Food and Agriculture Organization of the United Nations

General guidelines for developing and implementing a regional integrated pest management strategy for fall armyworm control in demonstration countries

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Contents

Acknowledgements

Africa; Mr David Hughes, Associate Professor of Entomology and Biology, Penn State University, Pennsylvania, USA and a TWG chair; Ms Vera Ros, Assistant Professor Wageningen University & Research, Wageningen, Netherlands; Mr Stephan Winter, Head of Department Plant viruses Leibniz-Institut DSMZ, Braunschweig, Germany; Mr Paul Jepson, Director of Technical Operations Oregon State University, Corvallis, USA and a TWG chair.

Representing NGOs/Civil Society: Ms Sheila Willis, Head of International Programmes Pesticide Action Network (PAN UK), Brighton, UK; Mr Mel Oluoch, Regional Director, SASAKAWA Africa Association, Kenya; Mr Emmanuel Okogbenin, Director of Technical Operations, African Agricultural Technology Foundation, Nairobi, Kenya; Mr Hans Mattaar, Technical Director, AgroCare, Brussels, Belgium; Mr Andrew Ward, Stewardship Director, Crop Life International, Brussels, Belgium; Ms Roma Gwynn, Vice-President, IBMA International Bio-pesticides Manufacturers Association, Brussels, Belgium.

Representing Development Partners: Mr Robert Bertram, Chairperson of the Technical Committee, Chief Scientist United States Agency for International Development (USAID), Washington, D.C., USA; Mr Chris Dale, Assistant Director, Plant Health Surveillance and Diagnostics Program Plant Health Policy Branch, Biosecurity Plant Division, Australian Department of Agriculture, Water and Environment; Mr Hatem Fellah, Principal agronomist, African Development Bank (AfDB), Regional Bureau, Dakar, Senegal; Mr Christophe Larose, Head of Sector, Sustainable Agriculture, (DG INTPA), European Commission (EC), Brussels, Belgium; Ms Panagiota Mylona, Policy Officer, DG SANTE, European Commission (EC), Brussels, Belgium; Ms May-Guri Sæthre, Senior Adviser, NORAD; Mr Neil Hausmann, Senior Program Officer, Bill & Melinda Gates Foundation.

Representing farmers: Mr Eduardo Cruz Rojo, farmer.

FAO participation: Ms Ismahane Elouafi, Technical Committee Vice Chairperson, FAO Chief Scientist; Mr Jingyuan Xia, Director, Plant Production and Protection Division (NSP); Mr Rémi Nono Womdim, Deputy Director, NSP; Ms Elisabetta Tagliati, Chief Technical Advisor, NSP; Mr Buyung Hadi, Agricultural Officer, NSP; Mr Yang Puyun, Agricultural Officer, Research and Extension Unit, Office for Innovation (OINR); Ms Rosanne Marchesich, Senior Emergency and Rehabilitation Officer,

1. Background

These guidelines provide a framework for the development of regional strategies aimed at managing fall armyworm (FAW) by developing evidence-based integrated pest management (IPM) packages. Of particular value is the list of various IPM options given in Tables 1-3. A narrative outline of IPM tactics is provided in Appendix 1.

Demonstration countries are asked to provide background documentation concerning the maize agro-ecosystems and FAW biology in each of the demonstration countries specifically; and in the demonstration zones in general.

1.1 MAIZE AGRO-ECOSYSTEMS

Describe the maize agro-ecosystems of the demonstration country specifically; and the demonstration zone in general. Include information on latitude, longitude, altitude, average temperature and average annual rainfall of the major maize growing areas and their duration.

1.2 MAIZE PRODUCTION SYSTEMS

Describe the total acreage of maize in the demonstration country (in hectares), its proportion relative to total maize area in the demonstration zone, and percentage of maize relative to arable land in the country. Describe the cropping calendar, cropping systems (e.g. rotational and/or intercropping patterns), common irrigation methods, common fertilizing system, and average farm size (in hectare) per major agro-ecosystem.

1.3 FALL ARMYWORM BIOLOGY AND HISTORY

Describe evidence-based or anticipated FAW biology in the demonstration country that is relevant for management decisions, such as the possible number of FAW generations per year, natural enemies reported in the country, extent of FAW infestation seen in previous years, average crop yield loss

and known host plants, for each major agro-ecosystem. Describe seasonal migration pattern(s), if known. Describe the history of FAW detection and the direction/progress of the spread across the country and the current situation (e.g. how many provinces or states are affected out of the total provinces/states).

