been derived from the **normal distribution** - the bell-shaped curve that describes natural variability which is widespread in living organisms (e.g. the height of people, the weight of cocoa pods, the ability of animals to withstand drought). By analysis of this dose response line, an estimate can be made of the **median lethal dose** or **LD_{50}** of a pesticide to a group of organisms (i.e. the exact dose which would kill 50% of a test population of pests).

The LD_{50} is derived from the dose-response curve and represents the dose at which 50% of test organisms (such as pests) are killed. In practical experiments, there is often considerable variability in measured mortality at different dose rates and statistical methods (called logit or probit analyses) are used to determine LD_{50} as accurately as possible.

Other levels of response can be used such as LD_{10} and LD_{90} (i.e. the 10% and 90% level of control respectively), but **LD_{50}** is most commonly used since it represents the point at which the dose can be estimated most accurately. In some bioassays, the pesticide is not administered directly to the target, so the true dose applied to a given individual is not known. Different **dosages** (see section 6.1) may have been applied (e.g. different rates of surface deposit from various concentrations of pesticide mixtures), in which case the **median lethal concentration** or **LC_{50}** will be quoted.

4.4 Pesticide properties and modes of dose transfer

There are hundreds of pesticides that work in various ways, and the different types of control action affect the amount, efficiency, speed and mode of **dose transfer** to the target pest.

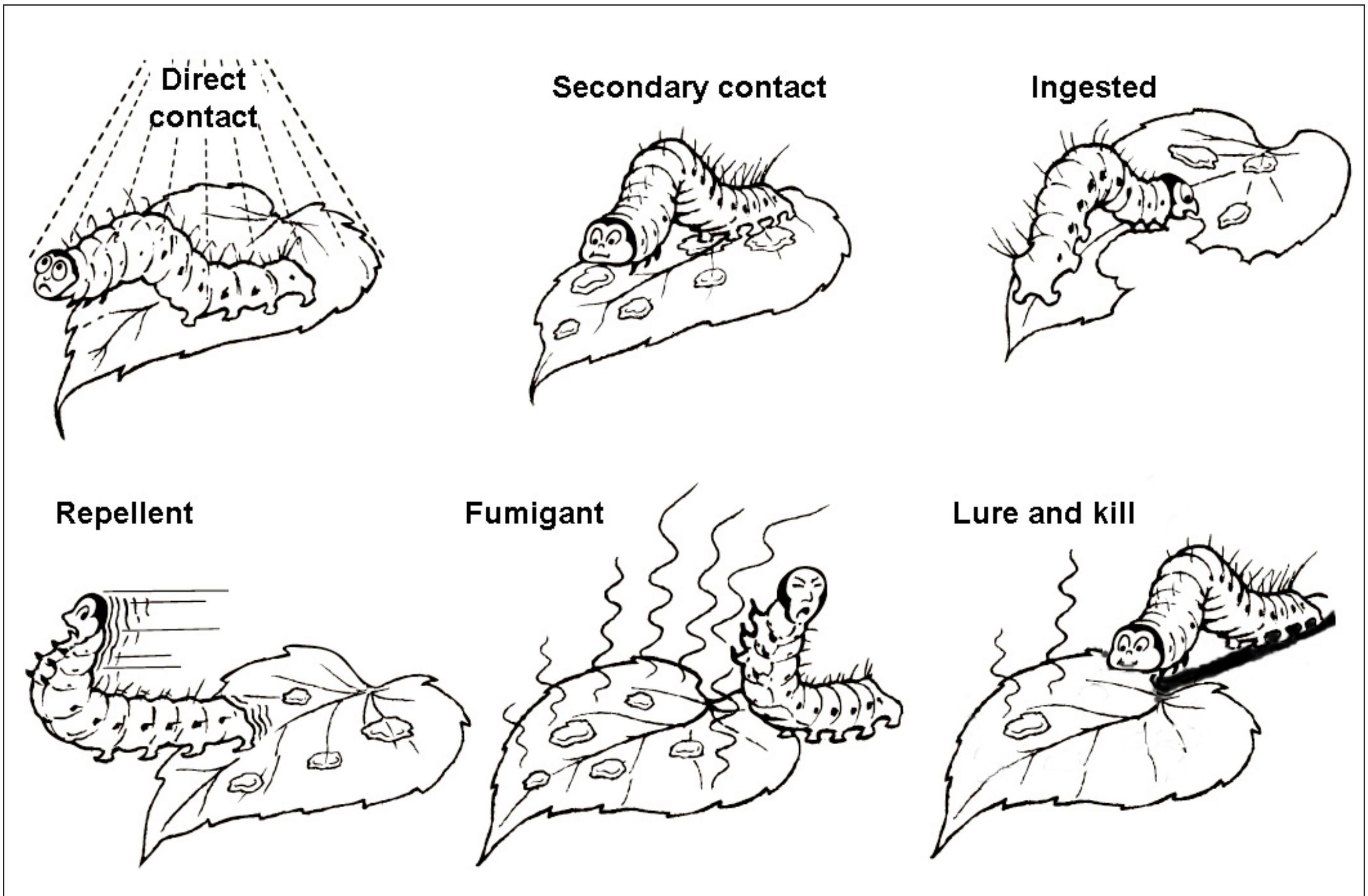


Fig. 4.4 A summary of the major insecticide dose transfer mechanisms.

Farmers (and researchers) may not always appreciate that, except in certain circumstances, **direct contact** with spray is a relatively unimportant dose transfer mechanism. Many insecticides rely on pests picking up a lethal dose after crawling over deposits (**secondary contact**) or by **ingestion**. Fungicides such as copper, which only have **protectant action**, must similarly be well distributed on the surface of the plant, in order to prevent infection by fungal diseases. In practice, contact insecticides and protectant fungicides must be applied with a good **coverage** of spray droplets in order to make contact with the target (although copper deposits may **redistribute** over the surface of the plant by rainwater). **Fumigant action** is especially important for control of storage pests. Certain older insecticides (e.g. lindane, endosulfan: see Insecticides below) were especially effective, since fumigant action often helped to compensate for inadequate application in the field (difficult at the best of times with cocoa). **Repellency** may not always be beneficial - especially if deposits are short lived or if pests consequently pick up sub-lethal doses. However, the concept of **lure and kill** (where an insecticide is mixed with an attractant) has been used very successfully for control of pests such as fruit-flies.

Ingestion of insecticides may occur via various routes: either from a **residual deposit** (as illustrated) or by **translocation** - where pesticides have an ability to be absorbed into the plant and are redistributed, including to the site of attack. Depending on their physical-chemical properties (section 4.4.1), some pesticides may be **trans-laminar** (travelling short distances through the surface of leaves into the tissues) or systemic (where the insecticide, fungicide or herbicide is translocated over greater distances).

Systemic action is an important feature of many modern fungicides and herbicides, besides being often effective for control of sucking insects (aphids, capsids, mealybugs, etc.) and 'cryptic' pests (e.g. insects that are unlikely to come in contact with a pesticide spray by burrowing into the plant). Systemic translocation is usually **acropetal**, moving up the plant from the point of application, or towards the edges of leaves if these are sprayed. Only herbicides (and rare examples of phosphonate fungicides and one recently introduced insecticide) move down the plant (basipetal translocation) towards the roots.

4.4.1 Physical and chemical properties (and where to obtain information)

Readers wanting to know more about pesticides can consult the *Pesticide Manual*[24], which is available either as a book or electronically (the latter is updated annually)*. Again, the importance of accuracy cannot be over-emphasised, and a reference work such as this is an essential tool for policymakers, senior crop protection scientists, etc. The *Pesticide Manual* includes information on:

- Names: both international nomenclature and common product brand names
- Physical chemistry and methods of analysis
- Commercialisation and toxicological reviews
  (including Chemical Abstracts Service Registry Number [CAS RN] and status in EU regulations)
- Mode of action, common uses and formulation types
- Mammalian toxicology
- Ecotoxicology and environmental fate

Although much of this information is specialist in nature, anyone advising on pesticides should be familiar with the function of certain crucial entries.

Information on properties such as vapour pressure, solubility and partition coefficient (log P) can give important clues on the behaviour of a compound in the plant or environment.

- **Solubility**: Unless stated otherwise, units for solubility in water are in mg per litre (mg L^{-1}). Measurements are influenced by the temperature, the pH and the method used.

- **Partition Coefficient: K_{ow} (expressed as Log P)** is a measure for the lipophilicity/hydrophilicity of a substance. With most pesticides and other organic substances, K_{ow} provides a useful predictor of their properties, provided the molecular weight is not too high. It is a dimensionless parameter and is the measured ratio (at equilibrium) of dissolved mass of the substance, between equal layers of n-octanol and water. K_{ow} is often expressed as Log P

* An free online resource listing many pesticide properties can be found on: www.sitem.herts.ac.uk/aeru/ppdb/en/search.htm

(which is log to the base 10 of the K_{ow}) and is considered to be a good indicator of:

- systemic action, with low values (generally ≤2) indicating likely systemic translocation of pesticides or pesticidal breakdown products; very low (or negative) values often indicate basipetal translocation, as with many systemic herbicides.
- accumulation in organisms and food chains (bio-accumulation: with a positive correlation with log P).

» **Vapour pressure (vp):** is a measure of how readily it will volatilise and for pesticides can be considered advantageous or in a negative light:

- a pesticide with fumigant action can have useful penetrative powers, but ...
- a high vp can cause vapour drift and environmental pollution; first noted with some of the early synthetic auxin herbicides.

The usually used SI unit for vapour pressure is the milliPascal (mPa = $g \cdot m^{-1} \cdot s^{-2}$ or 0.001 $N \cdot m^{-2}$).

» **Henry's constant:** or air-water partition coefficient (sometimes Kaw) describes the concentration ratio of a substance in equilibrium between air and water - thus the tendency of a material to volatilise from aqueous solution to air. Sometimes measured, but more usually calculated, as the ratio of vapour pressure (in Pascals) × molecular weight / solubility (mg L^{-1}).

» **Adsorption Coefficient:** K_{oc} is the ratio (at equilibrium) of the mass of a substance, adsorbed onto a unit mass of soil, relative to the mass remaining in water solution. It is heavily influenced by the organic carbon content (OC) of the soil and the value is also dependent on the type and pH of the soil; it must therefore be used carefully and a range of given values is commonplace.

4.5 Mode of Action (MoA) groups

Historically, pesticides have often been classified according to their chemical groups and this is useful for understanding the properties of a given compound (as above). However, the first entry given for most compounds in the *Pesticide Manual*[3] is the **mode of action (MoA)** group, which possibly represents the most useful pesticide classification for biologists.

MoA entries may be something like: 'FRAC G1', 'IRAC 2A' or 'HRAC G'. From a pesticide industry point of view, one of the most important threats to product sustainability and innovation is the onset of **resistance** (see section 4.6). Research-based companies collaborate (under the auspices of *CropLife International*) in order to develop better understanding of MoA mechanisms, and thus create a "common good" by mitigating the onset of resistance. Currently, there are four specialist committees:

» Fungicide Resistance Action Committee (FRAC)
» Insecticide Resistance Action Committee (IRAC)
» Herbicide Resistance Action Committee (HRAC)
» Rodenticide Resistance Action Committee (RRAC)

MoA describes the way a pesticide attacks some biological process (often a certain biochemical pathway in a particular kind of living cells) within the pest. For example:

» Selective herbicides might attack specific photosynthetic process in the chloroplasts of susceptible plant cells (i.e. weeds not crops).
» Pyrethroid and neonicotinoid insecticides (NNI) attack nerve cells (and have a fairly **broad spectrum**).
» Phenylamides that attack specific nucleic acid synthesis pathways in Oomycetes such as *Phytophthora*.

Classification of pesticides by using MoA is important for:

» <u>Resistance management</u> (often effective by rotating 3 or more MoA on a seasonal basis);
» Understanding the biochemical pathways by which a substance is effective, thus:

- Determining its likely effects (and often speed of action) on the target pest;
- Providing a convenient classification of pesticides for biologists.

Having entered an organism, pesticides are often **metabolised** – or changed - into one or more different chemicals. The metabolites (changed products) may be either more toxic or less toxic than the original pesticide ingredient. Given enough time, an organism may be able to metabolise certain pesticides to non-toxic metabolites, and survival or death may depend on the rate of metabolism before the toxic activity is complete or irreversible. On the other hand, some pesticides are effective only after they have been metabolized into a lethal compound in the organism.

The MoA will often determine the **Spectrum of action**: the degree to which a pesticide discriminates between target and non-target organisms. A **selective** pesticide affects a very narrow range of species other than the target pest. The chemical itself may be selective in that it does not affect non-target species, or it may be used selectively in such a way that non-target species do not come into contact with it. **Non-selective pesticides** kill a very wide range of weeds, insects, plant disease organisms, etc.

4.5.1 Insecticides

Insecticides (as opposed to fungicides and herbicides) are perhaps the most controversial of the pesticides. Historically, they have included some of the most toxic substances applied by farmers, but modern insecticides now include substances which can be formulated into products that are in toxicity class III or better (see section 5.1.1). The following is a brief description of the **IRAC MoA groups**, with a summary of the properties of insecticides in current use for cocoa given in *Table 4.1.*

- **Group 1 insecticides** inhibit the Acetylcholinesterase (AChE) pathway at nerve junctions. Because the AChE mechanism in insect synapses is similar to that of mammals, many group 1 compounds are extremely or highly hazardous (toxicity class I), although there are exceptions (e.g. malathion, temephos which are in toxicity class III). This group contains a number of systemic compounds (e.g. carbofuran, carbosulfan, dimethoate, monocrotophos) and with vp values >1 may have significant vapour action. They are divided into two chemical sub-groups:

  - A: carbamates such as promecarb and propoxur that have been used on cocoa, but are now withdrawn in the EU. Fenobucarb (BPMC) is still widely used against sucking pests in Asia, but not in Europe, so residue tolerances above the Limit of Determination (LOD) for these compounds in the EU are bound to be temporary.
  - B: organophosphorous (OP) insecticides such as malathion, chlopyriphos and pirimiphos

- **Group 2** compounds are called GABA*-gated chloride channel antagonists and include two sub-groups:

  - A - older organochlorine compounds: HCH** (hexachlorocyclohexane: of which the purified gamma isomer is called lindane) and the cyclodiene chemical group, that includes endosulfan. Both HCH and endosulfan have historically been very important insecticides in cocoa, but are now obsolete and have been withdrawn. Their fumigant action (high vp: see section 4.4.1) was considered to be a useful property for farmers - substituting for poor application - but is now unacceptable on environmental grounds; in 2009, the production and agricultural use of lindane was banned under the Stockholm Convention on persistent organic pollutants.
  - B - the relatively new (reported in 1992) group of chemicals called phenylpyrazoles or fiproles, represented by fipronil. Highly potent against a wide range of insects, it can be used at very low rates of application and formulated into products classified as toxicity class III. Nevertheless, fipronil has a toxic sulfone metabolite (MB46136) and, unusually, it has been assigned a MRL of 0.005 (which is below the 'default' LOD value). Also, with a known high impact on non-target organisms, it should be deployed with great care and is primarily used for its very effective protection of seedlings (and wooden structures) from termite attacks.

The organo-chlorine compound DDT actually belongs to the same IRAC group (3) as pyrethroids (see Box 2 below) - all these chemicals attack the insect nervous system, but in different ways. DDT and most compounds in groups 1-2 represent 'old insecticide chemistries' and have been most heavily decimated by regulatory and commercial factors over the past two decades.

* GABA - gamma amino butyric acid: important for nerve transmission in both invertebrates and vertebrates - but binds less strongly (so may be less toxic) to the latter.
** HCH: hexachloro-cyclo-hexane or (incorrectly but well-known) benzene hexachloride: BHC

The few that remain (mostly OPs) are usually 'softer' representatives of their class. They are considered practical and attractive to farmers because they are cheap, fast acting and have a broad spectrum of action. In terms of pest management strategy, they help maintain diversity of MoA for resistance management (IRM), OPs in particular do not build up in the environment and some have such a short persistence that they rarely present residue problems. Nevertheless, they are suspected endocrine disruptors (see Box 1) and a recent review[25] concluded that "The majority of well-designed studies found a significant association between low-level exposure to OPs and impaired neurobehavioral function" in humans. It is therefore probable that OPs are unlikely to remain permitted in most countries beyond the end of the decade.

- **Pyrethroids** (IRAC MoA group 3)

Previously the most important insecticides by market share, now the second largest sector of the synthetic insecticide market. They are highly effective against agricultural and public health major pests. First introduced thirty years ago by a team of Rothamsted Research scientists led by M. Elliott, they represented a major advancement in activity and relatively-low mammalian toxicity. Their development was especially timely with the identification of problems with DDT (see Box 2) which belongs to the same MoA group (they interfere with sodium transport in insect nerve cells).

Work consisted firstly in identifying the most active components of pyrethrum, extracted from East African chrysanthemum flowers and long known to have insecticidal properties. Pyrethrum rapidly knocks down flying insects, but has a low mammalian toxicity and negligible persistence - which is good for the environment but gives poor efficacy when applied in the field. Pyrethroids can be described as chemically stabilized forms of natural pyrethrum.

The 1st generation of pyrethroids, developed in the 1960s, include bioallethrin, tetramethrin, resmethrin and bioresmethrin. They are more active than the natural pyrethrum, but are unstable in sunlight. Activity of pyrethrum and 1st generation pyrethroids is often enhanced by addition of the **synergist** piperonyl butoxide (which is not itself biologically active). After EC 1107/2009, many 1st generation compounds were not re-registered, often because the market was simply not big enough to warrant the costs (rather than any special concerns about safety).

By 1974, the Rothamsted team had discovered a 2nd generation of more persistent compounds notably: permethrin, cypermethrin and deltamethrin. They are substantially more resistant to degradation by light and air, thus making them suitable for use in agriculture, but they have significantly higher mammalian toxicities. Over the subsequent decades, these were followed with other proprietary compounds such as fenvalerate, lambda-cyhalothrin and beta-cyfluthrin, but most patents have now expired, making them cheap and therefore popular (although permethrin and fenvalerate were not re-registered under the 91/414/EEC process). One of the less desirable characteristics, especially of 2nd generation pyrethroids, is that they can be **irritant** to the skin and eyes, so special formulations such as capsule suspensions (CS) have been developed.

Pyrethroids have been widely used against cocoa insects, especially mirids in West Africa (also *Helopeltis* and cocoa pod borer in South East Asia). They belong to commonly used examples, including bifenthrin, deltamethrin, cypermethrin and lambda-cyhalothrin. Synergized tetramethrin has been applied extensively for control of warehouse pests - partly due to its low persistence and irritancy, but (together with permethrin) it has not been re-registered. First generation pyrethroids have been replaced with natural pyrethrum (usually synergized) and other permitted, 2nd generation 'knock-down' insecticides such as cypermethrin. These must be used very carefully due to greater persistence and the general risk of insecticide resistance.

- **Neonicotinoid and similar insecticides** (IRAC class 4)

Nicotine, the 'active ingredient' for smokers, is also a very potent insecticide. Being a natural product, 'tobacco tea' was previously permitted for organic pest management, but purified nicotine would be classified as most toxic (class 1) if sold commercially. As with pyrethrum and the pyrethroids, the commercialised synthetic analogues, called 'neonicotinoid' or 'nicotinyl' insecticides (NNI) are more stable than their natural progenitors in sunlight. Unlike pyrethrum and pyrethroids but in common with other 'new chemistries', NNI typically have relatively low mammalian toxicities compared with their natural analogue, with several products available in toxicity class III.

Box 2: DDT in cocoa growing countries

The acronym 'DDT' (dichloro-diphenyl-trichloroethane) invokes many of the (often negative) perceptions about pesticides. The first major synthetic insecticide, introduced in the 1940s, this compound was accompanied by others in the group of chemicals called organochlorines. By the 1960s, Rachael Carson [i] and others were pointing out their negative side-effects, particularly associated with over-use in agriculture (environmental impact, resistance and resurgence). Perhaps the greatest alarm amongst the general public was caused by residues on food, which resulted in detection of DDT and its breakdown products in mothers' milk. It was one of the first compounds to be classified as a 'persistent organic pollutant' (POP). However, DDT has undoubtedly saved millions of lives: it is cheap and provides long-term control of malaria mosquitoes, with "a remarkable safety record when used in small quantities for indoor residual spraying (IRS) in endemic regions" [ii].

DDT is now never recommended in agriculture, but there are reports of misuse, with IRS insecticides being 'diverted' onto crops, so residues on food continue to be monitored. Malaria is frequently endemic in cocoa growing areas, so mis-use is possible; for this reason, practical MRLs have been set at: 0.5 ppm in the EU, 0.15 ppm in Russia, 1.0 ppm in the USA and 0.05 ppm in Japan.

[i] Carson, R (1962). *Silent Spring*. Houghton Mifflin (1962); Mariner Books (2002).
[ii] Yamey, G. (2004). Roll Back Malaria: a failing global health campaign. BMJ 328: 1086-1087.

Table 4.1 Properties of some insecticides in current use for cocoa

	Solubility (mg/l or ppm)	log P (Kow)	Vapour pressure (mPa)	bee tox. oral τ (µg/bee)	bee tox. contact (µg/bee)	WHO tox. Class (AI)	EU reg. status
OPs & Carbamates ***IRAC group 1***							
Diazinon	60	3.3	12	"Highly toxic to bees"		II	Y
dimethoate	23.8	0.704	0.25	0.12 (topical)		II	Y
chlorpyrifos (ethyl)	1.4	4.7	2.7	0.36	0.07	II	Y
fenitrothion	14	3.43	18	"toxic"		II	N
fenobucarb (BPMC)	420	2.79	13	-		II	N
malathion	145	2.75	5.3	-	0.71	III	N
pirimiphos methyl	10	4.2	2	"toxic"		III	Y
phenylpyrazoles ***IRAC group 2***							
Fipronil	1.9	4	3.7×10^{-4}	0.004 [26]		II	M
Pyrethroids ***IRAC group 3***							
β cyfluthrin *	0.0012-0.0021	5.9	$1.4\text{-}8.5 \times 10^{-5}$	< 0.025 (FAO)		Ib	Y
bifenthrin	<0.001	>6	1.81×10^{-7}	0.1	0.015	II	Y
α cypermethrin	0.01	6.94	2.3×10^{-2}	0.059		II	Y
deltamethrin	0.0002	4.6	1.2×10^{-5}	0.079	0.051	II	Y
λ cyhalothrin	0.005	7	2×10^{-4}	0.038	0.909	II	Y
Natural : pyrethrin I	0.2	5.9	6.9×10^{-2}	0.022	0.013	II	Y
pyrethrum : pyrethrin II	9	4.3	2.7×10^{-2}		(48 hr.)		Y
Neonicotinoids ***IRAC group 4***							
nitro(guanidine)-substituted							
clothianidin	300+ §	0.7	1.3×10^{-10}	0.0038	>0.044	III (EPA)	M
imidacloprid	610	0.57	4×10^{-7}	0.005 – 0.07 Ω	0.018 – 0.024 Ω	II	M
thiamethoxam	4,100	-0.13	6.6×10^{-6}	0.005	0.024	III	M
cyano-substituted (pyridylmethylamine)							
acetamiprid	4,250	0.8	$<1 \times 10^{-3}$	14.5	8.1	II	Y
thiacloprid	1,850	0.73	3×10^{-7}	17.3	38.8	III	Y

τ US EPA defines a pesticide as highly toxic to bees if the LD_{50} is < 2 µg/bee*
* β cyfluthrin: 4 pairs of enantiomers
§: depends on pH
Ω: various studies

* US EPA (2013): Technical Overview of Ecological Risk Assessment Analysis Phase: Ecological Effects Characterization,U.S. Environmental Protection Agency, Washington, DC. https://www.epa.gov/risk/ecological-risk-assessment

There are now about a dozen NNI that have been developed since imidacloprid was introduced in 1991 by Bayer AG and Nihon Tokushu Noyaku Seizo KK. They belong to three chemical sub-groups, of which two are of current interest in cocoa. All NNIs are systemic, having a high solubility and log P values of <1 (see Table 4.1). Probably the most controversial aspect with these compounds is the relatively high toxicity of some AI to bees (in spite of having passed through a whole raft of environmental testing before registration). In Europe, the problem was managed by engineering controls that greatly reduce drift of spray droplets and dust from seed dressings.

In 2013, a moratorium was placed on three NNI: clothianidin, imidacloprid and thiamethoxam in the EU (see section 4.8). At this stage, we can only speculate on the practical medium to long-term consequences of this moratorium and any further restrictions in cocoa consuming countries. Withdrawal from use in the EU could result in diversion of products to secondary markets (with possible consequent 'price competitiveness' or 'dumping' depending on the viewpoint). We could also expect cyano-substituted NNI to be promoted, justifiably, as 'more bee-friendly' or similar; the table above shows that they are more than 2 orders of magnitude less toxic to bees than the nitro-group, especially via the oral route. However, an even higher current priority in cocoa is residue management (see Appendix 3). There needs to be more information in the public domain of dosage, concentration level of AI and consequently, whether existing field application practices (and pre-harvest intervals) risk residue levels downstream exceeding of MRLs.

Other insecticidal modes of action

The insecticides described above all act on biochemical pathways in the insect nervous system and are thus be grouped as 'neurotoxic' or otherwise active on insect coordination. As understanding of the effects of insecticides on target biochemical pathways improves, updates are made available by IRAC*. Research-based agrochemical companies continue to explore new markets for their proprietary AIs and these are listed here in Appendix 3C, as information is made available to the authors. Companies have recently emphasised the 'natural origin' of a number of MoA groups: for example, groups 5 and 6 consist of fermentation products, with relatively large complex molecules called 'macrocyclic lactones'. These were derived from *Saccharopolyspora spinosa* and *Streptomyces avermitilis* respectively. There is considerable interest in the latest MoA group (28), the diamides or ryanodine receptor modulators, which are synthetic analogues of water-soluble extracts of the tropical shrub *Ryania speciosa*; exposed insects exhibit general lethargy and muscle paralysis leading to death, but mammalian toxicity is very low.

There are also reports of limited use of nereistoxin analogues (group 14) in cocoa: a small group of commercial alkaloid pro-insecticides derived from Nereis spp. (marine ragworms). Examples are cartap hydrochloride, thiocyclam and thiosultap-sodium: like NNI and spinosyns they affect, in this case block, the nicotinic acetylcholine receptor (NAchR) channel in insect nerve synapses. Although available in Asia and Africa, they cannot currently be recommended since MRLs have yet to be established in the EU and elsewhere.

Group	Mode of Action	Examples	Possible use in cocoa
5	Nicotinic acetylcholine receptor (NAchR) allosteric activators	Spinosyns such as spinosad	Broad spectrum against Coleoptera, Lepidoptera, etc.
6	Chloride channel activators	Avermectins such as emamectin benzoate	Broad-spectrum activity against Lepidoptera
9B	Selective feeding blockers: modulate chordotonal organs	Pymetrozine	Hemiptera such as mirids
28	Ryanodine receptor modulators (diamides) acting at the nerve- muscle interface	Chlorantraniliprole (CTPR), cyantranil-iprole, flubendiamide	Lepidoptera such as cocoa pod borer

* www.irac-online.org/documents/moa-classification/?ext=pdf

Several of the 'newer chemistry' active substances are especially attractive since they have low mammalian toxicities, thus helping to overcome one of the major criticisms of insecticide use. Older MoA groups, often of lower toxicity to both mammals and non-target organisms (IPM compatible) have included non-neurotoxic compounds that specifically target insect biochemical pathways. These include various mechanisms in the formation of insect cuticle, regulation of ecdysis (moulting) and other endocrine functions unique to insects and other arthropods. Usually slow acting (e.g. taking more than 2-3 days to show activity in the field), non-neuro-active products have proved more difficult to sell, involve greater levels of farmer training and may encounter difficulties at the registration stage (see section 4.7). Nevertheless, the need to find effective control measures against pests such as cocoa pod borer and maintain a diversity of MoA for resistance management, may yet establish a role for insecticide groups 15, 18 and possibly others. The tetronic acid spirotetramat (group 23) was the first insecticide to exhibit downward (basipetal) translocation, making it very effective against certain sucking insects; it is undergoing evaluation against the mealybug (Pseudococcidae) vectors of cocoa swollen shoot virus disease (CSSVD).