1.4 CURRENT MANAGEMENT PRACTICES

Describe the current FAW management practices widely adopted by farmers in the demonstration country and zone. Provide an estimate of effectiveness of each of the practices (wherever such data has been rigorously collected) and the source of the estimate. Describe the level of training received by farmers and extension agents in the country. For all products that have received regulatory approval for FAW use, list the current availability and use of synthetic and biological pesticide active ingredients, including the percentage of farmers using pesticides, if possible. Comment on the current availability and use of FAW pheromone traps at the country and farmer level.

1.5 MAJOR CHALLENGES

Describe major challenges in achieving sustainable and effective management of FAW in the demonstration country and zone. Include challenges in terms of coordination, resources, capacities in technical validation and extension, technological availability/affordability and farmers' capacity.

2. Objectives

2.1 REDUCE YIELD LOSS

Describe the country-level target indicator for yield loss reduction (e.g. yield loss due to FAW infestation is reduced to, on average, less than 5 percent in the demonstration plots and, on average, less than 10 percent in the demonstration countries).

2.2 REDUCE NEGATIVE ENVIRONMENTAL OUTCOMES

Describe the country-level target indicator for environmental outcomes of effective control methods for FAW management (e.g. pesticide application frequency reduced by 50 percent, application of the most hazardous pesticides reduced; and availability and use of safer biological and synthetic pesticides increased, natural enemy diversity and abundance increased compared to current farmers' practice, and increased planting of crop seeds with enhanced host plant resistance to FAW).

2.3 ENHANCE SOCIO-ECONOMIC OUTCOMES

Describe the country-level target indicator for socio-economic outcomes associated with better maize protection from FAW (e.g. increased farm profitability by 20 percent).

2.4 ENHANCE FARMERS' AND NATIONAL COORDINATION CAPACITIES FOR INTEGRATED PEST MANAGEMENT

Describe the country-level target indicator for capacity enhancement: both at individual level (e.g. farmers' use of effective IPM options for FAW management increased by 20 percent); and at the institutional level (e.g. establishment of a national task force for a critical pest; a number of new policies to support adoption of IPM options).

3. Integrated pest management action

3.1 PREPARATION

Explain in detail the preparations and costs for monitoring and management action across organizational levels. This may include the purchase of monitoring traps and pheromone lures; organizational arrangements and financial resources for monitoring (e.g. parties setting up the traps, validating identification, submitting, aggregating and analysing data); steps taken to make IPM options available at the local level, identify gaps, if needed.

3.2 MONITORING, SCOUTING AND EARLY WARNING

Describe the monitoring and scouting technologies and methods in detail (e.g. field scouting protocol, trapping, searchlight, radar, type of traps, density, reading frequency, maintenance, costs, etc.) to be used for the demonstration country. Explain the timing of the monitoring activities relative to the crop calendar. Expound on the methodology used to aggregate and analyse data to formulate early warning and recommendations. Describe the channels engaged to transmit early detection, scouting instructions and early warnings, and recommendations to farmers.

3.3 INTEGRATED PEST MANAGEMENT SCHEME

Detail IPM options currently available, and to be made available, at country level; arrange the activities sequentially across the maize growth stages, starting from pre-planting (e.g. seed and varietal selection, decision for intercropping, minimum tillage and mulching, etc.). Ensure coverage of the following IPM interventions: deployment of high-quality seeds and, where available, FAW-resistant seeds, best agronomic practices, including plant diversity and conservation biological control, augmentative biological control and risk reduction in biopesticide and pesticide use. Refer to the IPM pyramid in Appendix 1 and to Tables 1 to 3 to guide the selection and prioritization of the technologies and management practices.

4. Technology evaluation, demonstration, advisory services and training

4.1 EVALUATION OF NEW TECHNOLOGIES

Describe the new technologies/approaches to be tested in research plots and scaled up in the demonstration country for the next two years. Explain the methodology, such as the experimental design and protocol, data collection and analysis plan. Please note that there is a robust transferability of a number of management methods that have already been verified across Africa and Asia in the last four years.

4.2 ESTABLISHMENT OF FIELD DEMONSTRATION PLATFORMS

Describe the plan to establish field demonstration platforms in the demonstration country. Each platform consists of a large-scale demonstration with side-by-side comparison of best-bet technologies versus conventional practice. Mention candidate locations, size of the demonstration platforms, farmer-led experimental fields and the candidate technologies to be implemented and adapted on the platforms. Detail the demonstration protocols. List potential partners and their prospective roles.

4.3 ADVISORY SERVICES AND CAPACITY BUILDING PLAN

Describe the advisory services and training plan leveraging the innovation platforms. Methodologies such as the farmer field school (FFS), farmers' field days, extension and/or advisor training and mass communication campaigns using traditional media (e.g. TV, radio and print). More innovative channels (e.g. social media, text messages) should also be engaged. Detail the plan for cascading training from national, provincial and county levels. Estimate the target number of people reached through these methods and channels in the demonstration country. Plan for regional training events (in person or virtual events, as conditions allow) to share lessons learned with pilot countries in the demonstration zone.

5. Synthesis of global assessment of fall armyworm integrated pest management options

The three tables below represent an assessment of FAW technologies organized following an IPM approach as exemplified by the IPM pyramid presented in Appendix 1. Table 1 represents approaches taken prior to, or at, planting which align with standard Good Agricultural Practices (GAP) and contribute to FAW control. Table 2 lists technologies for use in controlling FAW infestations throughout the maize crop cycle. Each technique and technology is scored for its efficacy, safety (human, animal and environmental), cost, accessibility and scalability. Generally speaking, practitioners do not recommend mitigation technologies that result in less than 80 percent larval mortality and many do not recommend mitigation efforts that result in less than 90 percent larval mortality. In all cases, practitioners rarely recommend interventions which have not demonstrated efficacy as a function of protection from yield loss. Accordingly, assessments based on differences in damage ratings or percentage if parasitism, for example, while useful in research and development do not meet mitigation recommendations for farmers. Finally, Table 3 represents technologies requiring more research before they can be recommended for farmer use. In general, a weight of evidence (more than one or two research papers) is required before a technology or approach can be recommended.

The techniques and technologies listed in Tables 1 and 2 are examples of each IPM tactic and are not meant to form an exhaustive list of all globally available measures. Each technique and technology is scored for its efficacy, safety, costs, accessibility and scalability. The information on the scoring system is given in the footnotes for both tables. While all criteria should form important considerations in evaluating the techniques and technologies, the safety criteria – especially those of human and animal safety, as well as environmental risk and compatibility with conservation biocontrol – are especially important to low-resource farmers. They may lack protective equipment and may have to rely more on conservation biocontrol for managing this pest. Technologies scoring 0 in Table 2 are, relatively speaking, less hazardous for farmers and are more likely to be compatible with conservation biological control. On the other hand, technologies scoring 1 or higher in Table 2 would need some mitigation to ensure full human, animal and environmental compliance. IPM measures in these tables are meant to work together, thus a lower level of efficacy for a single measure should not be used as a standalone decision-making guide on implementing the measure.

TABLE 1. Good agricultural practices used in maize cropping systems

	Technology	IPM tactics	Efficacy[1] (scale: 1–5)[2]	Safety		Costs of product[4]			Accessibility		
				User safety PPE	Environmental risk/ compatible with biocontrol (scale: 0-3)[3]	Direct cost single treatment	Direct cost season	Indirect cost	Policy	Infrastructure/ supply chain (Scale 1-3)[5]	Scalability[6]
1	FAW resistant maize	Host plant resistance	Fair to good	1	0	Unknown	Unknown	Planting	Regulated	1	1
2	GM maize	Host plant resistance	Excellent	1	0	Unknown	Unknown	Planting	Regulated	1	1
3	Balanced fertilization using both organic amendment and inorganic fertilizer	Agro-ecology	Good	1	0	Variable	Variable	Variable	Unregulated for organic amendment, regulated for inorganic fertilizer	1	1
4	Mulching	Agro-ecology	Fair to good	1	0	Variable	Variable	Unknown	Unregulated	1	2
5	Minimum tillage	Agro-ecology	Fair to good	1	0	Unknown	Unknown	Weed management	Unregulated	1	2
6	Intercropping, including push-pull system	Agro-ecology	Fair to good	1	0	Variable	Variable	Planting multiple crops	Unregulated	1	1
7	Field margins (e.g. maintaining wild plants on the field margin)	Landscape management/ biological control	Good	1	0	0	0	None known	Unregulated	1	1
8	Habitat diversification in the farm level (e.g. introducing trees to the farm)	Landscape management	Good	1	0	Variable	Variable	Planting and maintaining multiple crops	Unregulated	1	1

1. Assessments for efficacy, safety and compatibility with biocontrol are derivative works of Jepson, P.C., Murray, K., Bach, O., Bonilla, M.A., Neumeister, L. 2020. *A Global Guideline for Pesticide Selection to Reduce Risks, and Establish a Minimum Pesticides List.* 23 August 2019. SSRN: https://ssrn.com/abstract=3441822 or http://dx.doi.org/10.2139/ssrn.3441822. Efficacy levels were assigned as: E = excellent (90–100 percent control); G = good (80–90 percent control); F = fair (70–80 percent control); P = poor (<70 percent control); Yellow cell with red stripes = efficacy unknown—more research needed. IPM measures in this table are meant to work together, thus a lower level of efficacy for a single measure should not be used as a standalone decision-making guide on implementing the measure.