Group	Mode of Action	Examples	Possible use in cocoa
15	Inhibitors of chitin biosynthesis, type 0: acting on Lepidoptera (AKA insect growth regulators)	Acyl-ureas such as lufenuron and novaluron	Lepidopteran pests such as cocoa pod borer
18	Ecdysone receptor agonists (mimics action of moulting hormone lethally accelerating the process)	Methoxyfenozide	Relatively specific for Lepidoptera: possibly useful against cocoa pod borer
23	Inhibitors of lipid biosynthesis (acetyl COA carboxylase)	Tetronic acids such as spirotetramat	Possibly useful against Pseudococcid CSSVD vectors

It is important to mention here the potential for microbial control agents (MCA) including entomopathogenic fungi (*e.g. Metarhizium* and *Beauveria* spp.) and viruses. These have yet to be assigned MoA groups by IRAC, but the bacterium *Bacillus thuringiensis*, the most important biopesticide world-wide, has been assigned into group 11A: 'microbial disruptors of insect midgut membranes'. It has been suggested that the 'cry' proteins that generate this action could be expressed in the cocoa husk and efficacious against pod borer[27], but genetic modification in this crop is considered highly controversial, even in the Americas.

In most cocoa-growing countries, insecticides constitute the greatest number of registered products: 'newer chemistries' are now being registered (see Appendix 3). However, the diversity of MoA remains limited and the market is dominated by NNI and pyrethroids, with mixed AI products increasing.

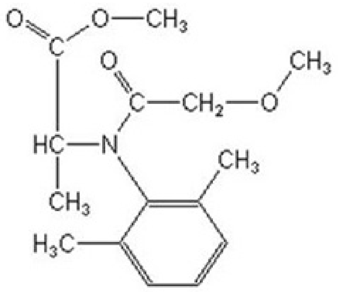
4.5.2 "Fungicides"

The term "fungicide" refers, as its name suggests, to agents that control fungi. However, the same substances may also be active against Oomycetes (or water moulds), the important group of organisms that contain *Phytophthora* spp., but have now been assigned to a completely different kingdom (the Chromalveolata).

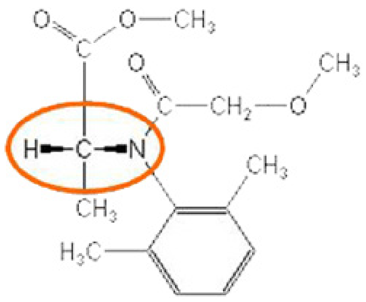
Perhaps the most widely-used fungicides are various copper compounds, which are active against a wide spectrum of plant diseases. Copper is more likely to be a soil/environmental issue, and since these compounds are essentially contact fungicides, it would be difficult to distinguish exogenously applied sprays from background levels in residue tests. The MRL set for copper ions is 50 mg/kg. Organic producers are still permitted to use copper, albeit on a restricted basis (see section 3.4.2). The MoA of copper compounds is described as multi-site (FRAC group M1), therefore the risk of fungicide resistance is considered to be low.

Phenylamide compounds (FRAC group A1) have protective, curative and systemic action against *Phytophthora*, disrupting the unique nuclear RNA synthesis pathways in Oomycetes. Metalaxyl was discovered by Ciba Geigy (now Syngenta) in 1977. It consists of a number of isomers (compounds with the same formula but a different arrangement of atoms in the molecule and different properties) and it was later discovered that one in particular, metalaxyl-M, showed greatest biological activity. In 1996, the company re-patented the latter as mefenoxam (marketed as 'Ridomil-gold') thus doubling the patent life. Residue studies and submissions for registration in the EU refer strictly to this isomer, which was included on EU/91/414 Annex 1 effectively as a new substance (confirmed under legislation 02/64/EC). Supervised GAP residue trials for the latter were carried out by Syngenta on fermented dry beans and using the local processing methods, in order to obtain MRLs. Residue trials included rates of 90 g mefenoxam/ha (2 x normal rate). Under EU legislation, the status of (chemically) unresolved metalaxyl has now been clarified and the MRL includes mixtures of all constituent isomers including metalaxyl-M (i.e. the sum of isomers).

Metalaxyl



Resolved: metalaxyl-m isomer



Residue analysis has recently focused on metalaxyl and benalaxyl, especially since farmers might spray within its one-month pre-harvest interval (PHI: one of the principal means of mitigating high residue levels). Extension efforts should therefore focus on **timely application** (regular monitoring) and **only applying copper fungicides near to harvest**. It is also thought that there is a high risk of resistance to these AI by *Phytophthora* spp. and agrochemical companies have introduced alternative MoA. Carboxylic Acid Amide (CAA) fungicides (FRAC group H5, previously placed in F5) disrupt cell wall deposition (the cell walls of Oomycetes differ from the fungi, and contain glucan-cellulose rather than chitin). Two AI, dimethomorph (DMM) and mandipropamid, have now been registered for use against *Phytophthora* in cocoa and provide much needed MoA diversity for better resistance management.

Table 4.2 Properties of some systemic black pod 'fungicides' in current use for cocoa

	FRAC code	Solubility (mg/l or ppm)	log P (Kow)	WHO tox. Class (AI)	EU reg. status
metalaxyl (~M isomer)	A1 (4)	8400 (2600)	1.75 (1.71)	III	Y
benalaxyl	A1 (4)	28.6	3.54	III	Y
dimethomorph (DMM)	H5 *	18 (pH 7)	2.63	III	Y
mandipropamid	H5 *	4.2	3.3	IV	Y

The 'newer chemistries' MoA groups active against Oomycetes, including FRAC F5 and C8 (QxI: Quinone x Inhibitor) compounds, are now being registered (see Appendices 3 and 4) in many cocoa-growing countries. The market remains dominated by copper-based control agents, with mixed AI products including metalaxyl and newer chemistries. Late season (near to harvest) applications of copper-only products probably present a lower risk of residue violations than mixtures, but the latter are important for resistance management.

* Target site group H: cell wall biosynthesis – FRAC code 40 - previously in FRAC target site group F5

4.5.3 Herbicides and sprouting inhibitors

Herbicides, or weed killers, occupy the largest global share of the pesticide market, although their use by smallholders is limited in comparison with intensive farming, amenity weed control, etc. Perhaps their greatest use in cocoa is in larger-scale, commercial plantings. They are most typically applied at an early stage to prevent young plants from being choked by weeds. Control is rarely required once the canopy closes (although mistletoes may become a problem in poorly managed cocoa).

Herbicides have been classified in several ways and, as with other pesticides, a number of chemical families can be grouped by their modes of action (using letters in the HRAC nomenclature). In practice, herbicides are often grouped according to their mode of use:

- **Contact** herbicides, where only the part of the plant sprayed is killed, such as the photosynthesis inhibitors paraquat and diquat (MoA group D);
- **Systemic** - pre-emergent and post-emergent herbicides include compounds that:
  - disrupt amino acid synthesis in chloroplasts, e.g. various salts of glyphosate (group G);
  - disrupt cell division in broad-leaved weeds: including synthetic auxins such as 2,4-D, triclopyr and picloram (group O).

Triclopyr is used as stump arboricide which has a specialised use in cocoa swollen shoot virus disease (CSSVD) control campaigns: to prevent re-growth of old trees, before re-planting with improved cocoa varieties.

In registration lists and surveys, glyphosate and paraquat have been recorded as widely used on cocoa (sometimes under "plantation crops"). After its patents expired, glyphosate became the world's top-ranking pesticide by sales, usually available as two salts (isopropylamine and trimesium), from a wide range of companies. Perhaps for this reason, it has received considerable criticism over the past decade, with claims about health risks (such a non-Hodgkin's lymphoma) and, perhaps more convincingly, its impact on soils and the environment with continuous use.[28] For these reasons, Registration Authorities appear to be withdrawing glyphosate in favour of glufosinate-ammonium, which has a slightly different mode of action (see Appendix 3).

It is important to appreciate that herbicides such as these are:

- treated as pesticides - certainly for scientific and regulatory purposes - even though many commercial operations consider weed control functionally as part of agronomic practices (as opposed to "poisons" used for other pest control);

- permanent crops such a cocoa constitute only a tiny part of the world pesticide market and even there principally used for land clearance, rather than regular applications to established cocoa crops. In this respect, agrochemical companies are interested principally in their use in conjunction with (often genetically modified, e.g. "Roundup ready") annual crops.

The synthetic auxin herbicide, 2,4-D has caused considerable concern, appearing as residues in cocoa beans from more than one country. The active substances include a number of salts*, acids and esters, some of which are moderately volatile (vp of acid = 1.9×10^{-2} mPa) and have a characteristic odour. In some cases, it transpired the residues originated from the ground on which the cocoa beans had been dried (roadsides, courtyards, etc.) had been previously treated with herbicides, or exposed to run-off after rain. The use of drying mats for cocoa beans, elevated off the ground, is therefore an important SPS recommendation and it is vital that exposure (including vapours) to cocoa beans is avoided at all stages in the supply chain, including storage and transportation.

* Many 2,4-D salts dissociate to the acid in water; at pH 7, log P of acid = 0.177, water solubility = 44.6 g/L.

In principle:

- Approved herbicides present a low risk when used judiciously for weed management in establishing trees
- ... which especially means care in application: avoiding the production and drift of small droplets onto non-target areas.
- Care and oversight is needed along the whole cocoa bean production and supply chain
- ... herbicide residues may originate from outside the cocoa garden.

In African and Asian cocoa-growing countries, glyphosate-based registered herbicide products dominate, with the more acutely toxic group 22 compounds such as paraquat still available in South America (see Appendix 3). They may not be specifically registered for cocoa, but there is a general usage especially in "Plantations" for land clearance.

4.5.4 Pesticides for vertebrate pests

A range of vertebrate pests, from elephants to smaller rodents and birds, have been recorded as cocoa pests[29]. It is significant perhaps, that vertebrates are probably responsible for most natural sowing of cocoa seed, with the Brazilian kinkajou (*Potos flavus*) specifically associated with cocoa in its centre of origin. The most consistently damaging species are probably rats and squirrels, with studies indicating crop losses of between 1% and 20%. Losses in South -East Asia and certain islands appear to be especially high, with anecdotal reports of high damage where cocoa is grown near food crops such as rice; the world average loss may be 5-10%.

For many years, there were essentially two groups of rodenticides: acute and chronic agents, which are by necessity all highly toxic to mammals. The older, acute toxicants such as zinc and aluminium phosphides could become ineffective due to 'bait shyness': where rats learned to associate the food bait with the poison. Sodium fluoroacetate ('1080') is another inorganic acute poison: considered effective for area-wide control operations (including aerial applications), but it has become unacceptable for "environmental, animal welfare and social pressures".

Anti-coagulants kill by preventing blood clotting, but the first generation of agents (e.g. warfarin) could be subject to bait shyness. They were supplemented with a number of 'second generation' anti-coagulant rodenticides (SGAR): that only require a single feed by the pest and have a delayed action. Anti-coagulants (e.g. bromadiolone, difenacoum and warfarin) are no longer permitted in the EU and are all subject to the default MRL of 0.01 mg/kg. Formulated together with the toxicant and a food-bait (often grain), with a warning colorant within a waxy, waterproof matrix: bait block (BB) formulations could simply be tied singly to cocoa trees but are now only for indoor use in the EU, due to the impact on raptors such as owls (see below).

Squirrel (above) and rat damage

Block bait formulation tied to a cocoa tree

The success of rodent control operations often depends on the scale of treatment and timing: it is usually better to apply over larger areas (e.g. whole villages) when alternative food sources for the pest are most scarce (e.g. the beginning of the field crop growing season). Very small-scale operations, such as treatments in single houses, may have only a short-term effect and be a false economy; large-scale campaigns should be accompanied with public education about the hazards of baits and supplies of the anti-coagulant antidote (vitamin K_1).

A combination of rodenticide resistance and concerns about their toxicity has prompted investigations into alternative methods over the last decade. A review of these[30] included certain plant extracts and cholecalciferol (calciferol or vitamin D3), which may be efficacious on its own or used in combination with SGARs such as coumatetralyl.

Biological rodent control approaches have included the services of barn owls, with their successful establishment in a cocoa-coconut agro-ecosystem in Malaysia[31]. Rodenticides must be used carefully: UK studies on their impact showed increased presence in birds, with widespread use towards the end of the 20^{th} century, but only 7% of contaminated owls (forming 2% of all owls examined) were judged to have actually died of rodenticide poisoning[32]. A microbial control method uses a product based on the protozoan Sarcocystis singaporensis[33] .

4.6 Technical problems with pesticides (the 'three Rs')

Besides **residues**, which will be discussed further in Chapter 5, two other phenomena can be described as 'technical issues', in that they relate to the effectiveness of pest control rather than the toxicological and environmental risks associated with pesticide use. However, in both cases one of the practical consequences is that some farmers, by not understanding these phenomena, may be encouraged to apply more pesticides in the short-term, thus increasing the risk of high crop residues.

1. Development of resistance

Where pests adapt over time after exposure to control agents, which become ineffective (e.g. loss of effectiveness of certain fungicides for the control of *Phytophthora* spp.). Among the first cases of insecticide resistance detected was resistance against organochlorines by cocoa mirids[34].

Resistance is an evolutionary process that has been defined as: "a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species" (source: IRAC).

Furthermore, the problem may be compounded by **cross-resistance**: where resistance to one pesticide confers resistance to another active substance, even if the pest has not been exposed to products containing the latter. Because insect and fungal populations are usually numerous and reproduce quickly, the rate at which resistance evolves is greatest when fungicides and insecticide are over-used.

2. Pesticide induced resurgence

Especially following the use of broad-spectrum insecticides that cause a 'flare up' of pests that were previously of minor importance; this is sometimes called the "pesticide treadmill". An example of resurgence in cocoa was the dramatic increase in populations of the trunk borers *Eulophonotus myrmeleon* (Cossidae) and *Tragocephala castinia theobromae* (Cerambicidae), which were previously considered to be minor pests, following destruction of their natural enemies with applications of BHC and dieldrin - applied to control insects such as mirids[35].

4.7 Efficacy (including AI mixtures)

There are two approaches to the regulation of efficacy of plant protection products:

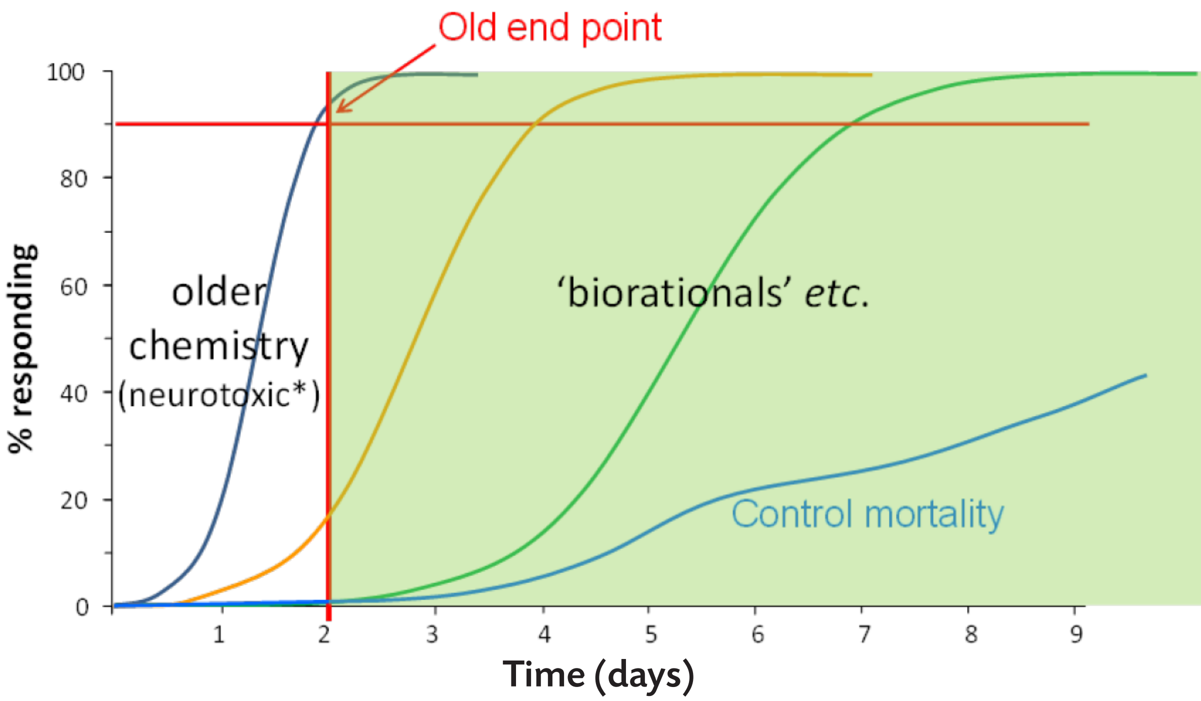
- A view that 'the market will decide' about efficacy and that the primary role of regulation is to ensure safety. This is considered appropriate in the USA and elsewhere, with farmers often benefiting from sophisticated agricultural extension support networks.

- More 'interventionist' policies (as in Europe): where toxicology studies are likewise emphasised, but companies must also demonstrate efficacy against key target pests in order to obtain registration.

A view taken in many cocoa growing countries is that farmers should be supported with advice on effective products, often via Government research and extension agencies. As described above, the list of pesticides that are suitable for use with cocoa has changed dramatically over the past decade, in light of changes to the regulatory environment in the EU, Japan and other importing countries. With the recent controversy surrounding the neonicotinoids, currently a 'strategic' MoA for the crop, research and Registration Authorities must maintain an ongoing review of registered pesticide products appropriate to 21st century needs. However, as with other crops, policymakers must also foster a strategy for 'sustainable intensification': in this case maintaining a diversity of appropriate and efficacious range of active substances, preferably belonging to 3 or more MoA, for control of key cocoa pests. This objective has been a factor when compiling the list in Appendix 3A.

In many cocoa growing countries, the withdrawal of older (and sometimes not so old), neurotoxic compounds has not been accompanied with commensurate adoption of newer products: so insecticides currently available in cocoa growing areas belong to only 2-3 MoA, often dominated by pyrethroids. This has potentially deleterious consequences for both integrated pest and resistance management strategies, besides perpetuating outdated pest control perceptions amongst farmers. In addition, chemical control against key insect pests was often established using compounds with fumigant action (e.g. HCH, endosulfan) that helped to compensate for poor application; this property is no longer acceptable to Regulatory Authorities. Researchers must therefore adapt mid-20th century protocols for pesticide screening where the end-points of assays rarely exceeded 48 hours, thus excluding many IPM-compatible non-neurotoxic substances (and possibly biological agents) that constitute a majority of the known insecticidal MoA. A further difficulty, illustrated below and a notorious problem with cocoa mirid experiments, is that control mortality increases over time to levels that exceed standard analytical assumptions.

ASSAY ISSUES
LT_{50} and control mortality



*organochlorines/OPs/carbamates/pyrethroids/neonicotinoids, etc

Over recent years, the number of products (including those of research-based companies) that contain mixtures of insecticide AI has risen substantially. Whereas there has long been a resistance management narrative for AI mixtures of fungicides with very specific target biochemistry, entomologists have generally discouraged insecticide mixtures because of the likely impact of insecticide mixtures on non-target organisms. IRAC has now brought out a document on this issue* which includes the following statements:

- In the majority of settings, the rotation of insecticide modes of action is considered the most effective IRM approach.
- Most mixtures are not primarily used for purposes of IRM.

Mixtures of insecticides may provide commercial advantages for controlling pests in a broad range of settings, typically by increasing the level of target pest control and/or broadening the range of pests controlled. There are cases when they help with combating a pest complex using a single spray (such as in cotton pest management) but broadening the spectrum of activity can quickly compromise IPM. There is a risk that mixtures use more chemicals than are genuinely required and a number of regulatory agencies are essentially opposed to their use.

* www.irac-online.org/content/uploads/IRAC_Mixture_Statement_v1.0_10Sept12.pdf (retrieved 2/2/2022)

4.8 Pesticides and pollinators

A growing controversy on the causes of bee decline (sometimes referred to as 'colony collapse disorder') over recent years has now resulted in an EU moratorium on the neonicotinoids (NNI): clothianidin, imidacloprid and thiamethoxam* (although cocoa is pollinated by midges not by bees). This forms an "Ongoing review of active substances" by the EU and a possible re-evaluation of fipronil is also of interest to cocoa producers.

The restriction on clothianidin, imidacloprid and thiamethoxam followed risk assessments by the European Food Safety Authority (EFSA)**, which "concluded the following for all three substances:

- 1. Exposure from pollen and nectar. Only uses on crops not attractive to honeybees were considered acceptable.
- 2. Exposure from dust. A risk to honeybees was indicated or could not be excluded, with some exceptions, such as use on sugar beet and crops planted in glasshouses, and for the use of some granules.
- 3. Exposure from guttation. The only risk assessment that could be completed was for maize treated with thiamethoxam. In this case, field studies show an acute effect on honeybees exposed to the substance through guttation fluid.

EFSA's conclusions contain tables listing all authorised uses for seed treatment and as granules of the three substances in the EU. Subsequently, a restriction of the use of the 3 NNI was adopted by the Commission. The move followed votes on 15 March 2013 by Member States' experts meeting at a Standing Committee on the Food Chain and Animal Health and on 29 April 2013 at an Appeal Committee where EU Member States did not reach a qualified majority – either in favour or against the Commission's proposal. The UK was one of the states voting against, influenced by a DEFRA evaluation of studies*** purporting to link the 3 NNI to bee harm: this provides a useful literature search and found that much of the evidence was based on laboratory work and would not normally occur in field scenarios. Prof. J Beddington suggested the EU was in danger of failing to understand risk saying: "This potentially legitimises an overly precautionary approach in the absence of scientific evidence showing any risk".

In the USA, the Environmental Protection Agency (EPA) similarly has been petitioned by activist groups, including beekeepers, to likewise ban NNIs. A USDA report**** describes several possible causes of national decline in honeybees, including: habitat loss, poor diet, diseases, parasites (especially *Varroa destructor*) and pesticide exposure (including sub-lethal effects that affect bee behaviour). Research so far points to a combination of these factors: which may be responsible for the 30% decline in honeybees annually since 2006. As in the EU, engineering controls can help minimise off-site dust movement from treated seeds, together with other standard good agricultural practices.

Registration Authorities in cocoa growing countries should remain vigilant and likewise maintain their ongoing review of registered pesticide products appropriate to 21st century needs. However, as with other crops, policymakers must also foster a strategy for 'sustainable intensification': in this case maintaining a diversity of appropriate and efficacious range of active substances in various (>2) modes of action for control of key cocoa pests.

Those concerned with pesticide policy in cocoa should be aware that NNIs and fipronil are now very much 'in the firing line' of environmental activists and that their regulatory status in Europe and N. America could change eventually. Short and medium-term strategies to manage these issues are required now. Imidacloprid-based insecticides in particular are now widely marketed in cocoa growing countries and MRL violation cases appear to be increasing. Attention to label rates (and clarity) for NNIs, field application practices and pre-harvest intervals in cocoa are clearly a priority issue for registration and extension staff.

* www.ec.europa.eu/food/animal/liveanimals/bees/pesticides_en.htm (April 2013)
** www.efsa.europa.eu/en/press/news/130116.htm?utm_source=homepage&utm_medium=infocus&utm_campaign=beehealth (Jan. 2013)
*** www.defra.gov.uk/environment/quality/chemicals/pesticides/insecticides-bees/ (May 2013)
**** www.usda.gov/documents/ReportHoneyBeeHealth.pdf (October 2012)

4.9 Biological control methods (and organic production)

As discussed in Chapter 3, there is no reason why the precautionary principle cannot be consistent with GAP: provided that it is under-pinned with rigorous science and, with available land becoming increasingly scarce, not a threat to productivity. GAP/IPM programmes rely heavily on the natural enemies, especially to keep insect pest populations in check where possible, with judicious use of pesticides only when needed. Withdrawal of older, especially broad-spectrum AI has brought about increasing recognition of biological agents as potential substitutes.

Amongst the practical issues in organic agriculture, is establishing precisely which pest management interventions are permitted or otherwise. Advice can even be conflicting as the editors of the *Manual of Biocontrol Agents*[36] have found. A useful guide to compatible management methods is on www.nysaes.cornell.edu/pp/resourceguide/index.php .

Biological control (BC) of pests has had a long history of highly cost-effective success, but there have also been many cases of failure or incomplete control. In practice, BC involves the active or passive deployment of three classes of organisms ('the 3 Ps'): parasitoids, pathogens and predators. There are various approaches to implementation[37], and important strategies are:

- 'Classical' biological control, where a co-evolved agent is taken, very often from the area of origin of the target disease (pest), and released in a way that it can multiply and reduce host population levels to a low level. Although there are many entomological examples (e.g. parasitoids are often the most effective solution to invasive Homopteran outbreaks), cases of successful classical BC against other pest categories are rare.

Parasitoids may be actively deployed in classical, inoculative or inundative biological control. Well-known examples include species of very small Chalcidoid wasps in the large genus *Trichogramma*. For cocoa, there appears to be interest using *Trichogramma* for management of cocoa pod borer.

This shows asexual and sexual *Trichoderma stromaticum*: on a pod diseased with witches' broom fungus; the hyperparasite has been mass produced and can be incorporated into IPM programmes.[38] Other *Trichoderma* species have been assessed for the management of various diseases (see section 7.2).

Source: Dr Victor Fursov, Wikimedia Commons

- Inoculation biological control: where an agent is released with the expectation that it will multiply and control the pest for an extended period, but not permanently. Whereas classical BC is also inoculative, inoculation biocontrol is usually used for situations such as the introduction of parasitoids and predators into glasshouses and where the older term 'augmentation BC' may not give a clear understanding of the ecological process taking place.

- Biopesticides: a form of inundative biological control. The term "biopesticide" is most useful when applied strictly to living microbial control agents which:
  1. are specific as individual products and thus confer some environmental advantage (unlike many but not all chemicals), and
  2. have a limited period of activity - and are therefore usually used with normal pesticide application techniques (unlike certain other biological control agents).

A predator: this *Nephila* spider (on Indonesian cocoa) is an example of one of the wide range of invertebrate natural enemies – populations of which may be particularly damaged by insecticide applications.

- Conservation of natural enemies: one of the more indirect advantages of not using broad-spectrum pesticides is that control of a pest may possibly be enhanced by preservation of its natural enemies.

05 Managing Hazards and Residues

Pesticide residues are a matter of great concern since members of the general public perceive a risk, but feel it is a matter over which they have little control. In response, authorities attempt to regulate by setting standards and monitoring exposure. This results (necessarily) in an arcane set of procedures and terminologies. A full list of terminologies and acronyms can be found on www.dropdata.org/download, with some of the more common ones listed in Appendix 1. Again, this booklet can only summarise these complex issues, but full accounts can be obtained from Standard texts. [1,39]

5.1 Classifying the hazards of pesticides

There are at least four aspects to pesticide 'safety' (i.e. managing hazards):

- acute (short-term) risks to farmers and other spray operators (only partially mitigated by protective equipment – see section 6.5)
- impact of pesticides on the environment
- residues remaining on food (and animal feed) and related to this
- real and perceived concerns about longer term effects of pesticides (including combinations of substances)

5.1.1 Acute Hazards and Operator Safety

The World Health Organisation (WHO) provides an internationally recognised system for classifying the acute hazard of pesticides. They are grouped in terms of their median lethal dose (LD_{50}) from Class I (most toxic) to Unclassified (unlikely to cause harm) with each class bounded by a 10-fold range of dose (in mg/kg body weight).

The WHO system recognises a 4-fold reduced hazard with solid formulations, in comparison with liquids. The classification was further developed by the US Environmental Protection Agency (EPA), which also recognises inhalation, eye and skin sensitisation effects. Both classifications should be based on **formulations** (where such information is available), but unfortunately, detailed information on individual products is often difficult to obtain, and many entries in the *Pesticide Manual*[3] are estimated from AI values. Member countries of the EU evaluate each product on a case-by-case basis and, if necessary, assign one of nine risk symbols and a large number of associated risk phrases*; this scheme also has been adopted by the International Labour Organization.

i. The World Health Organisation (WHO) classification
(LD_{50} to rats mg/kg body weight: of formulations where information is available)

Class		Solids Oral	Dermal	Liquids Oral	Dermal
Ia	Extremely Hazardous	≤ 5	≤ 10	1.75 (1.71)	III
Ib	Highly Hazardous	6-50	11-100	21-200	41-400
II	Moderately Hazardous	51-500	101-1000	201-2000	401-4000
III	Slightly Hazardous	≥ 501	≥1001	≥ 2001	≥ 4001
(U)	Unlikely to present acute hazard in normal use	≥ 2000	-	> 3000	-

* See: www.europa.eu/legislation_summaries/consumers/product_labelling_and_packaging/l21273_en.htm

ii. The US Environmental Protection Agency (EPA) system

Class	All formulations LD_{50} (mg/kg)		Inhalation LC_{50} (mg/l)	Eye effects	Skin effects
	ORAL	DERMAL			
I	≤ 50	≤ 200	≤ 2	Corrosive, corneal opacity not reversible within 7 days	Corrosive
II	51-500	201-2000	0.2 – 2	Corneal opacity not reversible within 7 days, irritation persisting for 7 days	Severe irritation at 72 hours
III	501-5000	2001- 20,000	2 –20	No corneal opacity, irritation reversible within 7 days	Moderate irritation at 72 hours
IV	> 5000	> 20,000	> 20	No irritation	Mild or slight irritation at 72 hours

In some countries, toxicity classification is illustrated by a colour coded stripe or triangle indicating the hazard of the product. This is excellent, but unfortunately not universal.

To summarise, for farmers and operators that do not have access to good protective equipment, the guiding rule should be:

Class I pesticides	extremely / highly hazardous	DO NOT USE
Class II pesticides	moderately hazardous	take great care
Class III pesticides	slightly hazardous	take care
Unclassified / Class IV pesticides	unlikely to be hazardous	still take care

Certain pressure groups, including the Global IPM Facility (supported by FAO and other organisations working with Farmer Field Schools) have suggested that Class I and II products should be withdrawn from general use, since smallholder farmers are unlikely to use appropriate personal protective equipment (PPE). With the development of new insecticide products, there are now only a very few cases where Class I pesticides can be justified at all, let alone for smallholder agricultural problems. However, complications could occur if all Class II products were to be withdrawn immediately. The problem here is especially with insecticides, where there is often a need for resistance management strategies involving alternations in the use of different groups of compounds. Therefore, a phased restriction / withdrawal of the more hazardous compounds may be more appropriate, before safer products become available.

EC Regulation No 1272/2008*, of the European Parliament and Council, provides a harmonised basis classification, labelling and packaging of substances and mixtures: including for example, such aspects as pictograms as discussed elsewhere. The original Directives it replaced: 67/548/EEC and 1999/45/EC were repealed on 1 June 2015 and **Regulation (EC) No 1907/2006****, concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (**REACH**) and which established a European Chemicals Agency, was also amended. As with AI, REACH restricted substance lists are regularly updated with adjustments made to the Annexes: a recent revision occurred in 2021.***

* of 16 December 2008: www.eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008R1272 (accessed 20/6/2015)
** of 18 December 2006: www.eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32006R1907 (accessed 20/6/2015)
*** www.chemsafetypro.com/Topics/EU/REACH_annex_xvii_REACH_restricted_substance_list.html (accessed 1/5/2022)

5.1.2 Other measures of toxicity and implications

From an operational point of view, **acute toxicity** is paramount, but other criteria are important - especially in food safety assessments. In order to register a pesticide, other toxicological information is required including:

- **Chronic (sub-acute) toxicity** over long periods (years) that include **generation studies** to find out if fertility has been impaired
- **Carcinogenicity** - whether the substance is likely to cause cancers
- **Teratogenicity** - whether the substance can damage embryos
- **Genotoxicity** - whether the substance damages genetic material
- **Irritancy** (especially for spray operators) and
- **Metabolism** - it is important to know how the substance is metabolised, into what (metabolites may be more toxic than the original pesticide) and how all metabolites are excreted.

Two important measures (and their associated terms) are especially prominent in legislation and debate. They are not actually linked to one another, but in some ways can be thought of as reflecting hazard and risk.

- 'Toxicological measures' based on known safety limits: including Acceptable Daily Intake (ADI: a key indicator for pesticide approval, described in section 5.3)
- Measures and limits of actual residues based on field studies: including Maximum Residue Levels (MRLs: practical specifications for food producers) for a given crop.

5.2 What are MRLs?

Pesticide residues on crops are monitored with reference to Maximum Residue Limits (MRL) and are based on analysis of quantity of a given AI remaining on food product samples. The MRL for a given crop/AI combination is usually determined by measurement, during a number (in the order of 10) of field trials, where the crop has been treated according to GAP and an appropriate pre-harvest interval (see section 5.8) has elapsed. For many pesticides, however, this is set at the Limit of Determination (LOD) – since only major crops have been evaluated and understanding of ADI is incomplete (i.e. producers or public bodies have not submitted MRL data – often because these were not required in the past). LOD can be considered a measure of presence/absence, but true residues may not be quantifiable at very low levels. For this reason, the Limit of Quantification (LOQ) is often quoted in preference (and as a 'rule of thumb' is usually approximately 2X the LOD). Useful further information on detection limits is provided by the European Commission.[40]

It follows that the adoption of GAP at the farm level must be a priority: including and especially the withdrawal of obsolete pesticides. With increasingly sensitive detection equipment, a certain amount of pesticide residue will often be measurable following field use. In the current regulatory environment, it would be wise for cocoa producers to focus on pest control agents that are permitted for use in major importing countries.

Testing for residues should be carried out in accredited laboratories (e.g. to ISO 17025 standards), following internationally agreed and validated methods; specific good laboratory practice (GLP) methods also apply (e.g. DIN, ISO, FDA) in many countries. Procedures include extraction and "clean-up" from samples, followed by analysis using various instruments, depending on the residue being analysed. Appropriate equipment for individual compounds is included in the Pesticide Manual entries. Analysis techniques include: gas chromatography (GC), gas-liquid chromatography (GLC), gel permeation chromatography (GPC), high-pressure liquid chromatography (HPLC) and various mass spectrometry techniques, so such laboratories are expensive to set up and maintain.

(photos: Jean Ponce Assi, SACO-CHOCODI)

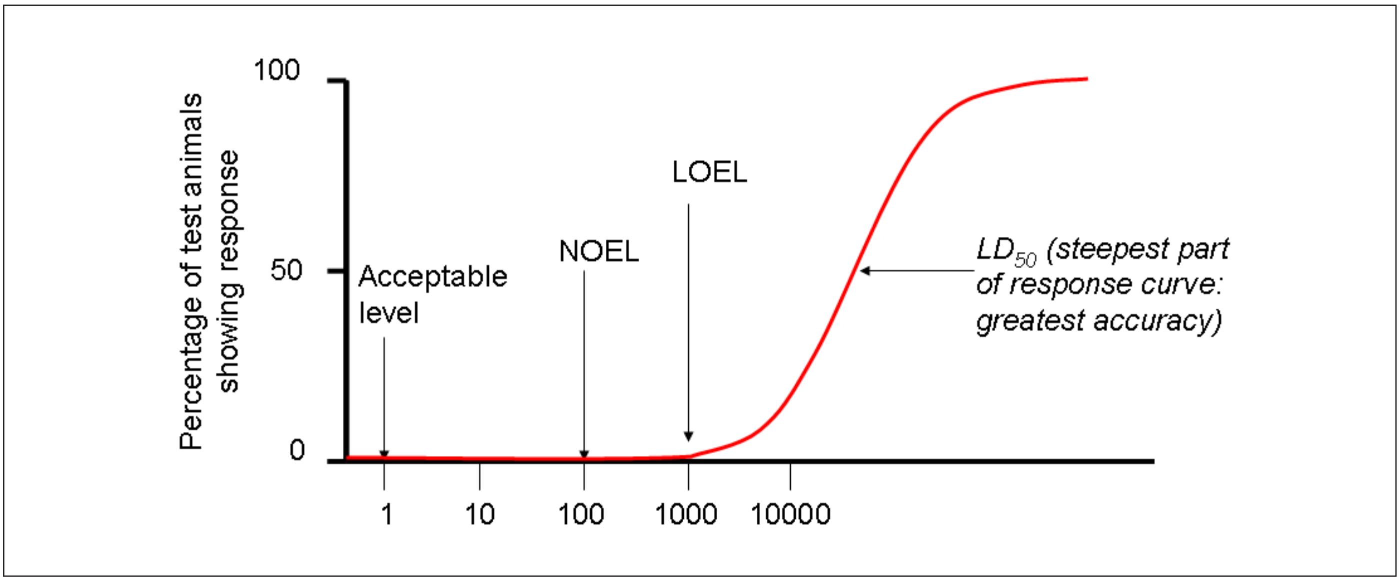
It should be stressed that MRLs are set on the basis of observations and **not** on ADIs, and it is also generally understood that MRLs would considerably over-estimate actual residue intakes. MRL studies take place after years of initial development and it is most unlikely that an agrochemical company would even carry them out (with a view to registering the product), were toxicological studies to raise serious question marks about a new compound.

5.2.1 Default MRLs

For substances that are not included in any of the annexes in EU regulations, a default MRL of 0.01 mg/kg normally applies. Default MRLs apply with the Codex and in Japan, but at the time of writing have yet to be set in the USA. It is interesting to note that for at least one registered AI (fipronil and its metabolite), the MRL is even lower than default.

5.3 Measures of 'safety': ADI, ArFD, OELs, etc.

A pesticide can only be approved for use if the risk to consumers, based on potential exposure, is acceptable. The limit set for a pesticidal active ingredient (AI), the ADI, is an estimate of the amount that can be consumed daily, for a lifetime, without harm to the person. The term "acceptable" is considered to involve a 100-fold safety factor from a measure called the No Observed Effect Level (NOEL) obtained in laboratory studies, which is 10 times lower than the Lowest Observable Effect Level (LOEL).



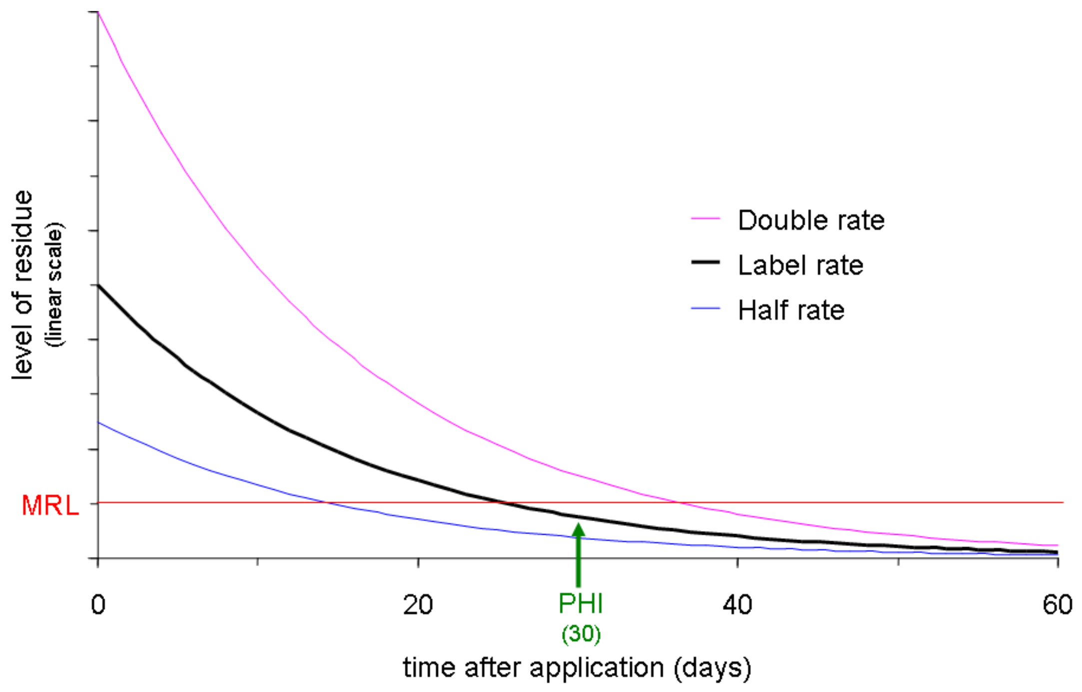
Data from laboratory studies is expressed as a dose (usually mg/kg bodyweight) and it is necessary to extrapolate these data for human exposure (be it dermal toxicity for AOEL or ADI for dietary safety). Dietary intake is often based on the National Estimated Dietary Intake (NEDI), estimate of a given foodstuff using surveys by national food standards agencies. Ideally, judgements would be carried out on Theoretical Maximum Daily Intake (TDMI), but there may be substantial variations between infants, children and adults even after adjusting for body weight. Another often quoted parameter, the Acute Reference Dose (ARfD), which is similar to the ADI, refers to short-term intake of an AI.

5.4 Pesticide breakdown

After application, pesticides are degraded by chemical and physical processes in the environment such as sunlight, soil and water (called **abiotic degradation**) or metabolised within living organisms (both target and non-target animals and plants, soil bacteria, etc.). Breakdown of a pesticide (and many other substances) in the environment can be thought of as following a decay curve. This is a function of the chemical's **half-life**, which is the time (most usually expressed in days) required for half of the applied pesticide to become converted into degradation products (which may in turn be biologically active and have substantial half-lives).

The rate of breakdown depends on many factors, not least the chemical stability of the pesticide in question, but factors such as temperature and pH are extremely important, so the half-life may be expressed as a range (e.g. 3-10 days). Probably the most important mode of pesticide degradation is **oxidation**: especially by activated oxygen (e.g. ozone and hydroxyl radicals generated by sunlight, hydrogen peroxide generated in plants, etc.) rather than O_2 in the atmosphere.

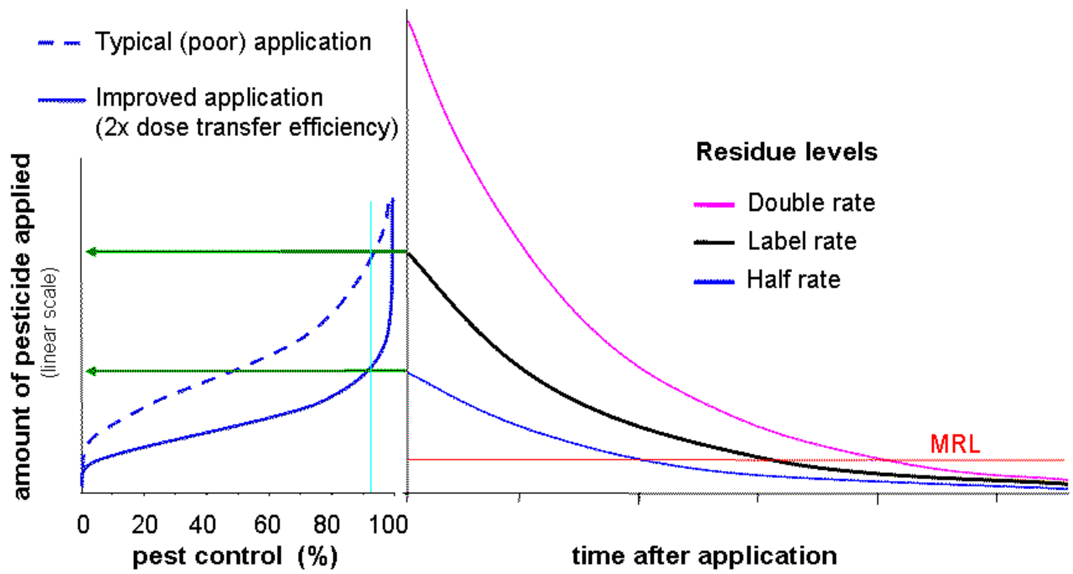
Allowing sufficient time to elapse between application and harvest enables any residue to degrade to acceptable levels (i.e. the MRL) and the Pre-Harvest Interval (PHI) has a built-in safety factor. Reducing the dosage reduces the time to which acceptable levels are reached, but pest control may be impaired. Excessive residues occur with short harvest intervals, overdosing, or worst of all both.



Breakdown of a pesticide after application (see text above). The curves illustrated are modelled on the basis of an 'industry default half-life' of 10 days (supported by limited data); all axes are linear.

5.4.1 Implications for application and environmental impact

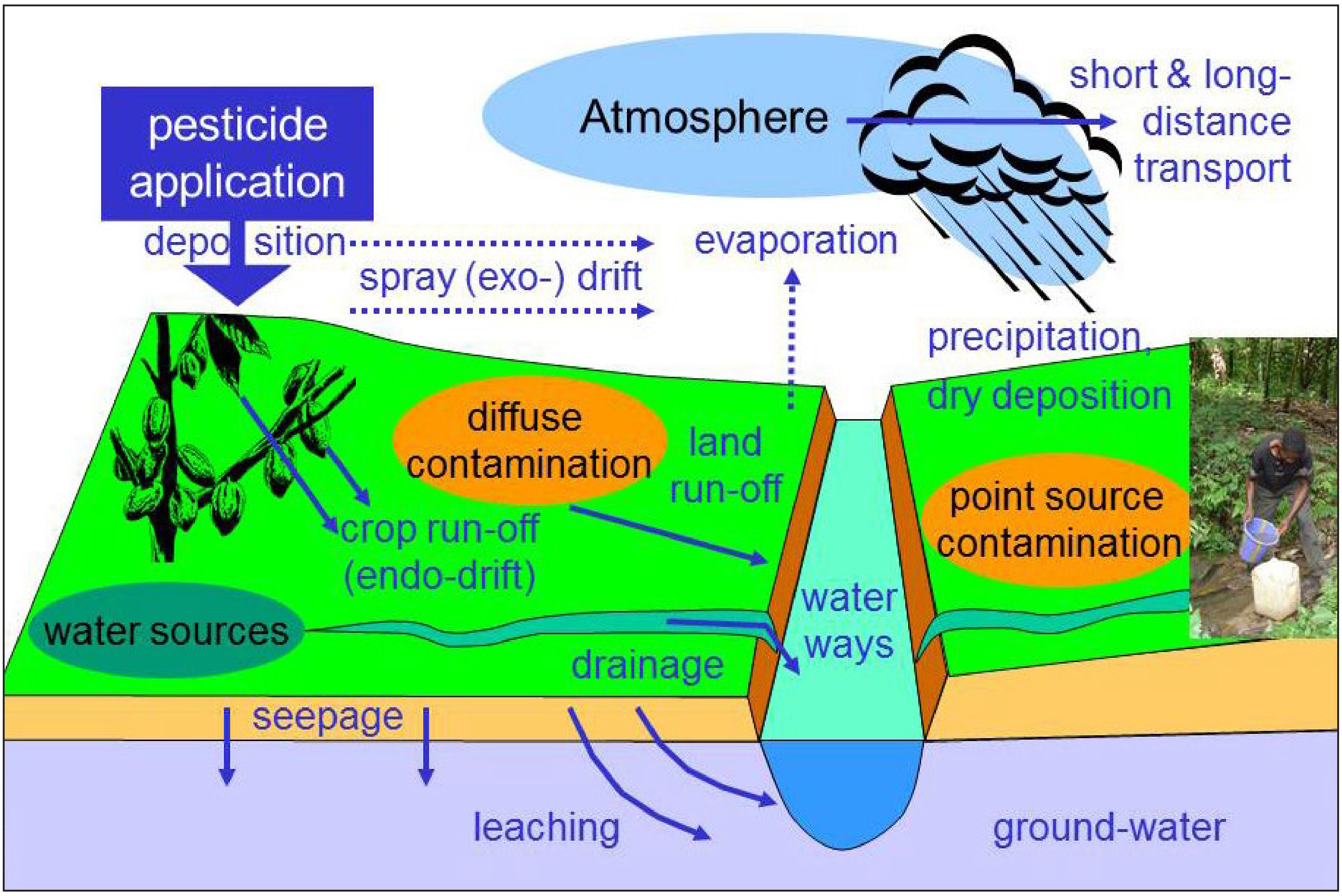
Improved (as opposed to just competent) application techniques are an especially promising way of mitigating residues and lowering environmental impact, but unfortunately research in this field has been very limited. Targeted dose-transfer[41] can increase pest mortality for a given level of application to the crop, while maintaining equivalent pest control[7].



Breakdown curves (as above) juxtaposed to rotated dosage response curves for indicative standard and improved application methods against a target pest. Typical label rates allow for sub-optimal application methods. If spraying can be improved, the benefits may include reduced environmental load of pesticide residues and savings for the farmer.

5.5 Environmental aspects

This is an enormous and complex subject, which can be summarised here in the form of a diagram:



Agrochemical companies are now obliged to allocate substantial resources to assess the **environmental fate** of compounds (and their metabolites). Even after registration, environmental concerns can be raised that may threaten the future of successful compounds (e.g. the neonicotinoids). The fate of a given treatment in the environment is a function of its chemical properties, the way in which the pesticide has been dispersed and the properties of the soil, run-off, waterways, etc.

Screening of new compounds includes risk assessment of both ground and surface water contamination, involving extensive testing and computer modelling. A number of standard tests take place on non-target organisms including birds (such as mallard ducks), fish (including rainbow trout), algae, water fleas (*Daphnia* spp.), bees and other beneficial species.

Inappropriate application can lead to off-target contamination due to **spray drift**, and "**run-off**" from plants causing contamination of the soil. Several studies have concluded that **point source contamination** (entry of pesticides to water courses/groundwater following spillage of concentrate or after washing equipment) often causes the greatest harm - especially to waterways.

During training sessions, time should be allocated to considering crop protection activities relative to the positions of water courses and wells. For example, in order to protect water sources, it is especially important that farmers consider waste flows when washing out sprayers and the management of empty pesticide containers. This is much more than empty containers being unsightly: malpractice potentially harms children, water sources, domestic animals, biodiversity, etc.

The disposal of empty pesticide containers remains problematic, but is now being addressed by the FAO/WHO/Global Environment Fund* and *CropLife* International** initiatives, including:

(a) multi-trip, returnable containers and (b) one-way, single-trip containers made from recyclable materials.

Leaving packaging in the field or burning containers is not acceptable. This photo is especially problematical, since discarded containers indicate mixing took place near an important water source.

Containers should be rinsed three times, then operators should pour rinsate into the sprayer. If there is any risk of inappropriate re-use, containers must be punctured.

Cocoa growing communities are advised to develop appropriate and safe disposal methods. Ideally, this would best be organised in container return schemes with the involvement of pesticide suppliers.

5.6 Disposal of old stocks

The withdrawal of recommendations for pesticides often raises questions at Government, distributor, through to farmer levels, about how to dispose of existing stocks of products. The problem should primarily be seen as an administrative one: **i.e. the situation should be avoided in the first place**. With sound policy and administration backed up by appropriate scientific support (see recommendations), future trends in pest control methods can be foreseen: it should be possible to avoid the use of substances which are subject to concern.

Stocks of older compounds should therefore be used up, and withdrawn from the marketplace, long before they are banned. On a small scale, applying older stocks of chemicals to crops is usually considered the most practical way of using them up, provided they are relatively safe and still registered in the country of use. **Safe disposal of obsolete chemicals is very expensive** and can only take place in one of a limited number of specialist facilities.

The comments above only apply when there is a substantial time to go before withdrawal of a given product. In the context of any new regulations concerning residues on imports, readers should be aware of the significant time lag (frequently >1 year) between the cocoa farm and the port of entry, so pesticides (or any other practices) that might cause problems, should not be used during the final season (and preferably for 2 seasons) before the deadline.

* Code of conduct (May 2008 - accessed 10/8/2014)
** See: www.croplife.org/crop-protection/stewardship/container-management/ (retrieved 2/2/2022).

5.7 MRLs for cocoa: what will be assessed in practice?

In the EU and USA, samples of cocoa beans are first de-husked before residue analysis takes place: with the cocoa bean seed coat (testa) removed before analysis. In Japan, whole beans ("beans without pods") were analysed, which was more likely to result in residue violations, but at the time of writing, the protocols for testing in Japan are changing to removal of husk. However, this reform is on a substance-by-substance basis and it remains important to consider individual AI.

Commission Regulation 396/2005/EC of the European Parliament and of the Council proposed maximum residue levels of pesticides for food products applied from 1 September 2008. This was amended by Regulation EC 149/2008 by establishing Annexes II, III and IV setting maximum residue levels for products previously covered by Annex I.

Annex III includes so-called temporary MRLs for cocoa (many subject to review within 4 years) and is split into two parts as follows:

- **Part IIIA**: Temporary MRLs for substances being in the approval circle for use in EU or substances that are no longer approved for use in EU.

- **Part IIIB**: Temporary MRLs for all active substances for new commodities (including cocoa) introduced under Regulation 396/2005/EC. These MRLs are based on national MRLs, where a risk assessment has been performed by the European Food Safety Authority (EFSA).

Annex IV contains plant protection products already evaluated at EC level for which it is not necessary to set MRLs (because of their low risk).

EU documentation is not light reading: easier access to the essential information (with a download facility), under "cocoa (fermented beans)" and "tea, coffee, herbal infusions and cocoa", is available at: www.ec.europa.eu/food/plant/pesticides/max_residue_levels/index_en.htm.

A description of regulations in Japan and the USA was given in Chapter 3. MRLs for cocoa imports into Japan are on: www.m5.ws001.squarestart.ne.jp/foundation/fooddtl.php?f_inq=13400 and information from the US EPA on: www.epa.gov/pesticides/food/viewtols.htm. A global MRL database (paywall) is available on https://www.globalmrl.com/home.

5.8 What can be done to mitigate residue problems?

Essentially, the key measures that can be taken at the farmer - operator level are:

- apply the right substance (s),
- in the right way,
- at the right time.

It follows that there are four important practical ways to avoid residue violations:

1. Establish whether pesticide application is the most appropriate way to solve the problem:
Will it be cost effective?
Are there viable alternatives?

Has a pesticide on offer been withdrawn?
- if so, do not use.

Is the pesticide likely to be withdrawn soon (Appendix 3)?
- if so, see section 5.6.

2. If it is appropriate, select the right pesticide for the problem.
Ask yourself:
Am I using a suitable product for cocoa?
Is it on the recommended list for controlling the problem?
Is it safe for me to use?
How would I need to use it?

3. Apply pesticides in the right way to achieve effective pest control. Good application includes control of the amount of product delivered to the crop. This means good nozzle selection, calibration and application technique (see Chapter 6). A frequently encountered misconception is that "Adding a little extra will make sure of good control"

4. Apply pesticides at the right time - before the Pre-Harvest Interval (PHI): which is the minimum permitted number of days between the last spray and harvest. This can be one of the most important considerations for avoiding harmful residues on produce.

For example, the product shown* is an effective and widely used fungicide for the control of black pod disease. The label ("Use recommendation") states that the recommended PHI is one month, but this may not always be adhered to by farmers during peak-season disease attacks. Trainers must emphasise this point with clear messages such as "don't spray within 4 weeks of harvest".

* Inclusion of compounds or products is for illustration only and does not imply recommendation or otherwise.