2. User safety as measured in terms of personal protective equipment needs is rated as follows: level 5 is the maximum level of protection needed while level 1 is the minimum requirement. The requirements for each level of protection are: 5 - Highly Hazardous Pesticides (HHPs) – maximum protection required; 4 - high-risk pesticides requiring maximum PPE with engineering and behavioural mitigations; 3 - high-risk pesticides requiring double-layer PPE, plus eye and/or respiratory protection; 2 - lower-risk pesticides requiring single-layer PPE, plus eye and/or respiratory protection; 1 - lower-risk pesticides requiring maximum personal protective equipment (PPE).

3. Compatibility with biocontrol/environmental risk was assessed, using a 4-point scale taking into account environmental risk assessments conducted on aquatic organisms, terrestrial animals and pollinators where a risk would require some kind of mitigation. A risk of 0 results when no risks were observed in any of the three categories while a risk of 3 results when risks were determined in all three categories. It is important to note that frequently risk, even high risk, can be mitigated through a variety of approaches. Accordingly, an effective technology carrying some risk could still be a viable option if there is a reasonable means to mitigate the risk.

4. Costs: In as much as the numerical costs listed here are available, they are provided by B.M. Prasanna and colleagues at CIMMYT India with a collection date of October 2020. An arbitrary scale was developed for comparative purposes with green bracketing (USD 52-USD 82), yellow bracketing (USD 83-USD 114) and red bracketing (USD 114-USD 144).

5. Infrastructure rating scale: 1 - requires no special storage and/or cold chain conditions; 2 - requires special storage and or cold chain conditions; 3 - requires special storage and/or cold conditions as well as infrastructure such as transportation.

6. Scalability rating. For technologies with commercialization potential (e.g. resistant varieties, augmentative release of biocontrol agents): If the private sector is already producing and offering a product for sale (realizing the need for addressing regulatory issues), then consider that technology fully scalable (a score of 1). If the technology requires a logistics stream, e.g., cold chain, then the potential for scaling over poorly developed rural areas is diminished and if the complexity of the technology is too high, then widespread adoption may be a challenge (a score of 2). Finally, if the technology requires infrastructure and maintenance investment from the public sector, then the potential for scaling is greatly diminished (a score of 3). For techniques (e.g. agro-ecological tactics), it is essentially knowledge and practice that we are trying to scale. So, scalability for techniques can be divided into geographic/socio-economic applicability and diffusion speed. Diffusion speed is determined by (i) availability of prior knowledge of the intervention across the target region, including locally tailored options; (ii) complexity of the intervention – how difficult is it to educate farmers for adoption; (iii) cost/benefit, including co-benefits to the farmer; (iv) scope of integrating the intervention into ongoing development initiatives. Locally tailored options that are relatively simple with co-benefits to farmers and ongoing development initiatives are scored as 1. Options that are relatively complex and thus, need some outreach efforts with non-obvious co-benefits for farmers are scored as 2. Options that require community-level agreement and need certain investment to incentivize adoption are scored as 3.

Source: Prasanna, B.M., Huesing, Joseph E., Eddy, Regina, Peschke, Virginia M. (eds). 2018. *Fall Armyworm in Africa: A Guide for Integrated Pest Management,* First Edition. Mexico, CDMX: CIMMYT. FallArmyworm_IPM_Guide_for Africa.pdf

TABLE 2. Augmentative biological control, biopesticide and synthetic pesticide options used in fall armyworm integrated pest management

| Technology | Approach according to IPM framework | Efficacy[1] | Safety | | Costs of product[4] | | | Accessibility | | |
			User safety PPE (scale: 1–5)[2]	Environmental risk/ compatible with biocontrol (scale: 0-3)[3]	Direct cost single treatment	Direct cost season	Indirect cost	Policy	Infrastructure/ supply chain (Scale 1-3)[5]	Scalability[6]
1 Augmentative biocontrol using Trichogramma spp.	Biological control	Fair to good	1	0	Likely below USD 52	Unknown	Biofactory, extension, logistics	Regulated	3	2
2 Augmentative biocontrol using Telenomus remus	Biological control	Excellent	1	0	USD 10-40	USD 20-80	Biofactory, extension, logistics	Regulated	3	2
3 Bt spray (Commercial)	Biopesticide	Fair to excellent	1	0	USD 28	USD 142	Labour, sprayer, PPE, cold chain	Regulated	2	2
4 Azadirachtin - Neem spray (Commercial)	Biopesticide	Fair to excellent	1	0	USD 32	USD 119	Labour, sprayer, PPE	Regulated	1	1
5 *Beauveria sp.*	Biopesticide	Fair	1	0	Unknown	Unknown	Labour, sprayer, PPE	Regulated	2	1
6 Metarhizium rileyi	Biopesticide	Fair	1	0	USD 3.15	USD 34	Labour, sprayer, PPE	Regulated	2	1
7 Baculovirus NPV spray (Biopesticide)	Biopesticide	Excellent	1	0	Unknown	Unknown	Labour, sprayer, PPE	Regulated	2	1
8 Spinetoram or Spinosad	Pesticide	Excellent	1	1	USD 35	USD 85	Labour, sprayer, PPE	Regulated	1	1
9 Emamectin Benzoate	Pesticide	Excellent	4	2	USD 40	USD 95	Labour, sprayer, PPE	Regulated	1	1
10 Chlorantraniliprole	Pesticide	Excellent	1	0	USD 34	USD 82	Labour, sprayer, PPE	Regulated	1	1
11 Lambda Cyhalothrin	Pesticide	Fair to good	4	2	USD 11	USD 37	Labour, sprayer, PPE	Regulated	1	1