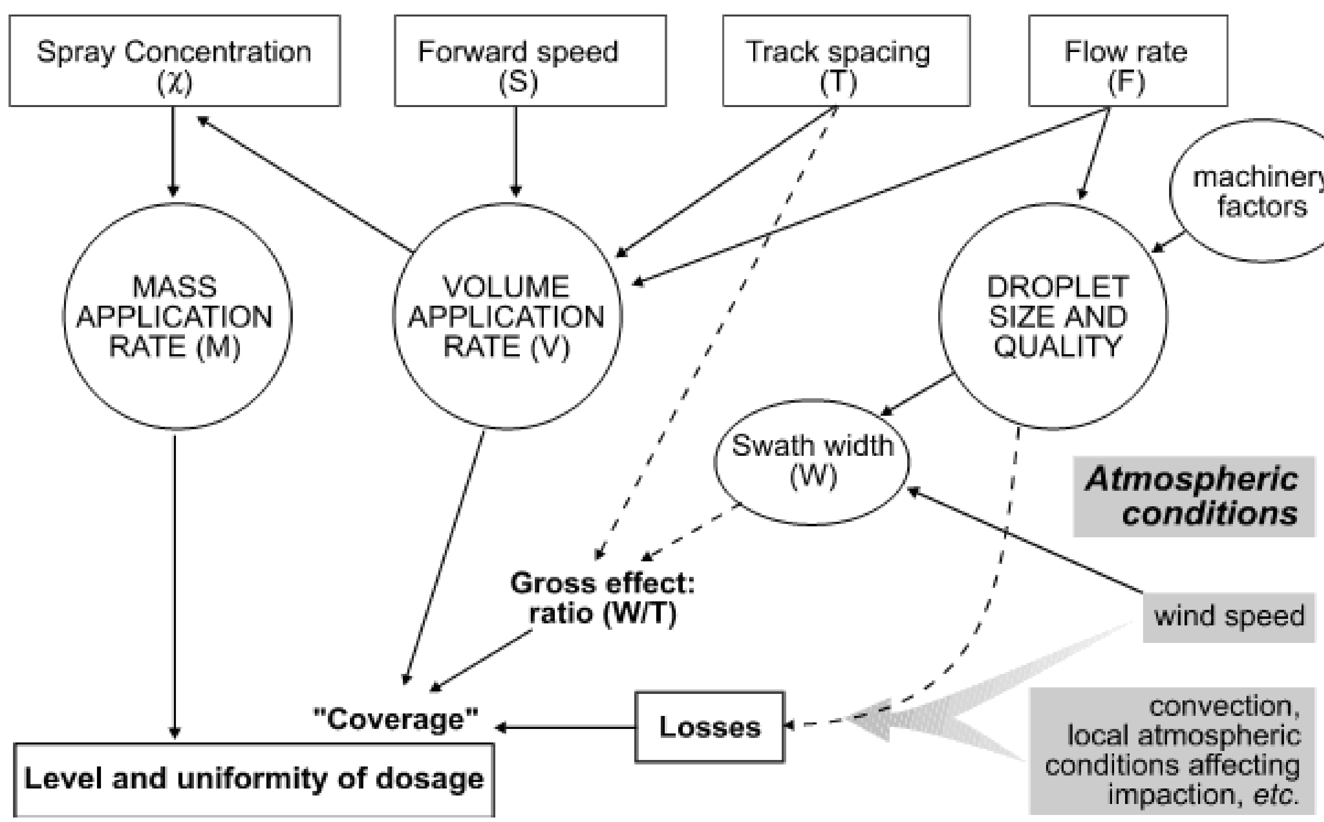
06 Application Methods for Cocoa

The process of application remains one of the most neglected aspects and often the 'weakest link' in pesticide use. It is not an exaggeration to state that many smallholder cocoa farmers are now using 19th century technology to apply 21st century crop protection products. Attempts to introduce effective GAP will always be confounded while farmers are equipped with sprayers that are impossible to calibrate accurately.

6.1 Application rate (the theory and the label)

Improving the efficiency of application has the potential to improve pest control, reducing both pesticide costs to the farmer and loading on the environment; spraying less to achieve at least equivalent efficacy may even reduce residues. However, only in the most sophisticated spray operations is any attempt made to control the various factors that affect spray deposition on crops.

In practice, the smallholder cocoa farmer can best assess the number of trees per tank-full (see calibration sections below). It is rarely appreciated just how inefficient normal existing application practices are in crops. Winteringham's work[42] highlighted the inefficiency of dose transfer to the biological target; when lindane sprays were applied to cocoa mirids, only 0.02% of the total leaving the tank reached the biological target. Exceptionally, efficiency may reach 30% for herbicide sprays on grass weeds; thus at best, perhaps only 70% of the pesticide mixture in the tank is wasted!



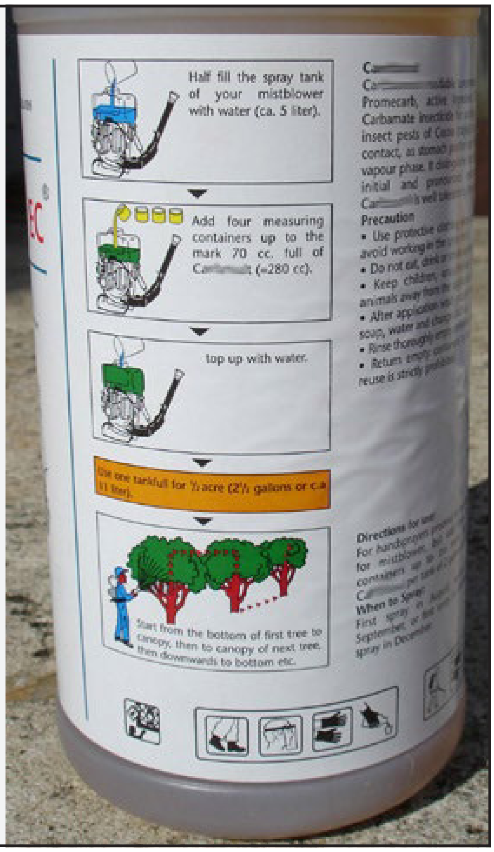
During any spray operation, the amount of pesticide landing on the biological target depends on a number of factors, often resulting in complex interactions.

In general, experience has shown that for most spray operations, calibration is most effective when it focuses on the **volume application rate (VAR)**. By mixing in a known quantity of pesticide formulation, an accurate **dosage** is applied to the target area (a group of trees, a field, etc.). It is important to distinguish dosage from dose: which is an exact quantity of substance delivered to an individual organism (e.g. in a bioassay). VAR in itself makes little difference to the quality of deposit, which is dependent on the various interacting factors shown below. From this, an appropriate formulation dilution rate is calculated to accurately achieve a certain dosage per tree or per hectare.

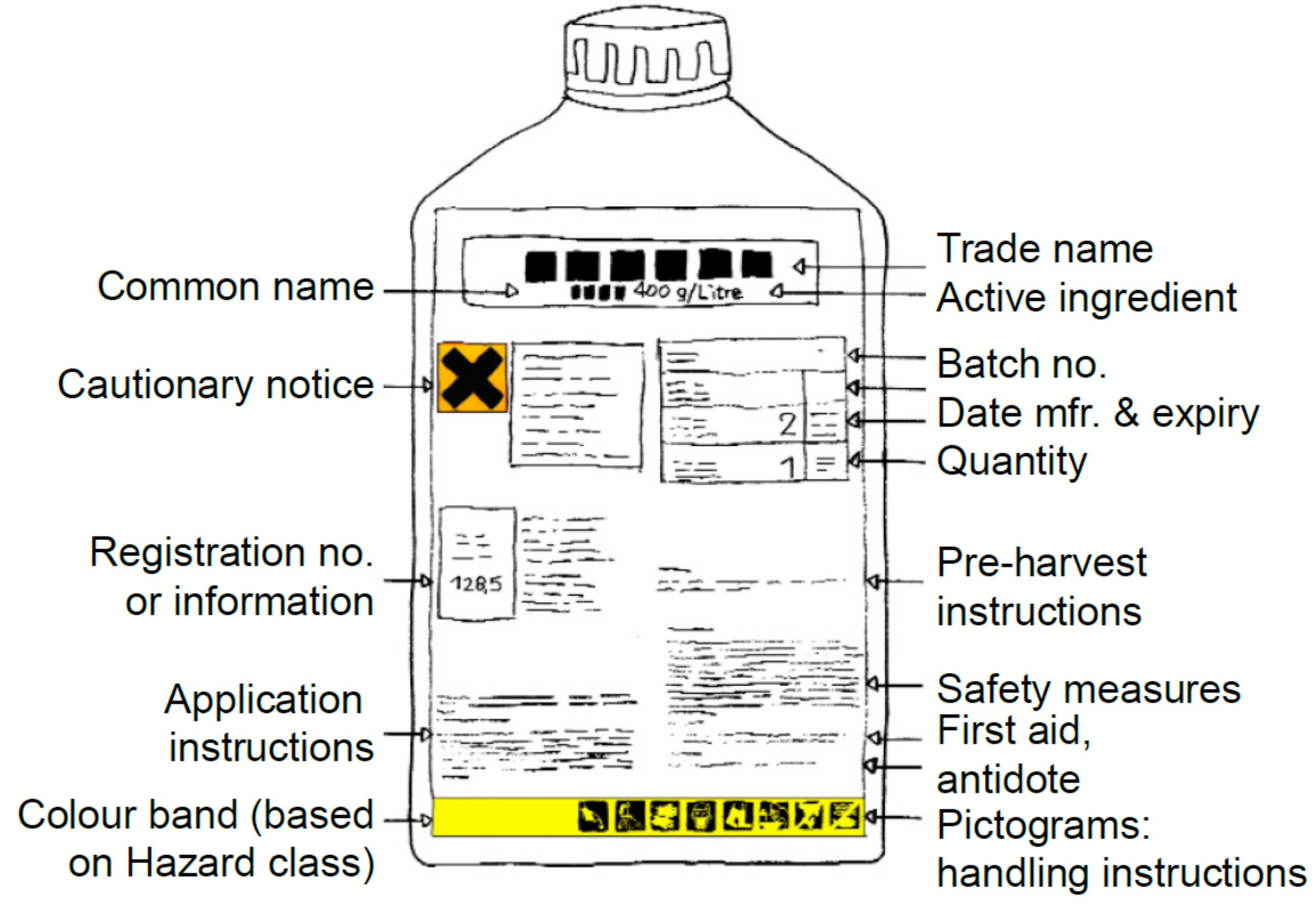
In practice, such calculations are only rarely made by operators. Attention to product labels is far from general practice, but labels remain the most available source of information to farmers and spray operators. However, even label application rates **can be flawed if more than one type of sprayer is used in an area**, since typically they assume a given (often very high) VAR will be used. For tree crops such as cocoa, the pesticide label will give application rate in the form of a recommended tank mix concentration; good labels may also give useful advice on application.

This shows a (sadly rare) example of clear application instructions being provided on a pesticide label.

Unfortunately, this is displayed on a bottle containing a hazardous (Class I) insecticide that has now been superseded. Although the pictograms (at the bottom of the label) indicate the need for protective equipment, the operator illustrated just above is using a motorised mistblower, but wearing neither a face-visor nor ear defenders (see section 6.5).



The product label provides the means of communication between the producer, the regulator and the farmer (or his/her advisor). As such, labels are crucially important and therefore must be a key part of regulatory scrutiny. National regulators have labelling policies and labels must always be written in the appropriate local language(s), but international advice is available on harmonising label formats, which will have similarities to those of standard pesticides. An example is shown below. It is incumbent on regulators to establish whether the information on the label is compatible with GAP and that a mechanism is in place for checking the quality of the contents.



Important components of a pesticide label (courtesy *CropLife* International)

6.1.1 Consumer protection, operator safety and GAP

Before finishing this description on pesticide labels, it is important to stress the need for rigorous registration and label approval processes for permitted products. National pesticide guides that focus on locally recommended plant protection products are increasingly being published and are an important source of information on trade names, recommended application rates for different crop uses, etc. Where they are not available (or difficult for farmers to obtain), provision of such guidance, in a user-friendly form, is an important role for Government and NGO extension agencies.

6.2 Spraying equipment for field pests

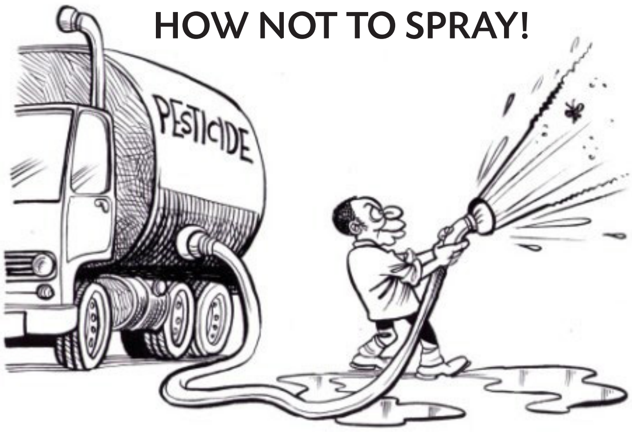
The method of pesticide application is crucial, but it is often a more neglected aspect of pesticide use. Applying less, by applying more efficiently, should be a fundamental maxim in IPM, yet practices have not improved over recent decades in many countries: in some, standards have actually gone down.

Together with attention to pre-harvest intervals (PHI) and number of sprays, careful application is one of the ways in which pesticide residues can be controlled, since it determines the dosage delivered to the crop. Whether a chemical, biological or 'biorational' pesticide is to be applied, the performance of a good control agent will be severely reduced by poor delivery systems*, so application is also a key factor to achieve efficacy.

* 'delivery system' describes the careful selection of appropriate formulations and application equipment

In practice, there are a number of important considerations in pesticide application:

- **Assessing the target and equipment selection**
- **Health & safety**
- **Nozzle selection and setting**
- **Calibration**
- **Application technique**
- **Maintenance and repair of equipment**



(courtesy H. Dobson & J. Cooper, 2005 - Vegetable production and pest management calendar).

Further detailed information is available in *Pesticide Application Methods*[43], with notes also available online at **www.dropdata.org/DD/**.

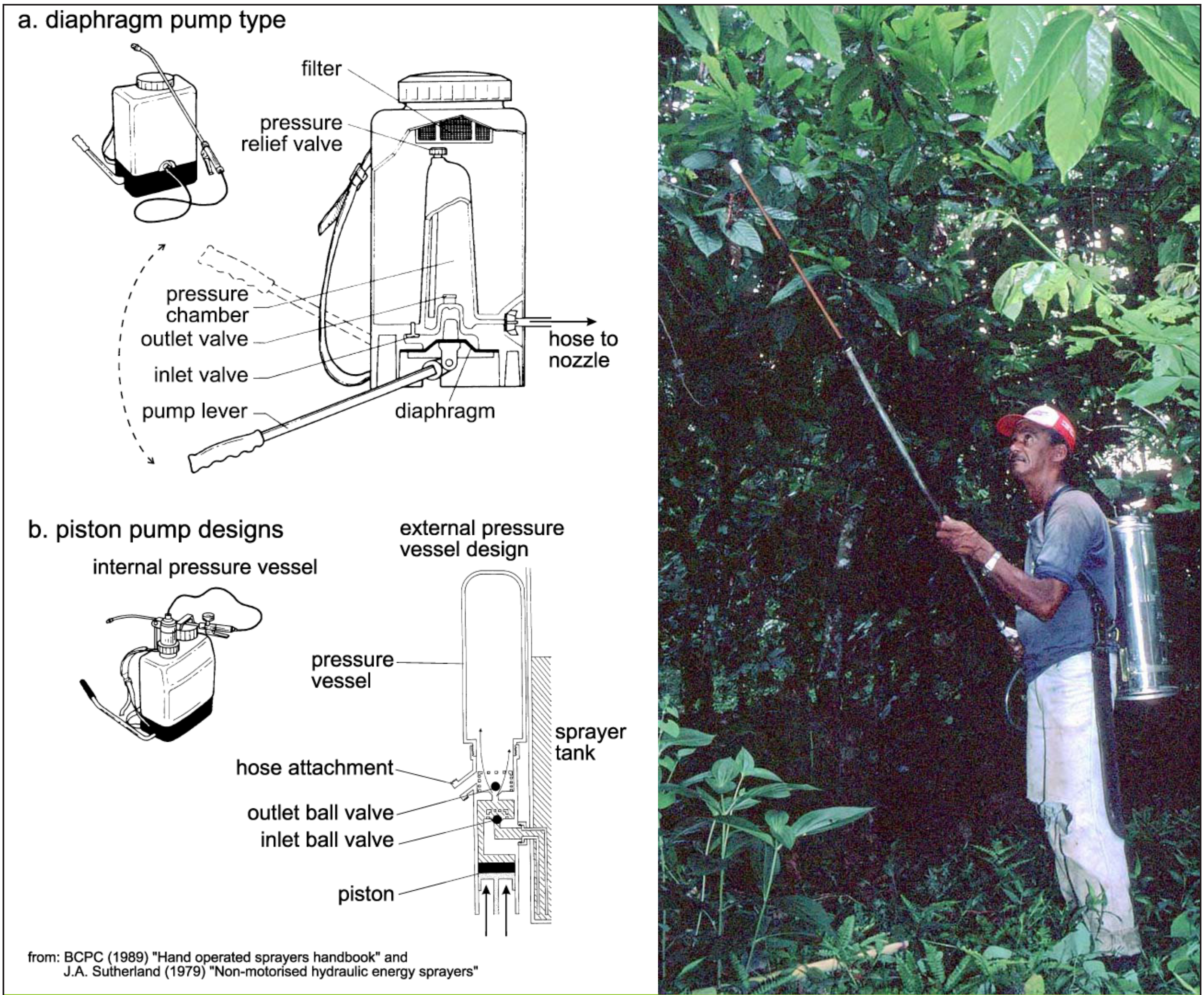
There are essentially two types of equipment commonly used for spraying cocoa trees: motorised knapsack mistblowers (or air-blast sprayers) and manual (hydraulic) sprayers.

- Almost all smallholder farmers use manual (hydraulic) sprayers, which are globally the main method of pesticide (especially fungicide) application to cocoa.
- Motorised mistblowers now have many uses, but they were originally developed for obtaining good droplet coverage in the tall cocoa trees of West Africa.

Chemical control of both mirids in Africa and cocoa pod borers in South -East Asia was initially validated using insecticides such as lindane and endosulfan, whose volatility helped overcome deficiencies in application. Nevertheless, it was estimated that less than 0.02% of active ingredient reaches the biological target when applying control measures to cocoa using motorised mistblowers[44]. Newer chemical products may be substantially more expensive than the more familiar generic compounds used hitherto, and volatility is no longer an acceptable property for insecticides, so improving the quality of application has become most important. FAO provides guidelines on the *minimum requirements for agricultural pesticide application equipment*[45], but unfortunately in any visit to sprayer stores or farmers in the many cocoa growing areas, it can be difficult to find equipment that complies with these requirements. For portable equipment (as used by most farmers and especially smallholders), specifications are given for sprayer tanks, pumps, etc., with specific requirements on nozzles (see below). FAO envisaged that member countries should put sprayer quality standards into law as with pesticides, but sadly, few countries have implemented this; however in 2008, Cameroon changed a statute to include the prohibition of import of sprayers that do not comply with FAO Minimum Requirements.

6.3 Hydraulic (manual) sprayers and nozzles

Hydraulic nozzles remain the most widely used method of spraying chemical pesticides. They are fitted to a wide range of spraying systems, ranging from the very basic hand-held 'trombone' sprayers, side-lever knapsack sprayers, compression sprayers (originally designed for vector control, but used by some cocoa farmers) as shown below:



from: BCPC (1989) "Hand operated sprayers handbook" and J.A. Sutherland (1979) "Non-motorised hydraulic energy sprayers"

Three types of manual hydraulic sprayer used in cocoa

The two common forms of manual side-lever knapsack sprayer are illustrated: (i) where the tank mixture is pumped using a diaphragm or (ii) a piston mechanism; both require two valves. 'Pulsation' (variations in pressure with pumping) is minimized with a pressure chamber that is mounted either internally (often as part of the pump mechanism) or outside the main tank, and certain sprayers have a pressure control mechanism mounted either in the tank or on the spray lance ("wand"). Filters beneath the tank lid are usually fairly coarse, so farmers should be careful to use clean water to avoid blockage of the finer filters next to the nozzle tips.

Compression sprayers are less than completely filled with water and added pesticide, then pumped-up to 600 kPa or more, before lifting on the back and spraying. This has the advantage of leaving both hands free for operating the lance; however, unless a pressure regulating device is fitted, the pressure and flow at the nozzle gradually decreases until the sprayer is pumped up again.

In addition, especially in Asia, motorised hydraulic sprayers are becoming increasingly available: where the energy provided by manual side-lever action is replaced with an electric pump, or even a 2-stroke engine. It is important not to confuse these **motorised hydraulic sprayers** with **motorised mistblowers** (below). Whereas the latter can be used to reduce volume rates, motorised hydraulic sprayers are often fitted with very high flow rate or multiple nozzles, so there is a danger of increasing VAR in comparison with manual spraying. When buying this sort of spray-equipment, it is important to check the flow rate range and validate with calibration.

Distribution of spray deposited with a lance depends very much on the skill of the operator in keeping a steady pumping and walking speed and directing the nozzle to the target areas (pods, foliage, branches, etc, depending on the pest).

The FAO has produced guidelines on minimum equipment standards[46] for manual sprayers that include various aspects relating to weight, durability, leakage, ease of cleaning and maintenance, instruction manuals, etc. The guidelines specifically indicate the responsibility of sprayer manufacturer to comply with requirements for atomizers supplied including:

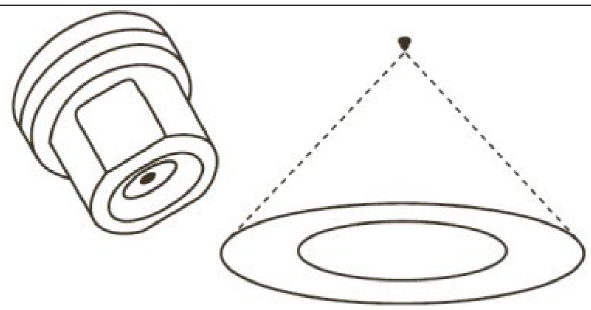
- "Nozzles supplied with or recommended for a sprayer should be manufactured to international standards (ISO)*.
- "The sprayer manufacturer should include in the sprayer manual, information on: nozzle flow rates, characteristic spray patterns and spray angles..."

6.3.1 Hydraulic nozzles

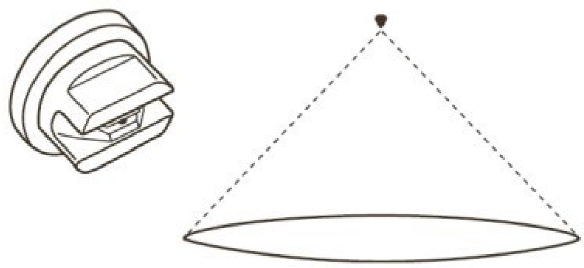
The volume of water used per hectare (volume application rate) directly affects the amount of pesticide applied, and is dependent on the nozzle used, together with the operating pressure. The latter also affects the spray angle and spray quality, which in turn affect the effectiveness of spray application (efficiency of dose transfer to the target pest).

The most common spray nozzles, and the pattern of spray produced, are as follows:

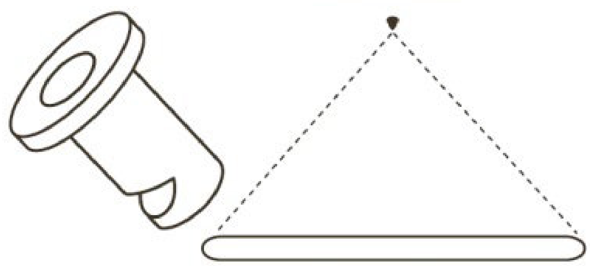
Top
Cone nozzle (most commonly used, for fungicides & insecticides)



Middle
Flat fan nozzle -
general purpose and spray booms

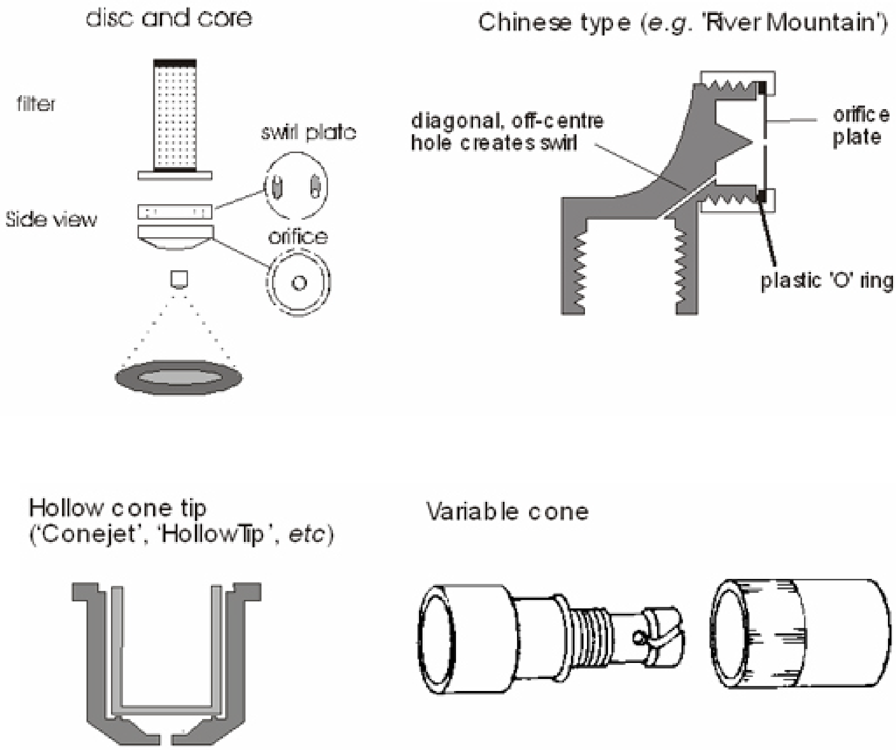


Bottom
Deflector (anvil) nozzle -
for herbicides



* ISO 10625:2005 specifies a system of colour coding for identification of standard hydraulic spray nozzles (e.g. flat fan, deflector and single component cone nozzles). Another standard defines their fitting to nozzle holders (ISO 8169: 1984)

Types of cone nozzle
The right combination of disc and core nozzle (e.g. D1.5-25) can be pre-fixed to maximise the spray deposited on pods and branches.



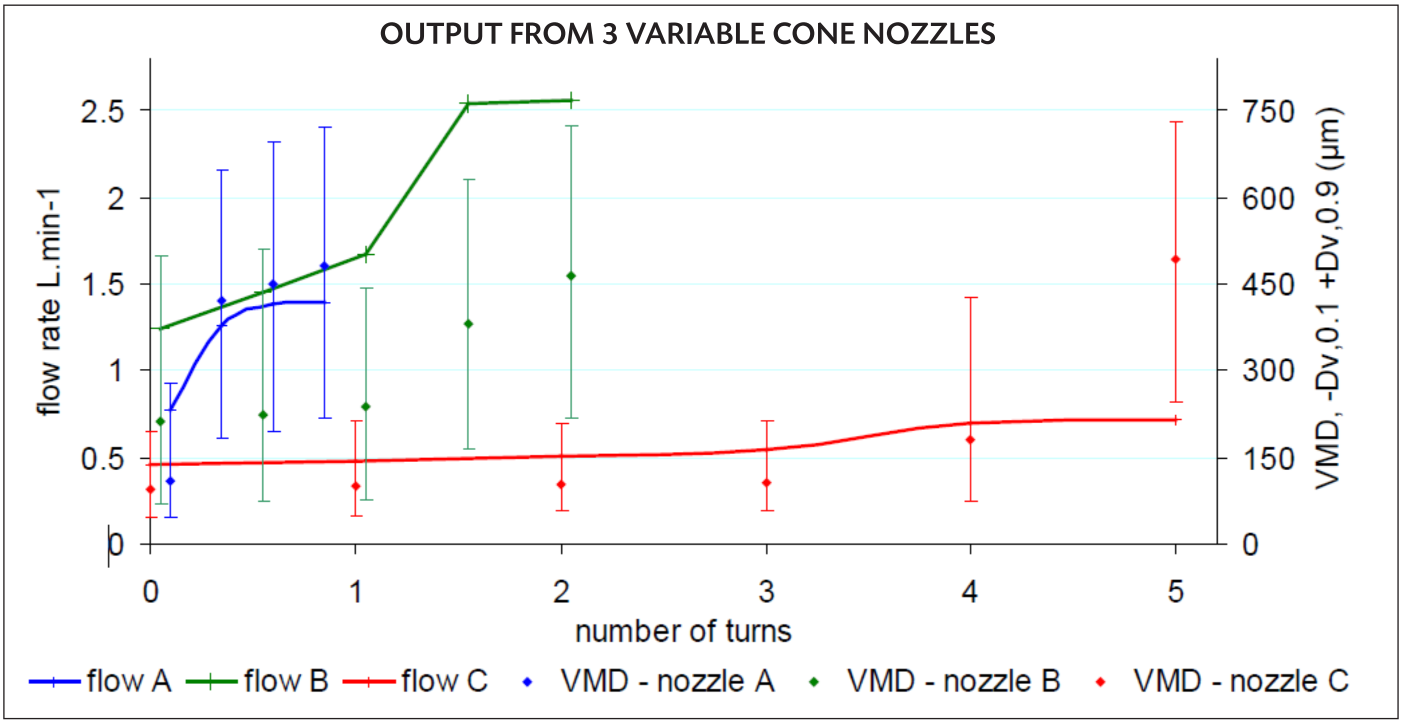
6.3.2 The need for nozzle standards in cocoa growing areas

Unfortunately, many manual sprayers used by smallholder cocoa farmers worldwide are fitted only with variable cone nozzles, and few farmers know which setting to use. When screwed down to its minimum setting (i.e., a very fine spray), they produce a hollow cone spray, comparable in quality to standard fixed geometry cone nozzles. However, even unscrewing the outer cover slightly to produce a spray jet (as commonly done when attempting to treat high branches of tree crops) results in a dramatic increase in droplet size[47].

Spray quality matters: a relatively small number of large droplets may represent a large proportion of the spray volume (that could have been turned into a large number of more efficient small droplets). These larger droplets are highly likely to run off leaves, fall back onto the ground ('run-off' or exo-drift) and be wasted. This is a contributory factor to poor or variable efficacy.

The figure below illustrates the enormous variability of variable hollow cone nozzles: with a sample of three nozzles, taken from cocoa-growing areas. Measurements were taken at a relatively high pressure (500 kPa) to emulate farmer practice when attempting to achieve a very fine spray or long throw in the 'jet' mode. Not only is there a 2 to 5-fold increase in Volume Median Diameter (VMD)*, but there is also 60-80% variation in flow rate.

* The VMD or D[v,0.5] is the most commonly used measure of 'typical' droplet side in a spray cloud, measured in µm. 50% of the total spray volume is in droplets of greater diameter and 50% are smaller.



Output (L min^{-1}) and spray characteristics of three variable cone nozzles, used in different cocoa growing areas, using water with a surfactant at 500 kPa. (Note: different number rotations required to change from full cone [minimum] to maximum liquid jet settings). Spray quality is described by measured VMD (diamonds) with the 10% and 90% percentiles by volume ($D_{[v,0.1]}$ and $D_{[v,0.9]}$ as bars).

It follows that **accurate calibration is impossible** with variable cone nozzles. Reliably achieving recommendations on effective dosage is obviously unattainable with such equipment.

Worldwide, millions of dollars have been spent over the past 30 years in order to improve nozzle design and there are a number of established international standards for hydraulic nozzles, such as those that define their fitting to nozzle holders (ISO 8169: 1984). Work has been done to develop a fixed geometry 'cocoa nozzle' by assessing suitable nozzle settings for increasing spray deposition on pods or other relatively narrow targets such as branches[48]. A narrow cone of fine spray can be achieved using disc and core nozzle combinations where a relatively small disc plate is 'overloaded' with an over-rated swirl plate (in terms of the more normal 80 by the manufacturer). In controlled tests, fitting combinations such as a D1.5-25 (or a D3-45 if blockage is likely to be a problem) should greatly improve dose transfer efficiency of contact fungicides for cocoa pod diseases such as *Phytophthora* spp. and *Moniliophthora roreri*. Validation tests have been variable, with good results achieved with farmers (who presumably wish to save on fungicide bills), but difficulties with operators 'trained' to 'spray to run-off': with this idea in mind, the technique simply slowed them down waiting for run-off to occur!

Such technology is of limited value unless accompanied by training: with emphasis on dose transfer efficiency and saving money on pesticides. Unfortunately, in many cocoa growing areas, it can also be difficult to find equipment that complies with basic requirements spraying equipment such as ISO 8169 compliant nozzle holders, so farmers are unable to benefit from the R&D described above.

6.3.3 A simple calibration procedure

There are various methods and devices to aid calibrating manual sprayers; a simple method appropriate for smallholder tree crops is as follows:

1. Place a small volume of clean water into the sprayer tank and operate pump to check for leaks and that the nozzle is operating correctly.
2. Empty the sprayer then put in a known volume - say 5 litres into a 15-litre tank.
3. Spray part of the crop and measure the number of trees treated.
4. This number multiplied by 3 will give the number of trees treated by one tank-load.

5. From this, the number of tank-loads needed to cover the whole of the crop area can be estimated. If 12 tank-loads are needed for one hectare, then the dosage of pesticide per hectare divided by 12 equals the amount that has to be added to each tank-load.

6.3.4 Maintenance and repair

Manual knapsack sprayers are typically maintained by farmers themselves, although there have been Government or cooperative support initiatives. It can be difficult to convince smallholders that it usually pays in the long-term to **choose a good quality, robust sprayer**, as they will always ask the question "**Will I be able to find spare parts for it?**". A few basic extension messages:

Before spraying the farmer should check:

- **Is the sprayer working properly?**
  Before each spray operation, **check** equipment using clean water only
- Are there any faults or blockages? Check pump, valves, filters and nozzle.
- Are there any leakages?
  If spare parts are not available, joints can be repaired with white (plumber's PTFE) tape or rubber seals (can be made out of old tyre inner tubes). Replace worn and leaking hoses.

Leaking sprayers are a problem because of:

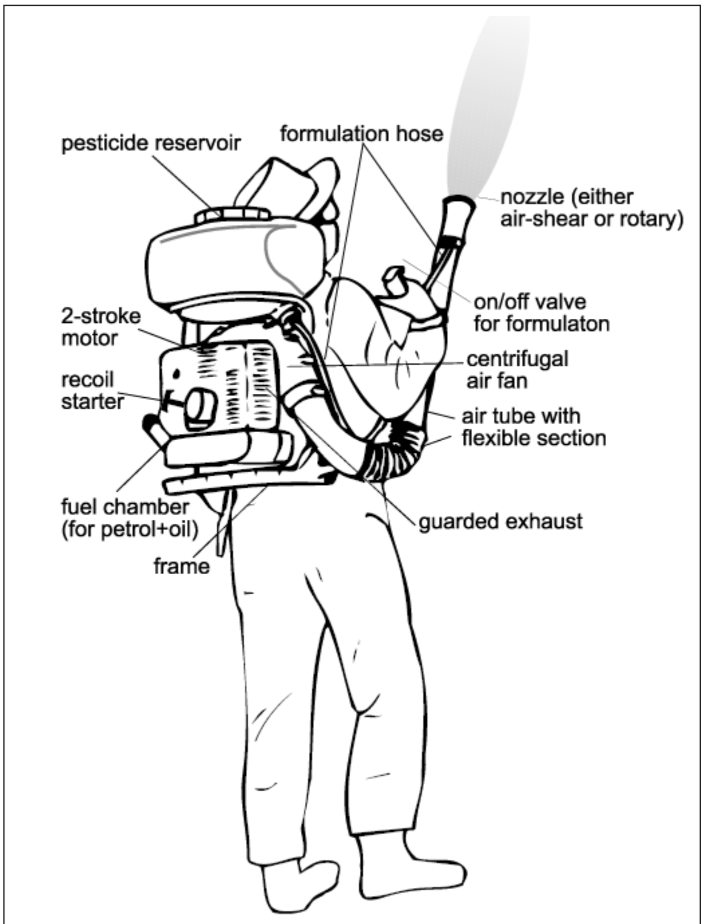
- operator exposure to tank mixture
- incorrect application rates*
- increased soil contamination

* The cost of pesticides is much greater than the cost of spraying equipment, so even within a short period, investment in quality equipment and spare parts should pay for itself.

6.4 Motorised mistblowers

Cocoa was one of the first of the tropical tree crops to use motorised knapsack mistblowers for pest control using a fan to project the spray high into the cocoa trees. It is not uncommon to find trees in excess of 14 metres, but tree height management is strongly recommended for effective IPM. Mistblowers are designed to produce a fine spray or 'mist' and apply lower volumes than conventional knapsack sprayers (e.g. 20-100 L/ha rather than 200-1000 L/ha), many machines can also be adapted to apply granules and dusts, but these are not suitable for cocoa.

Mistblowers are the preferred method of insecticide application for area-wide control of mirids (capsids) and used by CODAPEC* for operational spraying in the most heavily infested parts of Ghana. They are also in widespread use by larger (>4 ha) farms and plantations: where the high initial capital cost of the machinery is offset by a higher work rate, and therefore reduced labour costs[49]. Since their early development in the 1950s, dozens of manufacturers have marketed a wide range of machines: each with different characteristics and a choice of settings for flow rate (output), etc.



A motorised knapsack mistblower in use for spraying cocoa trees

* The Ghana Cocoa Board's National Cocoa Diseases and Pest Control programme or "Mass Spraying Exercise"

6.4.1 Construction

Mistblowers typically consist of a 35 - 70 cc two-stroke engine, which drives a centrifugal fan. The larger size engine is required to drive a fan with a greater output of air volume. These heavier sprayers are needed to spray taller trees, as the greater volume of air emitted can project droplets higher than the small mistblowers. It is rarely possible to project droplets higher than 10m vertically, even with the larger motorised knapsacks.

The engine and fan unit are attached by anti-vibration mountings to a knapsack frame, designed to allow the sprayer to stand upright on the ground. The frame, with straps, also carries a pesticide tank, spray delivery tube, fuel tank and an air delivery hose. A nozzle is mounted at the end of the air delivery tube.

The volume of spray liquid emitted is controlled by a variable or fixed restrictor, and there is an on/off tap also attached to the air delivery tube. The tank is usually of 10-12 litre capacity. Some with larger tanks are made, but the extra weight in addition to the fan and engine, is considered unacceptable. The tank has a wide opening to facilitate pouring liquid into it. The floor of the tank should also slope to a low outlet point. Some air is fed from the fan into the spray tank and usually ducted to the base of the filter at the filler opening to provide low pressure (25 kPa) for delivering the spray liquid to the nozzle. This air pressure is most important if the standard air delivery tube is pointed upwards, when the nozzle may be above the level of liquid in the tank. The large lid on the tank must therefore have an air-tight fit. On some machines, instead of relying on this air pressure, there is a separate pump, which is usually mounted directly on the fan drive shaft. Mistblowers fitted with formulation pumps produce a considerably more reliable flow (especially at low rates) and are easier to calibrate, but retrofitting pumps is expensive (usually >€/$100).

The simplest of mistblowers have a single tube to direct the spray liquid into the high velocity air stream. However, several manufacturers have developed alternative ways of spreading the liquid thinly into the air stream. On some machines, rotary nozzles are fitted; these can provide a more uniform spray droplet size distribution, but the quality and price of these devices vary considerably. Flow rate and air velocity have a major effect on droplet size and mistblowers must always be operated at full throttle.

The flow rate is not determined by the nozzle, but by a restrictor mounted in line with the nozzle. On many sprayers, there is a variable restrictor, often with a number of settings. Users will frequently set this restrictor to the maximum open setting to empty the tank as quickly as possible. This may lead to poor atomisation, so the recommendation is to use a sprayer with separate fixed restrictors. When the appropriate restrictor is in place, it cannot (and should not) be changed by operators in the field.

6.4.2 Maintenance and repair

These engines need specialist maintenance, so their large-scale use should be restricted to areas with qualified mechanics, able to service the equipment. In extensive areas of small farms, mobile workshops are an effective way of assisting users who would otherwise have difficulty in transporting their equipment to a central workshop. One of the most common problems relates to formulation hoses and their joints. Some chemical formulations cause hoses to expand so that they leak: operators (or local stockists) are advised to keep spares of these parts, together with hose clips.

6.4.3 Operation and Calibration

With motorised mistblowers, collection of the spray in an air stream is virtually impossible; simply measuring the flow of liquid in the formulation line past the restrictor will always give a substantial (often >30%) under-estimate of operational flow since there is no tank pressure or "suction effect" at the twin-fluid nozzle. The flow rate can also vary substantially with the angle at which the nozzle tube is directed (e.g. spraying upwards into trees vs. horizontally into crops). Tank pressurisation may thus be inadequate for consistent formulation flow, and we recommend that sprayers should be selected with an independent pump. Accurate calibration involves the following procedure:

1. Place the sprayer on a firm horizontal surface and note (or mark) a level in the upper half of the pesticide tank;
2. make sure that the formulation tap is off; fill the tank with clean water (or blank formulation) to the reference level;

3. start the engine and operate at normal operating speed (full throttle);
4. spray normally, with the nozzle directed at a typical working height and angle (on the crop itself if possible), for a measured length of time (usually 2 minutes);
5. turn the engine off and place the sprayer on the same horizontal surface as in (1);
6. using a measuring cylinder, carefully find out how much water is needed re-fill to the reference mark;
7. calculate flow rate F = volume/time (e.g. 700 ml in 2 minutes = 350 ml/min).

The canopy volume of trees and bushes can vary enormously between cocoa fields at different stages of development. This makes single rates for volume application and amount of pesticide inappropriate (recommended mixing rates for chemical pesticide are therefore usually given as a concentration or ratio rather than per hectare). Spraying may be confined to a single row and the volume per tree calculated on the basis of the time needed to project spray to all sides of a tree. Sufficient time should be given for the volume of air in each tree to be replaced with the air carrying spray droplets.

An examination has been made on how to improve the dose transfer process with motorised mist-blowers by assessing spray to target efficiency[50]. Two spray techniques, every row and alternate row, were examined at different VAR. Comparative deposition on key biological targets, such as cocoa pods, was measured using a spectrophotometric technique with two commercial food dyes for the different application regimes. Based on this work, the most efficient spraying takes place when spray operators are trained to reduce flow rates and walk along every row to improve uniformity of coverage. In practical terms, the reduction in VAR by using flow rates of <0.5x but spraying every row represents a reduction of one tank-load per hectare. The reduced cost of chemical and time reduction for tank-filling may well help to mitigate the unquestionable increase in time taken to walk up every row. However, the greatest benefit should be seen as an increase in the efficiency of the spraying and an increase in uniformity of deposition. This means that there is a greater likelihood of providing efficacious control of pest populations and therefore increases in productivity and quality.

6.5 Personal Protective Equipment (PPE)

For decades, the use of PPE (mask, goggles, gloves, etc.) has been recommended to smallholder farmers to protect them from the effects of pesticides. Whereas PPE should always be used when available, visits to many rural, cocoa growing areas will reveal that equipment is neither used nor available. In addition, PPE is only of value if they are well maintained and worn properly.

Since it may also be too hot to wear heavy protective gear, a rational approach would be to recommend:

- Selection of less toxic products
- Guidelines on minimum standards for personal protection (as opposed to none)
- Appropriate application skills for avoiding exposure when spraying
- Hygiene and cleanliness after application (Good Agricultural and Warehouse Practices: see Chapters 7 & 8)

We reiterate here the importance of extension and other outreach programmes emphasising that **children must not take part in spray operations**: pesticide application must always be treated as potentially hazardous and **children are especially sensitive to pesticides** (see section 2.1.2).

Minimum Personal Protection Measures

- ✓ **Wear a hat** to protect against falling droplets
- ✓ Wear comfortable clothing that protects as much of the body, arms and legs as possible.
- ✗ Never put on previously contaminated overalls or other clothing
- ✓ A face visor is especially important if you are using irritant or harmful pesticides (see box below).
- ✓ Wear trousers on outside of boots

Farmers should be made aware that **it is safer to use no gloves at all than gloves with holes in them.**

If you use a **motorised mistblower** ear defenders are essential.

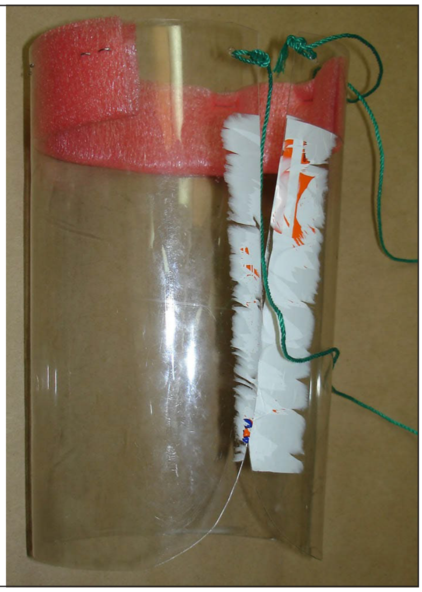
A team of spray operators treating a commercial cocoa plantation. They have been reasonably well equipped with PPE, but can you suggest what might be improved here?

6.5.1 Protection of the face and prevention of droplet inhalation

The use of "masks" to prevent spray droplet inhalation and protection of the operator's nose and mouth is a generally accepted protective measure. It has been understood for a long time that surgical and ordinary cloth face coverings provide incomplete protection, but the COVID-19 pandemic has focused design, development and awareness about commercial masks and quantification of their effectiveness.*

Failing the use of respirators designed for this purpose, inexpensive, comfortable and well-fitting masks can achieve up to 99% filtration and standards have been established: in Europe, the FFP2 standard is recommended for the general public, which is approximately equivalent to NIOSH N95 in the US and KF94 in South Korea; the KN95 "standard" in China lacks strict government regulation and may under-perform.[51]

Face visors protect the face from irritating or toxic sprays, but commercial equipment is expensive and may cost more than €/$20. The INIAP, Ecuador face visor (as shown here) was developed as a very low-cost alternative. It can be made from a 2 L plastic (but not ribbed) soft drinks bottle, tied on with strings.



6.6 Mass spraying and service providers (SSP)

In Ghana, safe and efficient application of insecticides against cocoa mirids, has long been considered best achieved by Government coordinated mass spray campaigns (CODAPEC) since the 1950s: which included provision of materials and training of spray operators. However, there have been technical concerns about this approach and it has been suggested that mass spraying has not contributed to improving income from cocoa.[52] Operational priorities have encouraged calendar spraying (typically August through to December in West Africa) rather than the use of 'action thresholds' for mirid populations, compatible with IPM (see chapter 7). There have long been concerns that the "1950 recommendations on the timing of insecticide application need revising".[53]

As an alternative to these large-scale campaigns on the one hand and the efforts of individual farmers at the other extreme, the concept of Spray Service Providers (SSPs) is to provide greater expertise through training and cooperation at (say) district level. The scheme has been promoted and funded by the World Cocoa Foundation and *CropLife International*, for the benefit of cocoa farmers in Côte d'Ivoire, Ghana, Nigeria and Cameroon. An SSP is typically a farmer who has received special training to apply pesticides and hires out his services to fellow farmers to spray their crops. *CropLife* states that "The purpose of the SSP network is to ensure pesticides are only handled by those that are trained; to reduce the risk towards human health and the environment; to ensure the correct pesticides are used at the right dosage, for effective pest control and increased yields; to plan the purchase of pesticides and avoid the accumulation of obsolete stocks; and to safely dispose of used containers." [54]

* www.wikipedia.org/wiki/Mechanical_filter_(respirator)#Filtration_standards

07 Good Agricultural Practices for Cocoa

This section is for general guidance in training: with suggested 'key messages', and explanation on why they should be prioritised; each sub-section could be an individual training session. **Note**: the term GAP also applies to weeding, fertilizer application and other practices, besides pest management.

DROPDATA reference: these notes have been summarised in the leaflet: *Spraying Cocoa: 10 Essentials*, which is now available in Bahasa, English, French, Spanish, Tok Pidgin and Vietnamese versions.
Download these from: www.dropdata.org/cocoa/training.htm.

This manual is **not** about promotion of pesticides, and it must be emphasised that pest management measures have little or no relevance, if the nature of the pest attack is not understood or if the crop is poorly managed. Responsible Pesticide Use has at least four components:

(i) accurate diagnosis of problems and consequent decision making;
(ii) if their use is needed, the responsible use of pesticides or alternative control techniques;
(iii) choice of appropriate products that are registered for control of that problem and rotation of products to avoid build-up of resistance;
(iv) efficient application to maximise efficacy and minimize costs and impacts on non-target organisms.

7.1 Crop architecture

IPM usually means that farmers must inspect crops regularly, and may involve **sanitary harvesting** to remove diseased infested pods. It is virtually impossible to do this well in very tall crops. Good spraying, to maximise coverage on the biological target, likewise needs well managed trees.

The first message for cocoa farmers ...

Tall trees are very difficult:
- to monitor
- to spray
- to harvest

(Cartoon courtesy J. Cooper, NRI)

Prune trees regularly: reducing the height of tall trees (to 3-4 metres) will make spraying easier, but you may lose a season of crop! This is probably the **most important** pre-requirement for implementing GAP: there are various methods to rehabilitate very tall cocoa, as illustrated below.

Drastic but necessary: cocoa rehabilitation

Left and centre: simple tree height reduction; cuts are made at approximately 1.5 - 2 metres above the ground then treated with copper fungicide. In order to maintain some production, this must be carried out in stages over 4-5 years (e.g. only cut 1/4 of the farm in any one year). ***Right:*** rehabilitation after chupon grafting.
Below: side grafting

7.2 Field pest identification, damage and IPM

This section provides a brief guide to common field problems of cocoa and is not exhaustive. The focus is on the key problems that are regularly sprayed in the field. Application of pesticides is costly and may be risky, so farmers should always attempt to first ask the questions: "What am I trying to control and is it worth the money I will spend?" These decisions will affect selection of the product and how it will be applied.

Some common problems that might be treated with pesticides include:

In younger cocoa

- Weeds
- Termites
- Defoliating insects (grasshoppers, beetles, etc.)

Principal crop production

- Black pod disease (*Phytophthora* spp. - especially *P. megakarya* in West Africa)
- The *Moniliophthora* diseases
- Mirid (capsid) bugs
    - o *Sahlbergella singularis* and *Distantiella theobromae* in Africa
    - o *Helopeltis* spp. in Asia
    - o *Monalonion* spp.in Latin America
- Cocoa pod borer, *Conopomorpha cramerella* in South -East Asia
- Cocoa swollen shoot virus disease (CSSVD)

More information on the individual insect pests, diseases, pesticides to control them, etc. is available on www.dropdata.org/cocoa .

A useful guide for identifying the major cocoa diseases and insect pests is available to download from Plantwise Knowledge Bank available Bahasa, English, French and Spanish for use on mobile phones or printable versions.

7.2.1 The practice and future of IPM for cocoa

With the general push to reduce or limit the use of the most hazardous pesticides in agriculture (i.e. EU Green Deal, discussed in Chapter 1), more emphasis is being placed on IPM for pest management. The EU and FAO define IPM as 'careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. 'Integrated pest management' emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.' The principles of IPM in its simplest form rely on prevention, monitoring and selection of the least harmful interventions.

Since the announcement of the Green Deal and Farm to Fork Initiative, there has been a considerable amount of interest in the application of biopesticides. Biopesticides include a range of substances from living organisms (bacteria, fungi, viruses, nematodes) to natural substances (minerals, plant extracts, fatty acids), semiochemicals (i.e. pheromones) and new technologies such as RNAi. Unfortunately for cocoa farmers, there are currently only a handful of biopesticide options registered for management of cocoa pests and diseases (see Appendix 3). Of the products currently registered for use on cocoa, little is known about their local availability and cost/efficacy in comparison to chemical pesticides. Therefore, at this point in time, is may seem to some a little hasty to reduce the number of 'tried and tested' Ais available for cocoa pest management. There is some light at the end of the tunnel, as part of the Green Deal, the EU has said it will revise legislation to facilitate the use of biopesticides. Currently in many countries, biopesticides must go through the same process of registration as chemical pesticides, so a revision may allow access of commercial biopesticide products to market more quickly.

The availability of a more diverse range of biopesticides will not on its own be a magic bullet, there are other aspects of IPM that need to be addressed and improved if it is to be a successful approach. Monitoring is a critical part of IPM which requires identification of the target pest in order to take appropriate remedial action. The widely used term "economic threshold level" (ETL) is essentially a theoretical concept, so many practitioners prefer "action thresholds": where management should be taken to avoid pest levels reaching economic injury levels. Widely agreed action thresholds do not appear to currently exist for many cocoa pests and management still relies on general recommendations, and a recent report from Ghana55 highlights the issue that a large proportion of farmers are still able to recognise the major cocoa pests and diseases on their farms. In any case, monitoring techniques and action thresholds may be country or more locally specific, and are still subject to unresolved scientific debate.

Three of the most important African cocoa pest problems are:


Mirids (damage)

Black pod disease


CSSVD

On a cautionary note – although both authors subscribe to 'minimum pesticides' approach for management of cocoa pests and diseases, pesticides remain a very important part of the IPM 'toolbox' and must not be excluded prematurely, particularly when no effective substitutes have been identified. Considering the major West African field problems (above), most IPM practitioners would agree that cultural control measures, especially crop sanitation (e.g. diseased pod and chupon removal) provide the principal foundation for pest management; in the case of CSSVD, replanting after complete removal of old trees may be the most realistic long-term solution. However, we would challenge those advocating no pesticide use (including copper compounds) to actually experience smallholders' quandaries: when facing high black pod pressure, for example.

7.2.2 Diseases

Black pod

In many growing seasons, the **black pod pathogen *Phytophthora megakarya*** causes the greatest crop loss in West Africa, the world's most important cocoa growing region. Fungicides, in combination with cultural control methods, are widely used for control of the disease:

- Cultural methods are essential: poor aeration within the crop canopy may encourage the disease, so thinning the canopy can help. Fungicides will only work well in combination with appropriate tree height and canopy management facilitate pod inspections.
- Weekly phytosanitation to remove diseased pods and ideally remove them from the field to reduce the risk of them becoming a secondary source to infection.
- It is important to remove soil on cocoa trunks (soil tunnels are often built by ants on the surface of cocoa trunks). This eliminates two sources of disease: spores carried in infested soil and those carried by the ants themselves.
- Apply appropriate fungicides using correct application methods.
    - o Copper compounds have contact action – so good coverage is essential.
    - o They can be supplied singly, or they may be mixed with ...
    - o Systemic compounds (Table 4.2) including: (a) phenylamides (metalaxyl and benalaxyl), which have long been widely available and are cost effective[56], (b) more recently CAA fungicides (group H5) such as dimethomorph and mandipropamid.

- Make sure that it is worth applying a pesticide. Establish that:
    - o the infestation is above an appropriate action threshold
    - o it is not too late to spray (i.e. if too much damage has already been done – as in this severe attack of P. *megakarya* black pod disease).
    - o With infestations such as the one shown here, the only useful control measure would be to remove and destroy the infected pods and bury them if possible, in order to reduce the release of spores.
- Soil health and general good crop management are essential. Soils contain nutrients for the cocoa trees, but also can harbour the pathogen. Soils with high organic matter and good drainage help prevent inoculum splashing and spreading in puddles of water.
- The hyperparasite, *Trichoderma asperellum* appears to be the most promising biological control agent found to date and was previously available as a commercial product in West Africa, but this no longer appear to be the case.
- Cankers can develop on branches and the main trunk when infection occurs through the pod stalks or from the soil at the base of the trunk. The diseased tissue should be scraped back and treated with fungicide before the infection kills the branch or trunk[57].
- In South -East Asia, *Phytophthora* trunk cankers have been successfully treated by trunk injection of potassium phosphonate.