1. Assessments for efficacy, safety and compatibility with biocontrol are derivative works of Jepson, P.C., Murray, K., Bach, O., Bonilla ,M.A., Neumeister, L. 2020. A *Global Guideline for Pesticide Selection to Reduce Risks, and Establish a Minimum Pesticides List*. 23 August 2019. SSRN: https://ssrn.com/abstract=3441822 or http://dx.doi.org/10.2139/ssrn.3441822. Efficacy levels were assigned as: E = excellent (90–100 percent control); G = good (80–90 percent control); F = fair (70–80 percent control); P = poor (<70 percent control); Yellow cell with red stripes = efficacy unknown—more research needed. IPM measures in this table are meant to work together, thus a lower level of efficacy for a single measure should not be used as a standalone decision making guide on implementing the measure.

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3. Compatibility with Biocontrol/Environmental risk was assessed using a 4-point scale, taking into account environmental risk assessments conducted on aquatic organisms, terrestrial animals and pollinators where a risk would require some kind of mitigation. A risk of 0 results when no risks were observed in any of the three categories while a risk of 3 results when risks were determined in all three categories.

4. Costs: In as much as the numerical costs listed here are available, they are provided by B.M. Prasanna and colleagues at CIMMYT India with a collection date of October 2020. An arbitrary scale was developed for comparative purposes with green bracketing (<USD 82), yellow bracketing (USD 83-USD 114) and red bracketing (USD 114-USD 144).

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TABLE 3. Fall armyworm integrated pest management options that require further research

				Safety		Costs of product[4]			Accessibility		
	Technology	Approach according to IPM framework	Efficacy [1]	User safety PPE (scale: 1–5)[2]	Environmental risk/ compatible with biocontrol (scale: 0-3)[3]	Direct cost single treatment	Direct cost season	Indirect cost	Policy	Infrastructure/ supply chain (Scale 1-3)[5]	Scalability[6]
1	Cyantraniliprole (as seed treatment)	Pesticide	Research needed	1	1	USD 32.80	USD 32.80	Labour, sprayer, PPE	Regulated	1	1
2	Pheromone mating disruption	Biopesticide	Research needed	1	0	Unknown	Unknown	Labour, sprayer, PPE	Regulated	Unknown	1
3	Spraying with sugar solution	Agro-ecology/ biological control	Poor	1	0	USD 13	USD 52	Labour, sprayer, PPE	Unregulated	1	2
4	Crushing egg masses and picking larvae	Mechanical control	Research needed	1	0	USD 8	USD 65.50	$$$	Unregulated	1	3
5	Providing nest sites for natural enemies	Agro-ecology/ biological Control	Research needed	1	0	Unknown	Unknown	Unknown	Unregulated	1	1-2
6	Habitat diversification at landscape level (e.g. forest restoration and management of semi-natural habitats at landscape level)	Landscape management/ biological control	Research needed	1	0	Variable	Variable	Variable	Unregulated	1	2-3
7	Optimal timing of planting in areas along FAW seasonal migration	Agro-ecology	Research needed	1	0	0	0	0	Unregulated	1	Unknown
8	Augmentative biocontrol using Bracon brevicornis	Biological control	Research needed	1	0	Unknown	Unknown	Biofactory, extension, logistics	Regulated	3	2

1. Assessments for efficacy, safety and compatibility with biocontrol are derivative works of Jepson, P.C., Murray, K., Bach, O., Bonilla, M.A., Neumeister, L. 2020. *A Global Guideline for Pesticide Selection to Reduce Risks, and Establish a Minimum Pesticides List*. 23 August 2019. SSRN: https://ssrn.com/abstract=3441822 or http://dx.doi.org/10.2139/ssrn.3441822. Efficacy levels were assigned as: E = excellent (90–100 percent control); G = good (80–90 percent control); F = fair (70–80 percent control); P = poor (<70 percent control); Yellow cell with red stripes = efficacy unknown—more research needed. IPM measures in this table are meant to work together, thus a lower level of efficacy for a single measure should not be used as a standalone decision making guide on implementing the measure.