Cocoa swollen shoot virus disease (CSSVD)

CSSVD is endemic to West Africa and is a new encounter on cocoa. Several different strains of the virus exist, and the most severe strains cause drastic yield losses and tree death in susceptible trees within 5 years. Following a countrywide survey In Ghana in the 1940's, a campaign was implemented to try to eradicate the virus by 'cutting out' or destroying 50 million infected trees. The campaign was ultimately unsuccessful and CSSVD is widespread today in both Ghana and Côte d'Ivoire. Due to the lack of effective control methods for this disease, a similar eradication programme is again underway in West Africa to try and stop the spread of the virus.

The virus is transmitted by several different species of mealybugs (Pseudococcidae) which are tended and redistributed on plants by black ants. As there are currently no direct methods to control the virus itself (apart through breeding for resistance), management strategies have concentrated on control of the mealybug vectors.

Systemic organophosphate insecticides (that are no longer permitted under EU regulations) have been tested for control of the mealybugs, but they were hazardous and had little effect. Although modern insecticides are under test, it is too early to recommend them as an effective control technique, and current research on managing this virus is focused on breeding resistant varieties.

Biocontrol using predators, parasitoids and entomopathogenic fungi has been explored, but not successfully. Classical biocontrol of papaya mealybug has been a success in Ghana using parasitoids from Central America, the area of origin of the pest, but the situation is more complex with CSSVD as the main vector is an indigenous mealybug. Barrier crops (non-host) have been used to try and restrict the movement of the juvenile mealybugs[58], but this requires long-term planning, land and is expensive. Without adequate control measures, eradication being the best current option and a lack of resistant/tolerant cocoa planting material to replace the susceptible plants, it may only be a matter of time before cleared and replanted areas become re-infected again.

Witches' broom (WB)

Causal agent *Moniliophthora perniciosa* is present in South America and the Caribbean and infect cocoa stems, branches, flower cushions and pods causing multiple symptoms, but the most recognisable are the brooms on the branches and pink basidiocarps on dried brooms. Losses can range from 50-90% in the most severely infected areas. The deliberate introduction of the disease into Bahia, Brazil in 1989 resulted in cocoa production falling by more than 50% within 10 years, the economic and social results were devastating for the region.

- The disease is spread through spores produced in the canopy from fruiting bodies that develop on the dried brooms. The spores can move long distances but spread has been associated with movement of infected plant parts i.e. budwood, unlike frosty pod rot (FPR) the disease has also been reported to be seedborne.
- The best combination for management is through a combination of phytosanitation and planting resistant/ tolerant material. Pruning of the infected dry brooms is carried out during the dry season, and the pruned material should be removed from the field and destroyed to prevent the development of the fruiting bodies and reinfection.
- 'Hidden brooms' are difficult to remove so trees should be kept well pruned and a manageable height to facilitate phytosanitary pruning.
- Fungicides are not normally recommended for management of WB, due to the difficulty of targeting multiple infection sites. *Trichoderma stromaticum* is a biocontrol option developed and marketed by CEPLAC, to be sprayed onto the pruned dry brooms to reduce the production of the fruiting bodies in the field.

Cocoa branch in Ecuador: showing pod infected with frosty pod rot (*M. roreri*: **left**) and leaves-twigs killed with witches' broom disease (*M. perniciosa*). The latter may take several forms, including cushion galls (**right**).

Frosty pod rot (FPR)

Fungal disease, *Moniliophthora roreri* related to M. perniciosa, has reduced yields dramatically in Latin America. Although not the most economically important disease in Latin America where it has appeared, it has rapidly overtaken both black pod and witches' broom to become the most serious disease with yield losses of up to 90% in the most suitable climates. Confined to Ecuador and Colombia, the disease appeared in Costa Rica in the 1970's and from there has gradually spread north into Central America, south into Panama and the Amazon. Still in an invasive phase, FPR has been detected in Jamaica in the Caribbean (2016) and in State of Acre in Brazil in 2021.

The disease, unlike WB, only affects the pods of cocoa and can infect the pods at any stage of development. Symptoms can take several weeks to appear and some pods, especially those infected at a later stage, may show no external symptoms. In young pods only, slight swellings may appear and pods 1-3 months old show the classic dark lesions followed by the thick mat of cream-coloured spores. The beans in pods at all stages of infection will rot and be unusable.

- In Costa Rica[59], the oxathiin fungicide flutolanil, which had previously been shown to be efficaceous against WBD in Trinidad[60] and copper-based fungicides provided the most effective chemical control of FPR: but the benefit / cost ratio was limited (approx. 1.7 after 8-10 sprays at 2003 prices). A review of fungicide efficacy against the *Moniliophthora* diseases in Ecuador[61] suggested that asoxystrobin gave at least as good control as the chemical standard (clorothalonil plus copper oxide).
- Classical biocontrol has also been explored using various fungal endophyte. In Costa Rica, *Trichoderma ovalisporum* (oil formulation) in field trials was found to be as effective as flutolanil and copper hydroxide fungicides in managing FPR62.
- To effectively manage FPR, cultural practices remain the best option. Rehabilitate cocoa to reduced tree height to make phytosanitary pruning more effective, maintenance pruning to reduce humidity in the canopy.
- Weekly phytosanitation to remove diseased pods, preferably before they start to sporulate – it is essential that farmers are taught to recognise the earliest symptoms. The cut pods should be covered with leaf litter or piled up and sprinkled with lime or sprayed with 15% urea and covered with plantain leaves.
- Many producers do not effectively manage FPR using cultural methods as labour is too costly.

Vascular streak dieback (VSD)

Ceratobasidium theobromae is an important fungal disease in the South -East Asia and Pacific region, infection causes dieback of the branches. The disease is particularly dangerous for seedlings, but also capable of killing mature trees of susceptible varieties. This is another 'new encounter' disease on cocoa, from an endemic host in the region which as yet has not been identified.


Symptoms of VSD: staining in the tissue of the leaf scar-three brown dots (**left**) and white fungal growth on the leaf veins and stalk (**right**). Curtesy Phil Keane

In addition to leaf chlorosis, internal staining and dieback new symptoms have recently been seen in Indonesia, including leaf necrosis and spore production on the leaf veins and stems, leading to the suspicion that there may be a more severe strain of the disease.

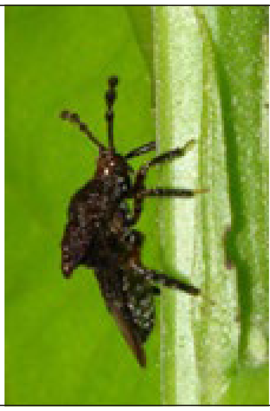
- Management of VSD has centred around planting resistant/tolerant materials, monitoring and phytosanitary pruning to remove affected branches.
- Suitable fungicides are still being investigated to primarily protect young plants in the field and seedlings in nurseries when disease pressure is at its highest – fungicide application to mature trees is not effective or economical at this time.
- Biocontrol is not thought to be an option for management in the field, however, there is a Trichoderma product commercially available in Indonesia for application to the soil which requires further investigation.

7.2.3 Insects

Mirids

Since the beginning of the 20th century, cocoa mirids (*Sahlbergella singularis* and *Distantiella theobromae*: also known as capsids) were reported in West Africa[63]. These insects have become the most damaging insect pests in the region and are thought to cause annual crop losses in excess of 200,000 tonnes. They are an example of 'new encounter' pests - cocoa originated in the Amazon region of South America, and having been introduced to West Africa in the 19th century, became infested with local insects that adapted to a new food source. Similarly, a complex of true bug pests (called **Hemiptera**) adapted to cocoa in South East Asia, including a number of mirid species in the genus *Helopeltis*.

Both nymphs and adults of *S. singularis* and *D. theobromae* cause economic damage to cocoa by feeding on shoots and immature pods by piercing and sucking sap with their needle-like mouth parts. Mirid feeding results in lesions on immature stems, branches and pods which can lead to secondary fungal infections and cankers. Mature pods do not suffer significant internal damage but the classic dark circular feeding lesions are usually the first symptoms that can be seen, younger pods (less than three months old) have less chance of surviving the damage. :


From **left** to **right**: *Sahlbergella singularis* (immature), *Distantiella theobromae, Helopeltis theivora*

Entwistle's book[54] remains the best overview of early development of mirid control measures. Insecticide application techniques on cocoa remain essentially based on experiments that were carried out in the 1960s when the organochlorine gamma-HCH (also called BHC and lindane) was the AI of choice. Two properties, persistence and fumigant action (vp = **4.4 mPa**), helped to overcome inadequacies in application and HCH remained in widespread use until the 1990s. Resistance (see: section 4.6) to this organochlorine by cocoa mirids was detected in the 1950s and, as with other pests, necessitated the development of an **Insecticide Resistance Management (IRM)** strategy. A successful technique has been to interchange the compound with other insecticides, belonging to different MoA groups, in order to reduce selection pressure on a single biochemical pathway. Early screening of chemicals from the 1960s to the early 1990s focused on **carbamates** (IRAC group 1A) and **organophosphorus** (**OP**) compounds (group 1B). Examples of widely used AI included the carbamates: propoxur (vp = 1.3 mPa) and promecarb (vp = 1.4 mPa); the OPs: chlorpyrifos (available as methyl and ethyl compounds), diazinon and pirimiphos methyl and the organochlorine (IRAC group 2) endosulfan (vp = 0.83 mPa). Most of the compounds have **now been withdrawn** and fumigant action is now considered unacceptable in new pesticide development.

- Current management is often achieved with regular applications of pyrethroid (group 3) and neo-nicotinoid insecticides (NNI: group 4A) such as imidacloprid and thiamethoxam. The latter are of interest since they have systemic action and relatively low mammalian toxicities, but concerns have been raised about the possible impact on bees and other pollinators with the nitro-substituted NNI (Table 4.1). Spraying should be based on monthly monitoring of mirid damage but probably occurs on a calendar basis.
- Where outbreaks are limited to defined pockets, 'spot spraying' can be recommended to reduce the quantity of insecticides used.
- Cultural recommendations are to regularly remove chupons, which provide additional feeding and egg laying sites and to maintain a continuous canopy. Where the canopy is broken, new growth encourages mirid feeding – plantain can be planted to quickly close the open canopy.
- The search for alternative control methods continues, with two current lines of research (i) manipulation of mirid pheromones (mating attractants for better monitoring but not control64) and (ii) the use of biopesticides (plant extracts/oils and mycoinsecticides). Pest outbreaks often occur when a species is no longer controlled by its natural enemies (which in the case of Hemipteran insects include specific fungi that are diseases of insects). Mycoinsecticides are often formulated spores of such fungi and can be applied in a similar way to chemicals.
- A 2015 publication from CRIG, Ghana[65] proposes a more integrated/targeted approach for mirid management based on regular monitoring, forecasting and farm-specific recommendations based on levels of mirid damage to reduce the number of insecticide applications throughout the year.

Other Heteroptera: cocoa shield/stink bugs

It is worth noting that *Sahlbergella* and *Distantiella*: (i) contain several species, (ii) are just two of a number of closely related genera (in the tribe Dicyphini, subtribe Odoniellina: all from Africa), and (iii) have apparently taken on relatively different importance at different times and in different cocoa-growing areas. *Helopeltis* and *Monalonion* are also merely in a different subtribe (the Monaloniina) and there remains a possibility that other 'new encounter' or previously unrecognised sucking-pest species may come to light.

Another 'true-bug' pest, apparently becoming more important, includes the large (about 22 mm) green shield bug *Bathycoelia thalassina*, which feeds on developing cocoa pods, with adults especially causing damage to the beans. First encountered in the 1960s[66], the importance of this species might be due to resurgence (section 4.6) resulting from insecticide sprays.

Cocoa Pod Borer

The cocoa pod borer (CPB) *Conopomorpha cramerella* (Snellen) is considered to be one of the most serious cocoa pests in South-East Asia and the Pacific, since it not only causes crop loss but also greatly reduces cocoa quality. The spread of this apparently invasive pest species was a major setback for Malaysian cocoa production[67]. Although it has been argued that its pest status resulted from more than one new encounter with cocoa by this insect, which is endemic on rambutan and other species, recent research at USDA indicates that CPB in South East Asia is genetically very uniform.

Chemical insecticides became widely adopted as CPB control methods in estates until the 1990s, and when the majority of the South -East Asian production shifted to Sulawesi, they continued to be used by smallholder farmers. Extensive work was done during the Malaysian "CPB crisis" in the 1980s, but there has been an almost complete hiatus in pesticide research and development for well over a decade. Since then, agricultural chemistry companies have introduced a number of new molecules, belonging to novel modes of action (MoA) against Lepidoptera, but cocoa is not one of their priority crops for development. Previously, CPB infestations were sprayed with gamma-HCH (BHC) and subsequently endosulfan. As with cocoa mirids, the efficacy of these compounds was partly due to fumigant action, which compensated for inadequacies of application.

Photos top right: damage cause to the beans; **middle**: a moderately infested pod; **bottom**: an adult moth.

- Current techniques for applying insecticides: (i) based on the fruiting season so application is avoided during the time of peak harvest, (ii) monitoring so application is dependent on of CPB damage threshold {iii) all year application on a fortnightly basis (24 applications per year) which is reported to be a popular strategy but increases the risk substantially if resistance management is not taken into consideration[68].
- Compounds currently registered in Indonesia (the greatest user of CPB insecticides by far) include: pyrethroids (alpha cypermethrin, beta cyfluthrin, deltamethrin, lambda cyhalothrin, etc.), chlorpyrifos and, most recently, fipronil. Many farmers in Sulawesi, where most cocoa is grown, typically apply insecticides 3-5 times per year[69].
- The biological target has been broadly defined[70] and targeted spraying of pods and the undersides of near-horizontal branches is a preferred method of application for smallholder farmers.
- Ideally, management of this insect would focus on crop sanitation and regular complete harvesting of pods (Rampasan), but the level of labour and supervision required prevents successful implementation in many areas.
- Other effective techniques all involve the use of plastic sleeves to protect pods. Again, this is very labour intensive and unless the plastic is biodegradable, or if there are recycling schemes available, severe litter problems may occur.
- A number of biological approaches have been explored to manage CPB predators, attractants (pheromones), parasitoids and various entomopathogenic fungi but all are at the experimental stage, although many producers do encourage various predatory ant species on farm, which prey on CPB pupae and disrupt the behaviour of the adult moths.

Defoliating caterpillars

Ghana recently reported an outbreak of Lepidoptera spp. Attacking cocoa pods[71]. Subsequent surveys identified the caterpillars as *Anomis Leona*. Although *A. Leona* is not a new or major pest of cocoa in Ghana, it is known to feed on new growth which appear at the beginning of the wet season. What is concerning about the report from Ghana is the severity of the infestation (96% of trees in some communities) and that there was extensive feeding on pods, which leaves the pods open to secondary fungal infection and direct damage to young pods can stop their development. Severe defoliation can reduce photosynthesis and reduce yields. *A. leona* was also been reported in 2020 as an emerging pest on cocoa in Nigeria, the reasons for the surge in pest numbers in the region is unknow but monitoring in both countries has been advised. The outbreak in Ghana was reported to be successfully managed using the pyrethroid bifenthrin.

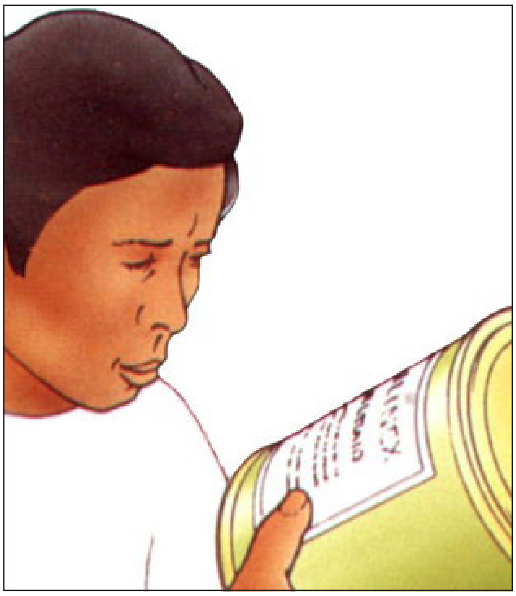
Cocoa fruit borer (Carmenta negra)

Carmenta foraseminis and *C. theobromae* are pod borers found in Latin America and the Caribbean. Not to be confused with CPB (*Conopomorpha cramerella*) which occurs in Asia and the Pacific, the symptoms produced by *C. foraseminis* are very similar to those by CPB, though *C. theobromae* is less damaging. *C. foraseminis* has been reported in Brazil, Colombia, Panama, Peru and Venezuela. The larvae burrow through the pod wall and feed on the beans and mucilage inside, causing very similar damage to CPB.

Larva of *C. foraseminis* and internal damage to the beans (**left**).
Adult moth (**right**).
Courtesy CNCH, Colombia.

One concerning aspect of *C. foraseminis* is that, unlike CPB, it completes its life cycle inside the pod, with the adult emerging, making it more difficult to target the larval stage as a control measure[72]. Observations from Peru[73] and Colombia[74] reported that average yield losses reached between 35 – 50% (respectively) if infestation levels are high. Research in Colombia found that parasitoid releases (*Trichogramma sp.*) and BT (*Bacillus thuringiensis*) were unsuccessful in managing the borer, some clones in the field were however observed to be less susceptible to attack. Application of pyrethroid insecticide every 2 weeks for 4 months significantly reduced losses.

7.3 Pesticide selection



Choose and use only the right pesticide:
think safety first ...and ask yourself "Will it be effective?"...

The lists given in Appendix 3 may help farmers and advisers make their decision: but only after having identified the AI.

Read the label or find out:

- Is this the right product for the job?
- Will it really control the problem? (cheapest is not always best!)
- How much will I need to apply?
- What is the Pre-Harvest Interval (PHI)?

It is important to understand the hazard labelling signs (pictograms) on labels. For products in/from the EU, the new 'CPL' Regulations* have changed hazard pictograms required for chemicals. The old and new signs include:

OLD

NEW

very toxic | harmful/irritant | danger to the environment | flammable | corrosive

If you do not have appropriate personal protective equipment (PPE – see section 6.5)

... DO NOT use hazardous products.

7.4 Application and Post-spray Evaluation

7.4.1 Consider the issues discussed in Chapter 5: especially disposal of old stocks

The withdrawal of recommendations for pesticides often raises questions at Government, distributor, through to farmer levels, about how to dispose of existing stocks of products. The problem should primarily be seen as an administrative one: i.e. **the situation should be avoided in the first place**. With sound policy and administration backed up by appropriate scientific support (see recommendations), future trends in pest control methods can be foreseen: it should be possible to avoid the use of substances which are subject to concern.

Stocks of older compounds should therefore be used up, and withdrawn from the marketplace, long before they are banned. On a small scale, applying older stocks of chemicals to crops is usually considered the most practical way of using them up, provided they are relatively safe and still registered in the country of use. Safe disposal of obsolete chemicals is very expensive and can only take place in one of a limited number of specialist facilities.

The comments above only apply when there is a substantial time to go before withdrawal of a given product. In the context any new regulations concerning residues on imports, readers should be aware of the significant time lag (frequently >1 year) between the cocoa farm and the port of entry, so pesticides (or any other practices) that might cause problems, should not be used during the final season (and preferably for 2 seasons) before the deadline.

* A new method for classifying and labelling hazardous chemicals: Regulation 1272/2008/EC: Classification, Labelling and Packaging of Substances and Mixtures (CLP regulations), was enforceable from December 2010.

7.4.2 Review of Application Methods, PPE, Calibration and Spraying

The previous sections have discussed the many aspects of selection, calibration and maintenance of application equipment. Having made sure your equipment is in good working order, there are several aspects to safe and effective application:

- Assessing the target
- Nozzle selection and setting
- Selection and use of appropriate personal protective equipment (PPE)
- Calibration
- Application technique: how to treat the target?

Where must the spray deposit be put ...

- o pods & trunks?
- o shoots?
- o whole tree canopy?

First, select the right nozzle: if your sprayer has a variable hollow cone nozzle, what setting should be selected? Remember that "overkill" will result in **high residues** and harm to the environment ... as well as **wasting money**.

Variable cone nozzle settings

Squirting with a jet as above is usually wasteful.
Remember: high flow rates mean:
o bigger droplets
o greater risk of run-off
o **wasted money**!

A wide spray cone is good for general canopy treatment, but can be wasteful for pods and narrow branches

For narrow targets like pods and branches, you need a narrow angle of spray.

It pays to Calibrate

Use the right amount of water (volume rate) and pesticide mixture.
Ask yourself the questions:

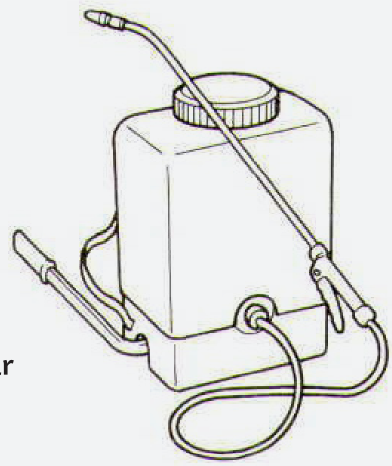
- how many litres can my sprayer tank hold?
- how many trees are treated per tank-load?
- how many tank-loads are required to spray the whole farm?

An example of a label for an insecticide product used in a major cocoa growing country is shown below.

The label states that (i) the recommended dosage is 0.5 L per ha, (ii) 125 ml should be used per sprayer tank-load for 0.25 ha, and (iii) two applications are recommended per year. No reference appears to be made to the volume application rate (VAR) or any standard tank capacity, but presumably refers to motorised knapsack mistblowers. Farmers might actually spray 0.25 ha with one load, but in order to do so correctly still requires a knowledge of how many tank-loads will spray a known area (typically perhaps, the whole farm). Since mistblowers generally have a 10-12 litre capacity (see section 6.4.1.), the VAR should be 40-50 L/ha. Some may claim that this is too complicated for farmers, but discrepencies will result in proportionate overdosing or underdosing of the product. The potential consequences include high residues and poor pest control respectively, so trainers, SSPs and certification staff MUST examine whether this is a common problem within their regions.

After spraying, ask yourself:

- Did you spray the number of tank loads expected?
  If not, why?
- Was it difficult to reach high pods and branches?
  If so - start pruning your trees
- Did the spray operation work?
  ... continue monitoring pests on your crop ...
  ... **if not, change your pesticide, timing or improve your application technique**



Application technique

Only mix as much pesticide as you need for the day
Be systematic: spray evenly and make sure you don't miss any target areas...
...or spray them twice!

Are all the target pests being sprayed effectively?

Is a lot of spray landing in areas that it should not be?

Specifically ...
... is there dripping from the pods or leaves?
... if so, you are spraying too much - reduce your volume application rate.

7.5 Pesticide Containers and Hygiene

- If you use sachets - dispose of them carefully
- If you must recycle pesticide bottles: rinse at least 3 times before disposal. If possible, use the water for rinsing in the next spray tank load
- ✗ Never use your mouth to clean nozzles ... or to prime your sprayer
- ✗ Never eat, drink or smoke while spraying
- After spraying: - clean out the sprayer first - then wash yourself and your clothes, but ...
- ✗ Never dispose of washing water near water sources (use waste ground or discard beneath the cocoa crop, away from children and animals)

08 Good Warehouse Practices

8.1 Cocoa quality standards

FAO gives useful guidance on management of storage pests[75], but in light of new regulations, specific control agents may need to be updated. The Federation of Cocoa Commerce Ltd. (FCC) has issued and updated a *Statement of Best Practice for Managing Infestation and Fumigation*[76]. This document, together with *FCC Superintendents Scheme Code of Practice*, provides information on techniques and procedures for improving cocoa quality.

8.2 Important storage pests

Storage pests[77] known to infest cocoa beans include*:

Warehouse moths (Lepidoptera) especially:		
Cocoa moth (=Warehouse moth)	*Ephestia elutella* (Pyralidae)	
Tropical warehouse moth (= Almond moth)	*E. cautella*	**
Dried fruit moth	*Corcyra cephalonica* (Pyralidae)	**
Beetles (Coleoptera) such as:		
Cigarette beetle (esp. after long storage)	*Lasioderma serricone* (Anobiidae)	**
Corn sap beetle	*Carpophilus dimidiatus* (Nitidulidae)	
Rusty grain beetle	*Cryptolestes ferrugineus* (Cucujidae)	**
Coffee bean weevil (esp. at high humidity)	*Araecerus fasciculatus* (Anthribidae)	
Rust-red flour beetle	*Triboleum castaneum* (Tenebrionidae)	**
Lesser grain borer	*Rhizopertha dominica* (Bostrichidae)	
Rodents	*Rattus* spp.	
Beans infested with warehouse moth larvae Photo: RBP		
Left - Rusty grain beetle *Cryptolestes ferrugineus* Right – Warehouse moth *Ephestia elutella* Courtesy The Food and Environment Research Agency (FERA), York. © Crown Copyright		

* FCC Sampling Rules, FCC Quality Rules: applicable to contracts made after March 2008
**: especially frequent on cocoa.

8.3 The increasing role of non-chemical controls

Established practice, together with more recent research and development[78], has shown that infestations of stored produce can be managed by:

General sanitation: as with most pest control, basic measures must be taken to prevent the carry-over of infestations by cleaning and clearing up debris that can harbour pests.

Maintaining a low moisture content: In most stored crops, if moisture content is reduced to below 8 %, all metabolic activity of any organisms present practically ceases. Drying is therefore a standard treatment before storage, but may require external energy and air movement to evaporate the moisture and remove the resultant water vapour. The energy may be derived from burning fossil fuel or wood (but care must be taken to **ensure that the cocoa beans do not come into contact with smoke**, since this will result in loss of quality and food safety issues), or from solar energy, as in sun-drying. Drying processes are well documented and results can be predicted reliably.

Other methods: such as the use of modified atmospheres (MA), where oxygen availability is reduced and temperature is well controlled (insect activity rises with increasing temperatures up to 42°C). These methods were rarely used in cocoa until steps were taken to withdraw the important fumigant **methyl bromide** (restricted under the International Montreal Protocol Agreement because of concerns about ozone depletion). Treatments involving MAs such as carbon dioxide have been investigated widely and are now seen as acceptable and viable alternative treatments.

8.4 Application and timing of insecticide treatments in storage

Insecticides, including fumigant treatments, are chemical methods for controlling storage insects. The most common methods of application have included:

Admixture of insecticidal dusts with the produce before loading it into the sack. Mixing was carried out in various ways, such as shovel mixing on a tarpaulin or, for large-scale operations, mixing in dust formulations in rotating drums or on conveyor belts. However, these techniques are likely to give rise to potential health hazards and are **no longer recommended** (except for seed treatments where they can be highly efficient).

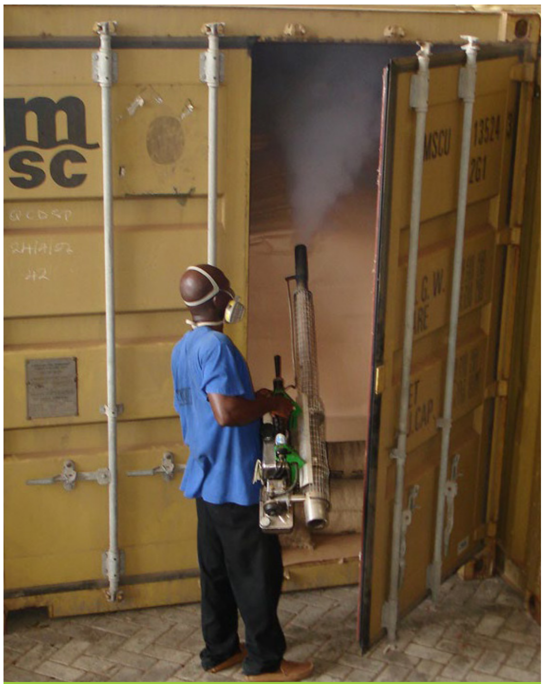
Applying liquid insecticide sprays or dusts to successive layers of sacks as the stack is built. Spraying or dusting successive layers of sacks with insecticides was considered less likely to build up residues, but is not always effective and is **no longer recommended**.

Enclosing a fumigant with the sacks under a gas-proof sheet. This is usually the most effective method of insect control and when used correctly, is safe and least likely to lead to residue problems. **Phosphine (phostoxin)** is a toxic gas that is generated from sachets containing metal phosphides. It is slowly released among bags covered by a gas-proof sheet: which is held down by "sand snakes" or similar weights. With phosphine, the covered stack is typically left for between 5 and 16 days, and then opened up to allow the gas to escape. The time depends on the temperature and the commodity, but is never less than 96 hours (whereas methyl bromide was popular because it was effective in less than 3 days). The Federation of Cocoa Commerce *Statement of Best Practice* provides further details of procedures.

Introduction of fogs into enclosed spaces such as containers. The application of insecticides (e.g. synergized pyrethroids) using thermal foggers is primarily designed to kill flying insects such as warehouse moths that might escape or hatch inside containers.

An issue that may be overlooked is the **treatment of the wooden pallets on which cocoa sacks are stored** - especially for the control of termites. Termite insecticides are often, out of necessity, persistent and toxic and have included chemicals such as chlorpyrifos and fipronil, together with other now obsolete organochlorines. It is now thought that some high residue incidents in produce have arisen from indiscriminate treatment of pallets, and that greater care must be taken in future.

a. Fumigating sacks under sheets with phostoxin-generating sachets (aluminium phosphide)



b. Space treatment with a pyrethroid UL formulation: using a thermal fogger before closing the container

8.5 Pesticide Selection

In the EU, fumigants, rodenticides and other pest-control products used in stores, are also legalised under Biocides regulation EU/528/2012, which entered into force on 1 September 2013 (replacing the Biocidal Product Directive: 98/8/EC). This environmental legislation* covers a very diverse group of products and aims “to provide a high level of protection for humans, animals and the environment”, and harmonise the European market for biocidal products and their active substances.

The following pesticides are known to have been used recently in cocoa warehouses:

Fumigants in IRAC MoA group 24: Mitochondrial complex IV electron transport inhibitors (i.e. insect energy metabolism)	Precursors of the fumigant gas phosphine (PH3 boiling point -87.4°C, v.p. 3465 kPa @ 20°C): aluminium phosphide and magnesium phosphide slowly release PH3 by reacting with moisture.
Fumigants in IRAC MoA group 8: Miscellaneous non-specific (multi-site) inhibitors including halogen-based compounds.	Methyl bromide (B.p. 3.6°C, v.p. 190 kPa): is no longer permitted in the EU and still in the process of being ‘phased out’ in N America and SE Asia. Sulfuryl fluoride (B.p. -55°C, v.p. 1700 kPa): a proposed alternative, is now permitted (Directive 2009/84/EC)
Surface treatments: These must be used with great care to avoid high residue levels. Note: approvals for certain products (including pirimiphos-methyl) for such treatments may soon be revoked in the EU.	Pyrethroids (IRAC group 3): natural pyrethrum, cypermethrin, deltamethrin

Following the withdrawal of methyl bromide in the EU and concerns over residues of non-fumigant insecticides (e.g. admixtures and sack treatments described above), there were grave concerns about increased reliance on the use of phosphine with associated concerns about the onset of resistance. An alternative fumigant currently available, also in IRAC group 8, is sulfuryl fluoride[79] which is now approved in the EU. However, maintaining a diversity of MoA and approaches, including the use of modified atmospheres when feasible, is strongly recommended.

Pest managers also consider factors such as time to penetrate cocoa sacks - thereby the time needed for fumigation. Although phosphine has a higher v.p. than the group 8 fumigants, it is slowly released from phosphide sachets (which provide much safer delivery of toxic, flammable PH_3 gas), so it is considered better for prevention than disinfestation. The latter was reviewed by Chaudry[80], who recommended that phosphine fumigation should only be carried out by trained staff to ensure:

- Acceptable standard of gas-tightness of the area under fumigation
- Appropriately-timed application of optimal doses, and maintenance of the exposure over a minimum required length of time
- Regular monitoring of gas concentrations, to ensure maintenance of effective levels
- Post-fumigation assessment of the effectiveness of each treatment
- Integration with other methods (e.g. surface treatments with approved residual insecticides, or provision of a physical barrier) to reduce the risk of re-infestation during subsequent storage.

8.6 Inspection, sampling, documentation and traceability

The introduction of residue monitoring will clearly add a major new aspect to the implementation of cocoa quality standards. A summary of the complexities of the supply chain can be found on www.icco.org/about/shipping.aspx and improved inspection and monitoring procedures are primarily a matter of concern for cocoa traders and their associations (such as the FCC and CMAA). Reference is made here to rules for sampling and quality as defined by the FCC (www.cocoafederation.com).

In order to pass as high-quality fermented beans, an assessment is firstly made of cocoa bean numbers for a given weight and the proportion of foreign matter. A 'cut test' follows by bisecting them lengthwise through the middle, in order to assess the proportion that are mouldy, slaty (indicating under-fermentation), purple (over fermented), insect damaged, germinated or flat beans. In addition, there are standards for moisture content (typically below 7.5-8%: as determined by International Confectionary Association [ICA] analytical method No. 43), free fatty acids (FFAs: ICA analytical method No. 42) and 'off flavours' (ICA analytical method No. 44).

An analytical laboratory in Côte d'Ivoire showing: early clean-up of cocoa samples (left) and measurement of moisture content (right). Photos courtesy Marc Joncheere, Cargill.

* See: www.ec.europa.eu/environment/chemicals/biocides/index_en.htm (accessed July 2015)

'Contamination' is currently defined as "cocoa which has smoky, hammy or other off-flavour taste or smell, or which contains a substance not natural to cocoa". In the past therefore, the focus has been on contaminants associated with artificial drying of cocoa, but consideration is now being given to other sources that might be introduced at any stage along the supply chain. Beside pesticide residues, monitoring may take place for other contaminants, including presence of:

- mycotoxins, including ochratoxin-A (OTA) - are produced by fungi (and are usually orders of magnitude more toxic than pesticides and may therefore be due partly to failures in pest management),
- poly-aromatic hydrocarbons (PAH) - which can result from cocoa beans coming into direct contact with smoke, for example during artificial drying using badly designed or poorly maintained driers,
- heavy metals (often associated with cocoa grown on volcanic soils or use of poor-quality fertilizers).

The initiatives being put in place to improve **traceability** were described in Chapter 3: Certification. The structure and length of the cocoa supply chain differs from region to region within the same producing country, as well as across producing countries. Methods of warehousing and shipping also vary, which will inevitably influence the point and level of sampling. Not every possible pesticide will be examined in every shipment, of course. Different levels of sampling will take place, according to different criteria and practical considerations (e.g. see section 5.7), but inevitably, it will be necessary to improve traceability of cocoa consignments.

For example, anecdotal reports suggest that the need to control insects has encouraged "risk averse" traders and middlemen to apply pesticides un-necessarily before intermediate points of sale, and thus raise the risk of residues being detected. It follows that review of procedures along the supply chain in cocoa growing countries will be required, in order to avoid a record of 'positive' residue tests.

09 Conclusions

9.1 General

The aim of this manual has been to raise awareness of both general principles and specific, practical issues relating to pesticide use in cocoa. Certain matters will be country specific, some will also involve commercially sensitive information, but it is generally agreed that much needs to be done to improve general knowledge of pesticide science and actual pest management practices.

In particular, the **need for accuracy** cannot be over-emphasised (e.g. the use of international standards, focusing on AI and not trade names and, at the farm level, calibration, etc.). There is much scope for collaboration within cocoa growing regions and for sharing knowledge of pest management practices. The choices may be bewildering at times, but many pest problems are common to adjacent countries. Throughout this manual, we have recommended the need for improved:

- choice of plant protection products
- application methods and timing of treatments
- communication of the above

Establishment of GAP is obviously not just about ensuring correct pesticide use and phasing out obsolete and problematic compounds. There are usually reasons for existing farming methods (be they good or otherwise), and it is very important to learn why they are practiced and by whom they are influenced. The choice of pesticides is nevertheless crucial and the lists of compounds in Appendix 3 have been reviewed on a quarterly basis.

Notes on AI lists in Appendix 3

1. Trade names are not used (they often vary between countries), but several products contain mixtures of AI.

2. Since residues can arise from any point in the supply chain, an AI can only be placed in ONE of the categories A, B, C or D (section 9.2).

3. Compounds for inclusion continue to be reviewed, and special care should be taken with any AI that remains on the "pending" (P) list. Compounds labelled 'M' are subject to the 2013 moratorium in the EU due to risk of bee toxicity.

4. For historical reasons, a number of compounds are recorded as being used on cocoa and have MRL values that are above the default value, yet are not on the list of substances on EC: Annex 1. It is important to appreciate that the authorisation of a pesticide on the EU market and the harmonised pesticide residue legislation (396/2005/EC, which includes MRLs for imported cocoa) are essentially two separate legal issues.

5. In principle, procurement agencies and cocoa growers are encouraged to consider carefully any products containing any AI listed in Appendix 3B and they should not be developed for new markets. However, this list is a 'mixed bag' of compounds that include those:
o that have import tolerances in some markets but not others
o for which no company has considered it economic to prepare and submit an adequate dossier for inclusion in Annex 1 in the EU.
o AI with known issues, but tMRL have been set in the interests of cocoa production and market competition, where a case has been made for continued use of compounds in at least 1 jurisdiction.

9.2 'Strategic cocoa pesticides': criteria

The need for specific guidance, for farmers and warehousemen, cannot be over-emphasised and the method of communicating such messages is important. The use of lists appears to be unavoidable, so the approach suggested here is to identify an **evidence-based**, positive list of '**Strategic cocoa pesticides**' (Appendix 4A) that can be recommended for **specific important pests and stages** in the supply chain. Extra special care is needed for pesticides used against storage pests, in warehouses and in cocoa transport, for reasons described in Pesticide Selection (section 8.5).

The criteria for selecting pesticides, as in Appendix 4, have developed since the first edition of this manual: it proved over-simplistic to divide pesticides simply into 'suitable' and 'unsuitable' for cocoa. As active substances have (and continue to be) phased out, it is vital to: (i) give forewarning about AI that have potential regulatory issues and (ii) help identify effective substitute pest management solutions. In previous editions, lists of promising but experimental control agents were included, that had relevant Codex, EU, Japanese and/or US import tolerances, or are likely to be submitted for registration. Some of these compounds are now placed in lists A or B, with experimental agents still under consideration as discussed in Chapter 7.

We now divide AI that are known to be used on cocoa into three categories, but emphasise that they are for guidance and have no legal status: although any proposal to utilise a substance in list C should be challenged with the utmost scrutiny. Even within a cocoa growing country, various organisations may publish lists of permitted pesticides, even if another institution is responsible (e.g. CocoBod Ghana, Coffee & Cocoa Council Côte d'Ivoire). Cocoa buyers would probably also filter these lists, with respect to those of cooperating certifying bodies (e.g. Rainforest Alliance). The three categories are:

A. List of strategic/registered pesticides for use in cocoa which:

- have relevant EU/Japanese/US/Codex import tolerances; some EU MRL (mg.kg-1) may remain tMRL and their status should be checked regularly; those listed here refer to "Cocoa (fermented beans)" as in Reg. (EC) No 396/2005.
- show acceptable levels of low mammalian toxicity and environmental impact and formulations do not belong to the highest toxicity group WHO/EPA Class I (apart from rodenticides and fumigants supplied as professional products).
- have proven efficacious against an important pest species of cocoa: with registrations in at least two regional cocoa growing countries and publication of trial results in (preferably refereed) scientific literature.

B. Compounds to be used with great CAUTION (limited lifetime, restricted markets, etc).
These active substances:

- are still registered in at least one OECD country (EU, USA, Canada, Australia, Japan...)
- have accepted MRLs in some markets, but not others and/or ...
- are likely to be considered for substitution in the future in EU, but ...
- have shown demonstrable efficacy in at least one regional cocoa growing country
- AI do not belong to WHO/EPA toxicity Class I (and must be Class II formulations or better): apart from rodenticides and fumigants supplied as professional products.

C. Pesticides that MUST NOT BE USED FOR COCOA
Substances that have been recorded as used on cocoa (e.g. by ECA/CABI/CAOBISCO projects), but have been rejected by major importing countries (usually for toxicological/ eco-toxicological reasons) and/or have no residue tolerances in major markets.

9.3 The precautionary principle

Both cocoa producing and consuming countries should benefit from the 'precautionary principle' as an approach to public safety and crop sustainability. Slogans such as the "Green Deal" and "From Farm To Fork" are used to raise public awareness of important issues that range from the safety of a single rural child to threats of climate change. We suggest that the challenges and discrepancies are essentially derived from practical measures that should be soluble, given: (i) awareness of the real technical issues (a purpose of this manual) and available alternatives, (ii) good governance, and (iii) an effective feedback mechanism where both producers and consumers are aware of each other's needs and expectations. For example, a truly "green deal" will only become reality if alternative pest management measures work well for the farmers who have to implement them. Chemicals remain an important part of the IPM mix simply because cocoa is not ready for a 100% biocontrol strategy, and biocontrol only remains a component of IPM. Furthermore, lumping together chemicals as probably hazardous in nature can only be described as a struthious approach. Failure to confront the needs of consumers, genuinely concerned about residues in their food, farmers potentially facing more than 50% crop losses and the risks to children and bystanders in rural producer communities, should never be an option.

9.4 The need for implementation of better pesticide application

The 'strategic cocoa pesticides' concept addresses only the qualitative issue of AI selection, but levels of residue require more attention to application methods and timing. Application techniques and pesticide selection received much attention and extensive research in the 1970s and 80s, but then went out of favour. There is now high-level recognition that supply problems of agricultural commodities in general (not just cocoa) are partly due to neglect of training research for nearly two decades[81]. Chapter 4 may provide assistance for preparation of training materials and identify areas for practical (especially adaptive) research where needed. National Regulatory Authorities are strongly advised to adjust legislation to include the express prohibition of the import and manufacture of sprayers that do not comply with FAO minimum requirements for the quality of application equipment. There must be a means for evaluating sprayers to see if they comply with these standards using the FAO Minimum Requirements*; inclusion of FAO standards for application equipment as well as pesticides has now been adopted in Cameroon.

9.5 Better communication

Pesticides have been "off the agenda" not only in research, but also in many farmer training initiatives. Responsible and scientific pesticide use must be put back on these curricula. Although the de-emphasis of pesticides in publicly-funded programmes is highly understandable, the **loss of pesticide-use skills** at the farm and extension service levels has been alarming. Booklets such as this and farmer training programmes can only provide guidance - they will only be truly effective under a proactive implementation policy framework in cocoa growing countries.

9.6 National and regional action

There is clearly a need to strengthen procedures and recommendations with producer country Registration Authorities. Specific guidelines on the distribution and use of pesticides are freely available from organisations such as FAO[82]. Cocoa growing countries need **pesticide scientists with up-to-date training**, capable of foreseeing issues before they arise. As part of the ICCO-coordinated project '*SPS capacity building in Africa*', organisational responsibilities and initiatives for cocoa quality were identified for a number of African countries and are listed in Appendix 2. A more comprehensive version of this table is available at the ICCO website.

* FAO Minimum Requirements for Agricultural Pesticide Application Equipment, Vol. 1 (2001)

9.7 Roles and responsibilities

National organisations understood to be primarily responsible for pesticide registrations are:

Brazil	Ministério da Agricultura, Brasília
Cameroon	Ministry of Agriculture and Rural Development (MINADER) (Department of Regulation and Quality Control of Inputs and Agricultural Products)
Côte d'Ivoire	Direction de la Protection des Végétaux, du Contrôle et de la Qualité, Ministère de l'Agriculture (DPVCQ/MINAGRI), Abidjan
Dominican Republic	Mostly organic production
Ecuador	Agencia de Regulacion y Control Fito y Zoosanitario (AGROCALIDAD)
Ghana	Environmental Protection Agency (Ministry of Food and Agriculture), Accra
Indonesia	Direktorat Jenderal Perlingdungan Tanaman Pangan, Departemen Pertanian, Jakarta
Nigeria	National Agency for Food and Drug Administration and Control (NAFDAC) HQ: Abuja; cocoa issues: Lagos office
Peru	Servicio Nacional de Sanidad Agraria (SENASA)

Your attention is drawn to comments made in section 5.6 concerning the avoidance of obsolete pesticide stocks. Those responsible in cocoa growing countries are reminded that, for cocoa to be exported to the EU and elsewhere, **the use of inappropriate pesticides must be phased out as quickly as possible**.

APPENDIX I
Technical Abbreviations

The following table lists some technical terms and abbreviations used in pesticide science. A more comprehensive list is given in "Understanding the Acronyms" in the DROPDATA download section.

ADI	Acceptable Daily Intake
AI	active ingredient(s): *CropLife*/FAO convention: also "active substance"
ALARA	As Low As Reasonably Achievable
AOEC	Acceptable Operator Exposure Concentration
AOEL	Acceptable Operator Exposure Level
ARfD	acute reference dose
c	centi-(x 10^{-2}) – as in centimetre (cm) Note: this is not an SI unit
CDA	controlled droplet application
CNS	central nervous system
CMR	substances that are carcinogenic, mutagenic or toxic to reproduction
CXL	Codex Maximum Residue Limit (Codex MRL)
DT50	period required for 50 percent dissipation (define method of estimation)
ED	Endocrine disruptor (~ion) ; previously used for electro-hydro-dynamic spraying
EPA	Environmental Protection Agency (of USA and elsewhere)
g	gram
GAP	Good Agricultural Practice(s)
GMP	Good Manufacturing Practice(s)
GWP	Good Warehouse Practice(s)
GLC	gas liquid chromatography
GLP	good laboratory practice
GMO	genetically modified organism
GSP	good storage practice
ha	hectare (10^4 m^2)
HACCP	Hazard Analysis Critical Control Point (Originally for arms manufacture, later food processing – now extended to the whole supply chain and other production)
HPLC	high performance liquid chromatography (sometimes high pressure ~)
HV	high volume
IPM	integrated pest management
IRM	insecticide resistance management
JMPR	Joint FAO/WHO Meeting on Pesticide Residues (Codex Alimentarius)
k	kilo (10^3) thus Kg – kilogram
K_{oc}	organic carbon adsorption coefficient
K_{OH}	hydroxyl radical rate constant
K_{om}	organic matter adsorption coefficient
K_{OW}	octanol water partition coefficient
L	Litre
LC_{50}	lethal concentration, median
LD_{50}	median lethal dose; dosis letalis media
LOAEL	lowest observable adverse effect level
LOD	limit of determination – has also been used for "limit of detection" (see LOQ)
LOEC	lowest observable effect concentration
LOEL	lowest observable effect level
LOQ	Limit of Quantification: LOQ is now preferred over LOD by JMPR
LV	low volume
µg	microgram (10^{-6} g)
µm	micrometer (micron)
m	metre, milli~ (10^{-3})
M	molar (g. molecular weight), mega~ (10^6)
MC	moisture content
mg	milligram

APPENDIX I
(Cont.)

mL	millilitre
MLD	minimum lethal dose
MLT	median lethal time
mm	millimetre
mM	milimolar
MoA	mode of action
mol	mole (usu. G molecular weight)
MRL	maximum residue level
MSDS	material safety data sheet
nd	not detected
NEDI	national estimated daily intake
NEL	no effect level
ng	nanogram
NOAEC	no observed adverse effect concentration
NOAEL	no observed adverse effect level
NOED	no observed effect dose
NOEL	no observed effect level
OP	organophosphorous pesticide
p	pico˜ (10^{-12})
Pa	pascal (1 bar = 100 kPa)
PBT	persistent Bioaccumulative Toxic chemicals
pH	pH-value ($\approx -\log_{10}\{[H^+]/[1 M/L]\}$)
PHI	pre-harvest interval
PIC	prior informed consent
po	by mouth (per os)
POP	persistent organic pollutants
Pow	partition coefficient between n-octanol and water
ppb	parts per billion (10^{-9})
PPE	personal protective equipment
ppm	parts per million (10^{-6})
QPS	quarantine pre-shipment (fumigation)
QSAR	quantitative structure-activity relationship
RfD	reference dose
RH	relative humidity
RPU	Responsible (or rational) pesticide use
SAS	Self-Assessment System (EDES)
SI	Système International – International standard units for measurement
SOP	standard operating procedures
sp	species (only after a generic name)
TLC	thin layer chromatography
TMDI	theoretical maximum daily intake
tMRL	temporary maximum residue limit
ULV	ultra low volume
UV	ultraviolet
VAR	volume application rate
VMD	volume median diameter or D[v,0.5], measured in µm.
vp	vapour pressure (in mPa)
vPvB	very persistent, very bioaccumulative
<	less than
≤	less than or equal to
>	greater than
≥	greater than or equal to
°C	degree Celsius (centigrade)

APPENDIX 2
Organisational Responsibilities for Cocoa Quality by Country

Function	Cameroon	Côte d'Ivoire
Overall responsibility for food safety La responsabilité globale de la sécurité alimentaire Responsabilidad general por la inocuidad de los alimentos	Ministry of Industry, Mines and Technological Development (MINMIDT), Department of Standardization and Quality (DSQ) sets norms.	Direction de la Protection des Végétaux, du Contrôle et de la Qualité (DPVCQ/MINAGRI§)
Authority responsible for registration and use of pesticides Autorité chargée de l'enregistrement et l'utilisation de pesticides Autoridad responsable del registro y uso de plaguicidas	MINADER§ coordinates 10 other ministries under CNHPCAT	DPVCQ/MINAGRI
Authority responsible for establishing maximum residue levels (MRLs) Autorité responsable de l'établissement limites maximales de résidus Autoridad responsable de establecer los límites máximos de residuos (LMRs)	MINADER§ (as above), Ministry of Scientific Research and Innovation; IRAD; Ministry of Trade (MINCOMMERCE)	DPVCQ/MINAGRI Direction de Production Vivriere et la Securité Alimentaire (DPVSA) Codex Committee
Main national/federal laboratory responsible for food control Principal laboratoire national chargé du contrôle des aliments Principal laboratorio nacional/federal responsable del control de alimentos	Laboratoire National d'Analyse et des Diagnostiques (LNAD : of MINADER§)	Laboratoire Central d'AgroEcotoxicologie du Laboratoire d'Appui au Développement Agricole (LCAE/LANADA)
Other important laboratories responsible for food control D'autres laboratoires importants responsables du contrôle alimentaire Otros laboratorios importantes encargados del control de los alimentos	Centre Pasteur du Cameroun (health: arbitration) HYDRAC (private), LCA/ONCC (Laboratoire Central d'Analyse)	Laboratoire National de Santé Public (LNSP) LANEMA
Main laboratory responsible for development of analytical methods for residues Laboratoire principal responsable du développement de méthodes analytiques pour les résidus Laboratorio principal responsable del desarrollo de métodos analíticos para residuos	LNAD: of MINADER§ will soon have ISO accreditation and accredit other labs. LCA/ONCC	LCAE/LANADA
Main organization responsible for applied research regarding pesticides for cocoa pests Principale organisation responsable de la recherche appliquée sur les pesticides pour les ravageurs du cacao Principal organismo responsable de la investigación aplicada en plaguicidas para plagas del cacao	IRAD and MINADER: Department of Regulation and Quality Control of Inputs and Agricultural Products	Centre National de Recherche Agronomique (CNRA)

Ecuador	Ghana	Indonesia	Nigeria
Ministerio de Salud Pública (MSP), Ministerio de Agricultura y Ganadería (MAGAP)	Food & Drugs Authority (FDA) (previously Food & Drugs Board)	Badan Pengawas Obat dan Makanan (BPOM)/National Agency for Drug and Food Control (NADFC); Kementerian Pertanian/Ministry of Agriculture (MoA)	National Agency for Food and Drug Administration & Control (NAFDAC)
Agencia de Regulación y Control Fito y Zoosanitario (AGROCALIDAD)	Environmental Protection Agency (EPA)	Directorate General of Agricultural Infrastructure and Facilities under the Kementerian Pertanian/Ministry of Agriculture (MoA)	NAFDAC: HQ: Abuja; Cocoa practice: Lagos
AGROCALIDAD Codex Committee	Ghana Standards Authority (GSA – formerly GSB); Codex Committee	MoA; Kementerian Kesehatan/Ministry of Health (MoH); regulated by the National Standards Agency (BSN); National Codex Committee	Codex Committee: (adapts international standards): includes SON and NAFDAC
Laboratorios de Referencia, Agencia Nacional de Regulación, Control y Vigilancia Sanitaria (ARCSA); Laboratorios de Diagnóstico de los Alimentos y Control de Insumos Agropecuarios (AGOCALIDAD)	FDA and GSA	BPOM	NAFDAC (with SON)
LASA (private), LABOLAB (private), Multianalityca (private)	Food Research Institute (FRI), CSIR, Accra (ISO 17025 accredited)	none	none
Laboratorios de Diagnóstico de los Alimentos y Control de Insumos Agropecuarios (AGOCALIDAD)	GSA	BSN (proficiency testing with private accredited laboratories)	NAFDAC
INIAP	Cocoa Research Institute of Ghana (CRIG)	Pusat Penelitian Kopi dan Kakao Indonesia/Indonesian Coffee and Cocoa research Institute (ICCRI)	Cocoa Research Institute of Nigeria (CRIN)

Function	Cameroon	Côte d'Ivoire
Main organization responsible for applied research regarding pesticides for cocoa pests Principale organisation responsable de la recherche appliquée sur les pesticides pour les ravageurs du cacao Principal organismo responsable de la investigación aplicada en plaguicidas para plagas del cacao	IRAD and MINADER: Department of Regulation and Quality Control of Inputs and Agricultural Products	Centre National de Recherche Agronomique (CNRA)
Institution acting as Codex contact point Institution qui agit comme point de contact du Codex Institución que actúa como punto de contacto del Codex	Cameroon Codex Commission - under MINMIDT (Department of standardization and Quality)	Direction des Productions Alimentaires et de la Diversification § (DPVSA/MINAGRI§)
Institution acting as SPS contact point (if different) Institution qui agit comme point de contact SPS (si différente) Institución que actúa como punto de contacto (SFS) (si es diferente)	MINADER	DPVCQ/MINAGRI
National association of pesticide manufacturers/ distributors Association nationale des fabricants de pesticides et les distributeurs Asociación nacional de fabricantes/distribuidores de plaguicidas	CropLife Cameroun: Douala and Yaoundé	1. CropLife Côte d'Ivoire (also Regional~) 2. AMEPHCI (Association des Petites et moyennes entreprises de Côte d'Ivoire)
Responsibility for Hazard Analysis Critical Control Point (HACCP) analysis of the cocoa supply chain La responsabilité de l'analyse des risques et maîtrise des points critiques (HACCP) analyse de la chaîne d'approvisionnement du cacao Responsabilidad del análisis de peligros y puntos críticos de control (HACCP) de la cadena de suministro del cacao	Conseil Interprofessionnel du Cacao et du Café (CICC) & ONCC (MINADER proposed)	DPVCQ/MINAGRI
Recent legal and regulatory documents concerning SPS Récentes des documents juridiques et réglementaires concernant SPS Documentos legales y reglamentarios recientes sobre SFS	Law on phytosanitary protection. Regulations on pesticide registration procedures, management and plant quarantine; Schedule of pesticides forbidden for cocoa	- Décret n°99-272 (6/4/1999) fixant les modalités du conditionnement du cacao à l'exportation; - Décret n°89-02 sur l'homologation et l'utilisation des pesticides *

Ecuador	Ghana	Indonesia	Nigeria
INIAP	Cocoa Research Institute of Ghana (CRIG)	Pusat Penelitian Kopi dan Kakao Indonesia/Indonesian Coffee and Cocoa research Institute (ICCRI)	Cocoa Research Institute of Nigeria (CRIN)
Servicio Ecuatoriano de Normalización (INEN)	GSA	Badan Nasional Standardisasi (BSN)/National Standardization Agency of Indonesi	Standards Organisation of Nigeria (SON): now has residue laboratory
AGROCALIDAD	Plant Protection and Regulatory Services Directorate (PPRSD) of MOFA§	Center for Plant Quarantine and Biosafety, Indonesia Agricultural Quarantine Agency, Central Office of Ministry of Agriculture	ditto
CropLife Latin America	CropLife Ghana	CropLife Indonesia	CropLife Nigeria
Laboratorios de Referencia, Agencia Nacional de Regulación, Control y Vigilancia Sanitaria (ARCSA)	CRIG, FRI and GSA	BPOM	NAFDAC
Decisión 804 - Modificación de la Decisión 436 (Norma Andina para el registro y control de plaguicidas químicos de uso agrícola)	Act 528, Pesticides Control & Management Act (1996)	Ministry of Agriculture Regulation No. 55/2016 sets MRLs for pesticides for fresh foods of plant origin	TBD

Function	Cameroon	Côte d'Ivoire
Organisations primarily responsible for implementing Good Agricultural Practices (GAP) in cocoa Organisations principalement responsables de la mise en œuvre de bonnes pratiques agricoles (BPA) dans le cacao Organizaciones principalmente responsables de implementar Buenas Prácticas Agrícolas (BPA) en cacao	MINADER (cocoa SPS project): IRAD, NCCB; Cocoa Development Society (SODECAO); various cooperatives of producers. Commission Nationale pour l'Homologation des Pesticides et la Certification des appareils de Traitements (CNHPCAT)	DPVCQ/MINAGRI et ANADER (Agence Nationale d'Appui au Développement Rural) ANADER; Conseil du Café et du Cacao
Organisation(s) responsible for implementation of good storage/ warehousing practices (GWP) for cocoa Organisation (s) responsable de la mise en œuvre de bonnes stockage / entreposage pratiques (GWP) pour le cacao Organización(es) responsable(s) de la implementación de buenas prácticas de almacenamiento/ depósito (GWP) para el cacao	Office National du Cacao et du Café (ONCC = National Cocoa and Coffee Board NCCB) certify CICC member produce; MINADER responsible for treatments	MINAGRI, Conseil du Café et du Cacao ANADER
Available list of pesticides registered for cocoa? Liste disponible sur les pesticides homologués pour le cacao ¿Lista disponible de plaguicidas registrados para cacao?	Yes - 28 Mar 2021	Yes – Aug 2021
Main organisation responsible for providing information on quality standards to cocoa producers Principale organisation responsable de fournir des informations sur les normes de qualité pour les producteurs de cacao Principal organismo responsable de brindar información sobre estándares de calidad a los productores de cacao	ONCC / CICC	DPVCQ/MINAGRI, Conseil de Café et de Cacao
Organisations advising on mitigation of mycotoxins, PAH, FFA, heavy metals, etc. Les organisations de conseiller sur l'atténuation des mycotoxines, HAP, FFA, les métaux lourds, etc. Organizaciones que asesoran en la mitigación de micotoxinas, HAP, AGL, metales pesados, etc.	ONCC / CICC / MINADER: with the help of resource persons (scientists and researchers at IRAD)	MINAGRI, CGFCC, ANADER Fonds Interprofessionnel pour la Recherche et le Conseil Agricoles (FIRCA: www.firca.ci)

§ Ministère de l'Agriculture, Ministry of Agriculture; Ministry of Agriculture and Rural Development (Cameroon: Department of Regulation and Quality Control of Inputs and Agricultural Products); Ministry of Food & Agriculture (Ghana)
* Also : (1) Arrêté intertdisant l'utilisation de certaines matières actives en agriculture (2) Note circulaire suspendant l'utilisation de certaines matières actives en cacaoculture

Ecuador	Ghana	Indonesia	Nigeria
INIAP	CRIG, CODAPEC CSSVD/CU of Cocobod; Quality Control Company Ltd. (QCCL: with 3 laboratories)	ICCRI	CRIN: Farmers Field Schools (FFS): especially via STCP; also, formal extension service
INIAP	QCCL	ICCRI	Federal Produce Inspection Service (FPIS)
Yes – Oct 2021	Yes – Dec 2021	Yes -	(May 2012)
AGROCALIDAD	QCCL	BSN	CRIN
AGROCALIDAD Ministerio de Agricultura y Ganadería (MAGAP)	CRIG/FRI, GSA and FDA under codex. (National surveys being undertaken to determine extent of problems) QCCL	BPOM BSN	Federal Ministry of Trade and Investment?