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Appendix 1: Integrated pest management strategies for fall armyworm control

BACKGROUND

Maize (Zea mays) is one of the most important cereals globally for grain production and ranks behind only wheat and rice for direct human consumption. To illustrate the importance of maize as a staple crop, about 70 percent of maize demand is used for human consumption in sub-Saharan Africa. In Asia, about 46 percent of maize is used for human consumption (Shiferaw *et al*., 2011). Maize is increasingly utilized as a major feed source for poultry and egg industries across the global south, helping make high-quality nutritious foods more affordable and available to the poor and nutritionally vulnerable. Maize is cultivated globally in various agro-climatic zones in latitudes ranging from 40° S to 52° N, and in altitudes ranging from sea level to higher than 3 000 meters.

Fall armyworm (Spodoptera frugiperda; FAW) is a major transboundary insect pest that has become a significant threat to food security and agricultural *sustainability worldwide*. FAW, a polyphagous pest native to tropical and sub-tropical regions of the Americas, was first detected in West Africa in 2016 and subsequently spread in countries across Africa. By 2018, FAW was detected in the Near East and Asia, and the pest has now spread in these regions. FAW can feed on multiple plant species. However, in Asia, Africa and the Near East, FAW appears to prefer maize, and has caused major damage primarily on maize crops. A range of 8 percent to 26 percent yield losses due to FAW infestation has been reported in the last few years from various countries in Africa (Baudron *et al*., 2019, Kassie *et al*., 2020, Tambo *et al*., 2019). Many of the reported data come from interviews with farmers and there is a need to accurately determine the yield losses due to FAW in various agro-ecologies.

FAW does not have a diapause mechanism and cannot survive low temperatures. Several studies found that 13.8 °C was the minimum threshold for development below which FAW egg, larval and pupal development stops (Early *et al*., 2018, Li *et al*., 2019). However, long-range migration is a well-known behaviour of FAW that helps the moth to seasonally expand its geographic range. Year-round survival and breeding typically occur in warmer regions where host plants are always available and temperatures rarely or never dip below certain thresholds. Long-range seasonal migration occurs in spring and sum-

mer, towards new regions that allow FAW survival during warm months. Such seasonal migration can take multiple generations. This means that FAW can arrive in an area along a seasonal migration pathway and establish itself. New generations of individual pests will then continue the migration to new areas as a function of host plant availability and climatic factors.

In North America, for example, parts of southern Texas and southern Florida are known to be year-round breeding areas, with seasonal migration towards northern states, such as Minnesota and Pennsylvania occurring in spring and summer (Nagoshi *et al*., 2012). Indeed, seasonally migrating FAW populations are found as far north as Canada (Mitchell *et al*., 1991).

In Africa, the Near East, and Asia and the Pacific, new patterns of FAW seasonal migration are expected. In Asia, for example, modelling studies have predicted trajectories and timing of such seasonal migration from year-round breeding areas in southern China to the north-eastern part of the country (Li *et al*., 2019, Wu *et al*., 2019). Another modelling study identified central Asian regions, such as western Afghanistan, southern Kazakhstan and southern Turkmenistan, as potential areas affected by seasonal FAW migration. As FAW establishes itself in North Africa, seasonal migration towards southern Europe is also expected (Jeger *et al*., 2018).

FAO has defined integrated pest management (IPM) as an ecosystem-based crop production and protection strategy that carefully considers and integrates appropriate measures to discourage the development of pest populations. At the same time, IPM keeps pesticides and other interventions to levels that are economically justified while reducing or minimizing risks to human health and the environment. The classic IPM pyramid (see Figure 1 on p. 18) provides an easy-to-grasp scheme of how different management strategies fit together. The base of the pyramid consists of various strategies that shore up plant and environmental health to increase the cropping ecosystem's resilience against pests. As such, they form the basis of IPM, improve natural pest regulation in the ecosystem and must be prioritized in an IPM programme.

Scouting and monitoring form the middle part of the pyramid to guide decision making for further interventions that are curative in nature. If deemed necessary and economically rational, biopesticides and pesticides form the top of IPM pyramid. Some critical considerations, such as risk reductions (e.g. selecting products with relatively low human health and environmental health risks, risk reduction during application) and pesticide resistance management are necessary when implementing these options. Both biopesticides and synthetic pesticides are sometimes used as parts of an IPM strategy when necessary.

Biopesticides are listed lower in the pyramid, as they are usually seen as of lower relative risks for human health and the environment.