APPENDIX 3

Indicative list of AI of registered products in some major cocoa-growing countries

The following table may be incomplete but gives an indicative list of active substances registered for cocoa in major producing countries. Comprehensive online data from South America (registrations "in cocoa culture") comes from Ecuador, the largest producer; other sources include Brazil and Colombia.

	MoA§		C. d'Ivoire	Ghana	Indonesia	S. America	Cameroon
"Fungicides"	B1	benomyl			*		
Single AI	B1	Carbendazim †				* († Brazil)	
	C3	azoxystrobin				*	
	C3	pyraclostrobin				*	
	C5	fluazinam		*			
	E3	procymidone				* (Brazil)	
	G1	difenoconazole			*		
	G1	hexaconazole			*		
	G1	propiconazole			*		
	H5	dimethomorph			*		
	H5	mandipropamid	*		*		
	M1	copper hydroxide	*	*	*	*	*
	M1	copper oxide	*		*	*	*
	M1	copper oxychloride	*	*			
	M1	copper sulphate	*		*	*	*
	M2	sulphur			*		*
	M3	mancozeb	*		*		
	M3	metiram			*	*	
	M4	captan				* (Brazil)	
	M5	chlorothalonil			*	*	
	P7	fosetyl-aluminium				*	
	P7	phosphoric acid			*		
	P7	potassium phosphonate	*				
	U27	cymoxanil			*		
	§ FRAC – accessed Sept. 2021						

	MoA§		C. d'Ivoire	Ghana	Indonesia	S. America	Cameroon
"Fungicides"	A1	benalaxyl-M	*			*	*
In mixtures :	A1	metalaxyl (including -M)	*	*	*	*	*
	B1	carbendazim			*		
	B5	fluopicolide			*	* (Brazil)	
	C2	boscalid				*	
	C3	azoxystrobin			*	*	
	C3	fluoxastrobin	*			*	
	C3	kresoxim-methyl				* (Brazil)	
	C3	pyraclostrobin					*
	C3	trifloxystrobin			*		
	C5	fluazinam		*			
	C8	ametoctradin	*				*
	F4	propamocarb	*			* (Brazil)	
	G1	cyproconazole				*	
	G1	difenconazole			*	*	
	G1	flutriafol				*	
	G1	propiconazole			*	*	
	G1	myclobutanil				*	
	G1	tebuconazole			*	*	
	G1	triadimefon				*	
	H5	dimethomorph	*	*			*
	H5	flumorph	*				
	M1	copper compounds various	*	*		*	*
	M3	mancozeb	*		*	*	
	M3	propineb			*		
	U27	cymoxanil	*		*	*	*

APPENDIX 3
(Cont.)

	MoA§		C. d'Ivoire	Ghana	Indonesia	S. America	Cameroon
Biological, botanical & misc. control agents							
		anarcadic acid			*		
		azadirachtin	*				
		diallyl disulfide - garlic extract			*		
		hydrogen peroxide				*	
	BM1	cinnamaldehyde + eugenol				*	
	BM1	*Melaleuca alternifolia* extract				*	
	BM2	*Bacillus amyloliquefaciens* is.D747					*
	BM2	*Bacillus subtilis* (isolate det.)				*	
	BM2	*Bacillus amyloliquefaciens* is.QST713	*				
	BM2	*Bacillus subtilis* is.IAB/BS03	*				
	BM2	*Trichoderma* sp			*		
	BM2	*Equisetum arvense* extract	*				
Total products			**98**	**23**	**35**		**59**
of which mixtures			**80**	**12**	**10**	**-**	**41**
Notes, dominant products		† carbendazim banned in Brazil (Aug 2022), but may be available in Colombia	Cu oxide + metalaxyl (34 products)	19 copper-based prods: 10 single AI	10 mancoz-eb-based prods: 5 single AI	FPR/WB fung. esp. trizoles, cymoxanil + mancozeb	53 copper-based prods: 17 single AI

	MoA§		C. d'Ivoire	Ghana	Indonesia	S. America	Cameroon
Insecticides							
Single AI	1A	BPMC, fenobucarb			*		
	1A	carbaryl			*	*	
	1A	carbofuran			*	* (Brazil)	
	1A	carbosulfan			*		
	1A	methomyl			*	* (Brazil)	
	1A	MIPC, isoprocarb			*		
	1A	propoxur			*		
	1A	thiodicarb			*		
	1B	acephate			*	* (Brazil)	
	1B	chlorpyrifos ethyl			*	*	
	1B	diazinon			*		
	1B	fenitrothion			*		
	1B	triazofos			*		
	2B	fipronil	*		*	*	*
	3A	alpha-cypermethrin		*	*		
	3A	beta-cyfluthrin			*		
	3A	beta-cypermethrin			*		
	3A	bifenthrin	*	*	*	*	
	3A	cypermethrin			*		
	3A	deltamethrin	*		*	*	
	3A	esfenvalerate			*		
	3A	etofenprox		*	*		
	3A	fenpropathrin			*		
	3A	fenvalerate			*		
	3A	lambda-cyhalothrin			*		
	3A	permethrin			*		
	3A	pyrethrins, pyrethrum	*	*			*
	4A	imidacloprid	*	*			*
	4A	thiamethoxam	*	*			*
	4C	sulfoxaflor	*	*			
	6	abamectin	*		*	*	
	6	emamectin	*				
	9B	pymetrozine	*				
	14	thiosultap-sodium, dimehypo			*		
	12C	propargite				* (Brazil)	
	28	chlorantraniliprole (CTPR)			*		

	MoA§		C. d'Ivoire	Ghana	Indonesia	S. America	Cameroon
Insecticides							
In mixtures:	1B	chlorpyrifos ethyl	*		*		
	1B	profenfos	*				
	3A	beta-cyfluthrin		*			
	3A	bifenthrin	*	*		* (Brazil)	*
	3A	cypermethrin isomers	*	*	*		*
	3A	deltamethrin	*	*			*
	3A	fentrothion		*			
	3A	fenvalerate		*			
	3A	lambda-cyhalothrin	*	*		*	*
	3A	pyrethrins, pyrethrum		*			
	4A	acetamiprid	*	*			*
	4A	dinotefuran	*				
	4A	imidacloprid	*	*		*	*
	4A	thiacloprid	*				*
	4A	thiamethoxam	*	*	*		*
	4C	sulfoxaflor (isoclast)	*				
	4D	flupyradifurone	*				*
Insecticides (std.)	5	spinetoram	*				
	6	emamectin benzoate	*	*			
	7	pyriproxyfen	*				
	15	novaluron	*			* (Brazil)	*
	15	teflubenzuron	*	*			*
	22	indoxacarb	*	*			
	23	spirotetramat	*				
	28	chorantraniliprole					*
Fumigants	24A	aluminium phosphide	*	(GWP regs)		*	
	24A	magnesium phosphide				*	
	UN	azadirachtin	*				
Biological &	11A	*B. thuringiensis + Serratia sp.*			*		
botanical		*Beauveria bassiana*			*		
		capsaicin		*			
		essential oil (citrus)	*				
Total products			**256**	**37**	**85**		**68**
of which mixtures			**206**	**18**	**7**	**-**	**41**
Notes, dominant products		NNI + pyrethroids (187 prods); only imidacloprid: 28		Single AI NNI & pyrethroids (9 mixtures)	Cypermethrin (20 prods), 44 pyrethroids		NNI + pyrethroids (37 prods)

	MoA§		C. d'Ivoire	Ghana	Indonesia	S. America	Cameroon
Rodenticides							
anti-coagulants:	1st G	warfarin, coumatetralyl, chlorophacinone, etc.	*ˇ		*		
	2nd G	brodifacoum, bromadiolone, difenacoum, flocoumafen, etc.	* (ditto-not only cocoa)	under GWP	*	*	*
	inorganic:	zinc phosphide, etc.			*		
Herbicides	Ø	MSMA	*				
Single AI	2	metsulfuron methyl	*				
	2	triasulfuron			*		
	4	MCPA				*	
	4	triclopyr butoxyethyl ester	*				
	5	diuron	*			*	
	9	glyphosate-isopropylammonium	*	*	*	*	*
	9	glyphosate-potassium	*		*		
	10	glufosinate-ammoniu	*		*	*	
	14	oxyfluorfen			*		
	22	diquat (dibromide)				*	
	22	paraquat (dichloride)			*	*	
In mixtures	4	2,4-D amines	*		*		
	9	glyphosate salts	**		*		
	4	triclopyr butoxyethyl ester			*		
	5	terbuthylazine	*				
	14	flumioxazin	*				
Total products			**>180 ** **	**1**	**36**		**none reg.**
of which mixtures			**-**	**-**	**6**	**-**	**-**
Notes, dominant products		** none registered for cocoa, but usage for "Toutes Cultures" & "Plantations" - dominated by glyphosate			glyphosate based products: 20; paraquat: 6	Paraquat products common	not cocoa: "Cultures diverses"

ˇ Public health product: not registered for cocoa

Appendix 4.A Lists of strategic / recorded active substances for use in cocoa

These AI conform to the criteria described in section 9.2 (updated: 29/10/2022)

(i) black pod diseases

Active ingredients	MoA group	EU status	EU MRL	JP MRL
benalaxyl M (only isomer)	A1	Y *	0.05	(0.01)
metalaxyl (unresolved)	A1	Y µ *	0.1	0.2§
metalaxyl-M (mefenoxam)	A1	Y µ	0.1	0.2§
Permitted strobilurins including:				
azoxystrobin	C3	Y	0.05	(0.01)
pyraclostrobin	C3	Y	0.1	
ametoctradin (Ω)	C8	Y	0.05	
pyrimethanil	D1	Y	0.05	
dimethomorph (DMM)	F5	Y	0.05	(0.01)
Mandipropamid	F5	Y	0.06	0.06

(ii) insects

Active ingredients	MoA group	EU status	EU MRL	JP MRL
As sprays (against Mirids, CPB)				
Permitted OPs & pyrethroids incl.:				
malathion	1B	Y	0.02	
pirimiphos methyl	1B	Y **ε	0.05	0.05
cypermethrin – isomers (not α) β	3	Y *	0.1	
deltamethrin β	3	Y	0.05	0.05 δ
lambda-cyhalothrin β	3	Y *	0.05	0.01
Permitted nAChR mods. including:				
acetamiprid	4A ξ	Y	0.1	(0.01)
sulfoxaflor	4C	Y	0.05	0.05
emamectin benzoate	6	Y	0.02	
spirotetramat	23	Y	0.1	
chlorantraniliprole (CTPR)	28	Y	0.1	0.08§

(iii) weeds and stump treatments

Active ingredients	MoA group	EU status	EU MRL	JP MRL
triclopyr δ	O	Y	0.1	0.03
glyphosate salts	G	Y	0.1	0.2

(iv) stored produce etc.

Active ingredients	MoA group	EU status	EU MRL	JP MRL
aluminium phosphide ***	24	Y	0.05	(0.01)
magnesium phosphide ***	24	Y	0.05	(as PH_3 : phosphine)
sulfuryl fluoride	8	Y	0.02	(as fluoride ion)
pyrethrins (pyrethrum) for fogging	3	Y	0.5	(0.01)
pyrethroids (treating sacks, etc.)	3	**if Y** as above and registered for purpose		
Registered **rodenticides** ***	(anti-coagulants – see list B and text)			

Appendix 4.B Compounds to be used with CAUTION (limited lifetime, restricted markets, etc.)

These AI:

- have permitted MRLs in some markets, but not others and/or ...
- may have have registration in at least one major cocoa growing country
- may have **temporary** (tMRL§) or strong possibility of phasing-out within coming years, but ...
- have shown demonstrable efficacy in at least one regional cocoa growing country
- do not belong to WHO/EPA toxicity Class I

(i) diseases

Active ingredients		MoA group	EU status	EU MRL	JP MRL
clorothaloni	δ	M5	N	0.05	0.05

(ii) insects

Active ingredients		MoA group	EU status	EU MRL	JP MRL
fenobucarb (BPMC)		1A	N *ø	(0.01)	0.02
MIPC, isoprocarb		1A	N *ø	(0.01)	0.02
diazinon		1B	N	0.02	
dimethoate		1B	N	0.05	0.01
fenitrothion		1B	N *	0.05	
chlorpyrifos (ethyl)	β	1B	N	0.01	0.01
bifenthrin		3	N	0.1	0.1§
beta-cyfluthrin	β,T	3	N	0.1	0.1
clothianidin	χ	4A	N	0.02	0.02§
imidacloprid		4A	N	0.05	0.05§
thiamethoxam		4A	N	0.02	0.02§
thiacloprid		4A ξ	N	0.05	
novaluron	π	15	N	(0.01)	(0.01)
pymetrozine		9B	N	0.1	
teflubenzuron	π	15	N	0.05	0.02
Useful especially for termite control					
fipronil	Y, β	2	N	0.005 Y	0.01

(iii) weeds

Active ingredients	MoA group	EU status	EU MRL	JP MRL
2,4-D dimethylamine salt	O	Y *	0.1	0.01
picloram	O	Y	0.01 (T)	(0.01)
paraquat, diquat δ	D	N	0.05 (T)	0.05

(iv) stored produce etc.

Fumigants ***	MoA group	EU status	EU MRL	JP MRL
methyl bromide **μ**	8A	N	0.01	& US:
(as inorganic bromide ion)			70.0	50.0
Rodenticides * **	(anti-coagulant – see text)			
brodifacoum,	3	N	(0.01)	(0.01)
bromadiolone, difenacoum	8A	N	(0.01)	(0.01)
warfarin (coumaphene)	24	N	(0.01)	(0.01)

Key

*	High residue levels have been found in imported produce to the EU and/or Japan (**: >10 cases since 2008)
***	High mammalian toxicity: to be used only by qualified personnel
§	Now to be tested in Japan after removal of shell (testa); Japan MRLs in brackets assumed to be at default.
M	Current moratorium on use in the EU due to suspected bee toxicity
α	No MRL given in Japan and copper is exempt in the USA
μ	Metalaxyl includes mixtures of all constituent isomers including metalaxyl-M (sum of isomers)
β	Registered (widely used) for cocoa pod borer control in Indonesia
ξ	Cyano-substituted neo-nicotinoid
δ	Includes deltamethrin and tralomethrin (as total)
π	Usually sold as a mixture (co-formulated with a pyrethroid)
σ	Mostly for stump treatments in CSSVD eradication
β	Chlorpyrifos is banned in Europe and persistent enough to present significant residue risk. Registered for cocoa pod borer control in C. d'Ivoire and Indonesia.
T	Toxicity of AI in class 1b, but still registered in some jurisdictions
Y	Fipronil (sum fipronil + metabolites). Five degradation products are known, depending on the mode of break-down: fipronil-sulfone, fipronil-sulfide, fipronil-desulfinyl, fipronil-amide, and fipronil-detrifluo-romethyl-sulfinyl. Fipronil is not permitted for use as spraying in the EU or USA and has generally permitted only for targeted applications such as baiting, in-furrow and seed treatments; however, it has been registered for spraying CPB (above) and mirids in 2 African countries.
ε	Use of pirimiphos methyl in cocoa is no longer defended by Syngenta; zero tolerance (i.e. LOD) for this AI in Australia.
δ	US MRL of 0.05
χ	Clothianidin appears to have had little use in cocoa to date, but for residue analysis note: Naeun et al (2003)[83]
μ	Restricted under the Montreal Protocol; to be phased out by EPA (mostly by 2017)

π Usually sold as a mixture (co-formulated with a pyrethroid)

ø P pesticides are used outside the EU but for which no toxicological data and no MRLs have been notified for inclusion in 396/2005/EC Annex III (neither by the member states, in the form of import tolerances, nor by third countries). Such compounds may have a clear purpose outside Europe (e.g. fenobucarb: which is widely used for control of hemipteran pests of rice in Asia, and has also been applied to cocoa in certain countries).

Appendix 4.C Pesticides that MUST NOT BE USED for cocoa

Active ingredients	MoA group	EU, MRL status 1 and notes
As sprays (against Mirids, CPB)		
acephate	1B	N
amitraz	19	N Ĵ
aldrin	2	N Φ Class 1
azinphos-methyl	1B	N Class 1
butocarboxin	1A	N
cabaryl	1A	N
carbofuran	1A	N Class 1 as spray formulation
carbosulfan	1A	N
cartap	4C	N
chlordane	2	N Φ
chlorpyrifos (methyl)	1B	N
cyhalothrin (unresolved)	3	N α
cyhexatin (acaricide)	12B	N Ĵ
DDT	3	N Φ (may be used against malaria: IRS)
dichlorvos (DDVP)	1B	N Class 1
dieldrin	2	N Φ Class 1
dioxacarb	1A	N
endosulfan	2	N Φ (MRL 0.1 mg/kg) ** Class 1
endrin	2	N Φ Class 1
fenthion	1B	N
fenvalerate	3	N **
hexachlorocyclohexane (HCH): all isomers	2	N * Φ
including lindane (a.k.a. gamma BHC)		
isoprocarb (MIPC)	1A	N Φ
methidathion	1B	N
methyl-parathion (= parathion-methyl)	1B	N * Class 1
methomyl	1A	Y β Class 1
methamidophos	1B	N
methidathion	1B	N
monocrotophos	1B	N Class 1

Appendix 4.C (continued)

nicotine	4B	N Class 1
permethrin	3	N
profenfos	1B	N *
promecarb	1A	N Class 1
propoxur	1A	N
terbufos	1B	N Class 1
thiodicarb	1A	N
triazophos	1B	N
tralomethrin	3	N
trichlorfon	1B	N

Herbicides		
ametryn	C1	N
atrazine	C1	N*
chlorpropham	K2	Y*
fomesafen	E	N
MSMA (methyl arsenic acid)	Z	N
2,4,5-T	O	N Ĵ

Fungicides		
benomyl	B1	N δ
captafol	M4	N Ĵ
hexaconazole	G1	N
pyrifenox	G1	N
triadimefon	G1	N
tridemorph	G2	N
zineb	M3	N

Stored produce		
allethrin (esbiothrin)	3	N
bioresmethrin	3	N
ethylene dichloride, ~ dibromide		N
fenitrothion	1B	N *
isoprocarb (MIPC)	1A	N ø
permethrin	3	N **
resmethrin	3	N
tetramethrin	3	N

Rodenticides		
arsenic compounds e.g. sodium arsenite	inorganic	N
cyanides: calcium, hydrogen, sodium	inorganic	N
sodium fluoroacetate (1080)	inorganic	N ø

[1] Compounds not included on 91/414/EEC Annex 1 and are not thought to be essential for cocoa production. However, it is important to note that several of these compounds have MRL above the default level.

* High residue levels have been found in imported produce to the EU and/or Japan (**: >10 cases since 2008)

Cocoa growers are strongly advised to stop using any products containing AI on this list. They may have been used previously for cocoa pests, but there should now be recommended substitutes: if this is not the case, please notify the author.

They include:

Φ All pesticides listed in the Stockholm (persistent organic pollutant or POP) Convention. In addition to the AI listed above, this includes compounds such as: chlordecone (kepone), heptachlor, mirex, toxaphene, etc. (never recorded on cocoa).

● Obsolete and banned compounds (e.g. promecarb).

α Note: unresolved cyhalothrin is not included on Annex 1, but the isomer lambda-cyhalothrin (used for mirid control) is permitted and registered in cocoa growing countries. Gamma-cyhalothrin is pending approval.

Ĵ Compounds specifically listed at LOD for cocoa in Japan

ø P pesticides are used outside the EU but for which no toxicological data and no MRLs have been notified for inclusion in 396/2005/EC Annex III (neither by the member states, in the form of import tolerances, nor by third countries). Such compounds may have a clear purpose outside Europe (e.g. fenobucarb and isoprocarb: which are widely used for control of hemipteran pests of rice in Asia, and have also been applied to cocoa in certain countries).

β Also breakdown product of thiodicarb: which is not approved in the EU.

δ Breaks down into the permitted compound carbendazim.

CAOBISCO: Association of the Chocolate, Biscuit & Confectionery Industries of the EU	https://caobisco.eu/
CABI	http://www.cabi.org
CABI BioProtection Portal	https://www.cabi.org/publishing-products/bioprotection-portal/
Certification bodies involved with cocoa traceability and GAP	
The Fairtrade Foundation	http://www.fairtrade.net
The Rainforest Alliance	https://www.rainforest-alliance.org/
Codex Alimentarius	https://www.fao.org/fao-who-codexalimentarius/en/
Official standards	https://www.fao.org/fao-who-codexalimentarius/codex-texts/list-standards/en/
Pesticide MRLs	https://www.fao.org/fao-who-codexalimentarius/codex-texts/dbs/pestres/en/
Cocoa Merchants Association of America (CMAA)	http://www.cocoamerchants.com/
COLEACP (horticultural GAP project)	http://www.coleacp.org/
CropLife International	http://www.croplife.org/
European Cocoa Association (ECA)	www.eurococoa.com
European Commission (Directorate General for Development and Directorate General for Health and Consumer Affairs [DG SANCO])	
EU legislation on MRLs	https://ec.europa.eu/food/plants/pesticides/maximum-residue-levels/eu-legislation-mrls_en
EU legislation on plant protection products (PPP)	https://ec.europa.eu/food/plants/pesticides/legislation-plant-protection-products-ppps_en
QC procedure	https://www.eurl-pesticides.eu/library/docs/allcrl/AqcGuidance_Sanco_2000_3103.pdf
European Initiative for the Sustainable development in Agriculture (EISA)	https://leaf-eisa.frb.io/
European and Mediterranean Plant Protection Organization (EPPO)	https://www.eppo.int/
Extension Toxicology Network, Pesticide Information Profiles	http://extoxnet.orst.edu/pips/ghindex.html
Food and Agriculture Organisation (FAO)	http://www.fao.org/
Understanding the Codex	http://www.fao.org/docrep/w9114e/W9114e04.htm
Global Forum on Agricultural Research (GFAR): (enhancing national capacities to adapt and transfer knowledge: hosted by FAO)	https://www.gfar.net/
JMPR: technical monographs	http://www.inchem.org/pages/jmpr.html
Federation of Cocoa Commerce (FCC)	http://www.cocoafederation.com/
Health & Safety Executive (UK formerly PSD)	https://www.hse.gov.uk/pesticides/
International Cocoa Organisation (ICCO)	http://www.icco.org/
International Union of Pure and Applied Chemistry Pesticide Properties Database, Hatfield, University of Hertfordshire	http://sitem.herts.ac.uk/aeru/iupac/
International Pesticide Application Research Centre (IPARC)	http://www.dropdata.org
Guidelines on cocoa pests and IPM	http://www.dropdata.org/cocoa/cocoa_prob.htm
Japan MRL list was (updated 2018)	http://www.m5.ws001.squarestart.ne.jp/foundation/note_en.htm

Joint Cocoa Research Fund (ECA & CAOBISCO)	https://jointcocoaresearchfund.eu/
Organic production IFOAM	http://www.ifoam.org/
Mars Inc. (sustainability team)	http://www.cocoasustainability.mars.com
Pesticide Action Network International	http://pan-international.org/
Examples: pesticide residue analysis (contract) available from CEMAS, UK:	https://www.cemas.co.uk/services/agrochemical/agrochemical-residues/
The Massachusetts Pesticide Analysis Laboratory (MPAL)	http://www.vasci.umass.edu/outreach/umass pesticide laboratory
Resistance Action Committees: useful for MoA classification & information about resistance:	
Fungicides	http://www.frac.info
Insecticides	https://irac-online.org/
Herbicides	https://www.hracglobal.com/
Rodenticides	http://www.rrac.info/
USA: Food and Drug Administration (FDA) guidance (2005) on pesticide residues	https://www.fda.gov/food/chemicals-metals-pesticides-food/pesticides
US Environmental Protection Agency (EPA): The Food Quality Protection Act (FQPA)	https://www.epa.gov/laws-regulations/summary-food-quality-protection-act
World Health Organisation (WHO)	http://www.who.int
Guidelines for predicting dietary intake of pesticide residues	https://www.who.int/foodsafety/publications/chem/en/pesticide_en.pdf

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