SCOPE AND PRINCIPLES OF THE GUIDE

This appendix outlines documented and available management strategies for Asia, Africa, and North Africa and the Near East and serves as a starting point for further development of regional IPM guides. The following principles were considered during the preparation of this appendix:

- This content is not meant to be exhaustive or mandatory. It provides general headings on IPM strategies against FAW in Asia, Africa and North Africa and the Near East regions and expounds briefly on the main considerations under each strategy.
- The regional IPM guides, to be developed in collaboration with country experts, government and research partners, as well as private-sector partners in each region, must be customized according to the context of each region. As such, the regional IPM guides will describe regional-specific details on FAW ecology, provide specific IPM options that are validated and available in the region and tailor the recommendations according to the socio economic contexts of maize production in the region.
- Commercially available options will not be mentioned by trade names in the guides to avoid conflict of interests; single-company products will not be

FIGURE 1. INTEGRATED PEST MANAGEMENT PYRAMID
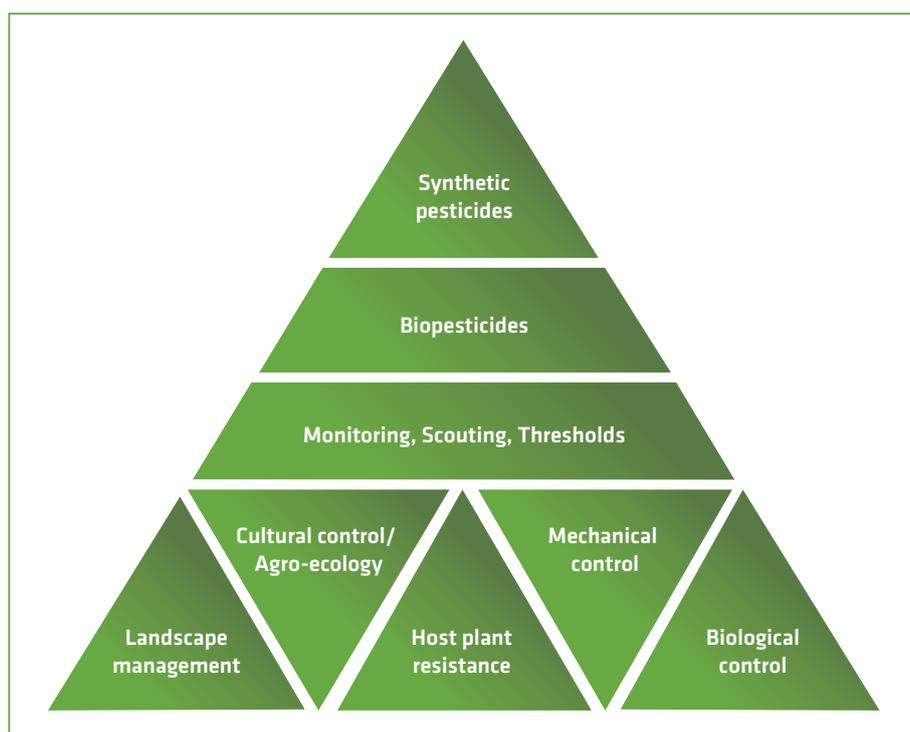
Source: modified from Naranjo 2011

promoted to avoid giving unfair competitive advantage. For example, biopesticides and pesticides will be referred to by their active ingredients and not by trade names.

INTEGRATED PEST MANAGEMENT FOR FALL ARMYWORM

IPM emphasizes tactics that reduce the environment's suitability for FAW multiplication. This is achieved by minimizing environmental elements that are favourable for FAW or by optimizing environmental elements that inherently regulate FAW populations. These tactics are designed to reduce the overall FAW populations to avoid outbreaks in these areas.

1.Monitoring and forecasting

FAW monitoring in its year-round breeding areas should be a sustainable process and should be considered as one of the main pillars of any FAW-IPM strategies.

1.1 At the field scale, **scouting and conducting agro-ecosystem analysis for FAW** is crucial to monitor not only the dynamics of the moth and the the word damages it causes, but also to take stock of the natural enemy activities and general plant health status. Farmers should be trained on proper scouting and agro-ecosystem analysis techniques, the type of information to gather and how to interpret the gathered information to guide decisions.

1.2 At the landscape scale, **FAW monitoring and early warning systems** can be enhanced by establishing a multilayer monitoring network (at the village, district, province, state, governorates and national levels) to cover areas with known host plants and suitable weather conditions. Gathering information at these scales helps with establishing national level knowledge-base on the pest phenology, behaviour and ecology which may be translatable back into practical recommendation at field scale. At least one focal point should be assigned for each village to maintain/collect the data, either from FAW traps or field scouting, all year-round even in the absence of the host plant. All members of the network should be well trained on the identification of the pest, field scouting, and FAW trapping in addition to how to collect and submit the monitoring data. All monitoring records should be analysed and mapped for a better understanding of the distribution of the pest and the dynamic of the FAW population in different seasons and under different cropping systems.

1.3 **Appoint a national monitoring network administrator** to follow up on the flow of field data on a regular basis across the year and address any gaps in the monitoring process. Decision-makers should always count on the compiled collected field data before taking any decision on the FAW management strategies.

1.4 A **centralized database** with an easy-to-use mechanism to upload data from the monitoring and scouting sites is crucial in accumulating standardized data. Mobile apps, such as the FAO Fall Armyworm Monitoring and Early Warning System (FAMEWS) platform can be used for this.

1.5 **Develop forecasting and advisory solutions** to translate the collected information in the database into a FAW forecasting and early warning system. The recommendation may guide field management decisions, such as planting date and scouting and agro-ecosystem analysis frequency.

2. Best agronomic/cultural practices

The practices below are among the best maize agronomic practices that will contribute to FAW management by ensuring the general health of maize plants or reducing the likelihood of FAW infestation.

2.1. **Use high-quality seed, including improved maize varieties with resistance or tolerance against FAW.** There are naturally occurring FAW resistant germplasms developed in South, Central and North America. There is also evidence of naturally occurring genetic variability in maize breeding lines adapted to the newly invaded regions that can be used in a breeding programme against FAW (Kasoma *et al*., 2020a, b, Prasanna *et al*., 2018). FAW tolerant inbred lines identified by CIMMYT, based on evaluations done in Kenya under artificial infestation during 2017-2010 (e.g., CML71, CML125, CML330, CML338, CML370, CML574), have been already disseminated to several public and private sector institutions in Africa and Asia. These inbred lines enable breeding institutions to develop improved maize varieties with native genetic resistance to FAW and adapted to target agro-ecologies. Elite FAW-tolerant first-generation hybrids have been anounced by CIMMYT to partners in Africa.

In the Americas, the Republic of South Africa and several Asian countries, use of transgenic maize expressing *Bacillus thuringiensis* proteins is, or is becoming, the mainstay of FAW management (Siebert *et al*., 2008a; Farias *et al*., 2014; Chandrasena *et al*., 2018). Despite occasional challenges to resistance durability, especially on varieties expressing single Bt toxin (Chandrasena *et al*., 2018, Farias *et al*., 2014, Farias *et al*., 2016, Huang *et al*., 2014, Storer *et al*., 2010). Bt maize is the dominant control method of FAW control in countries where the technology is available, Huang (2020) identified a number of risk factors associated with the development of resistance and suggested a number of strategies to mitigate the problem of resistance breakdown in the newly invaded regions:
- usage of only high-dose pyramided Bt traits;

- adoption of high dose/refuge (HDR) strategy among producers, which requires planting a refuge area composed of non-Bt maize in close proximity to the Bt maize fields;
- development and implementation of regional Bt resistance monitoring;
- evaluation of the efficacy of limiting transgenic Bt maize deployment in FAW year-round breeding areas to reduce selection pressure among FAW populations and slow down resistance breakdown.

National biosafety regulatory frameworks, societal acceptability of Bt seeds and resistance management are other elements to be taken into consideration. Although more expensive than non-Bt hybrid seeds, farmers may consider the investment worthwhile due to higher yields and savings associated with other FAW management methods.

2.2 **Apply soil health principles and balanced fertilization** to ensure healthy plants (Morales *et al*., 2001). Soil management techniques, such as **mulching, addition of organic matters (e.g. compost), no- or low-tillage** increase general soil health to help produce robust plants that can tolerate FAW injuries and improve the abundance and function of soil predators to reduce survival of FAW pupae in the soil (Rivers *et al*., 2016). Ants, for example, were found to kill over 95 percent of FAW pupae in the soil in fields with healthy soil biota (Perfecto *et al*., 1991). Healthy soils, with good soil organic matter content, promote balanced release of nutrients that ensure general plant health. This will help maize plants compensate for FAW damage.

2.3 Reports suggest that some smallholder farmers often conduct **egg crushing** and **hand-picking of fall armyworm caterpillars** and other local controls, as this is an option that is available to them, especially in the time of outbreaks. At this time, evidence is lacking as to this technique's efficacy, feasibility and cost. Reports showed that while mechanical control does not significantly protect yield as a standalone action, done together with other IPM actions, the method may improve yield protection (Kassie *et al*., 2020, Tambo *et al*., 2019). While this is a readily available option, there is a gap in knowledge on the cost effectiveness of the method. Timing the operation in tandem with other early field operations, such as thinning and gap filling may help reduce the cost.

2.4 **Intercropping.** Intercropping, defined as planting additional crops in strips or alleys among maize plants, has a number of potential benefits, including: (i) increasing general plant health by contributing to soil health; (ii) interfering with FAW host-plant searches by introducing contradictory cues, such as repellent volatiles; (iii) inhibiting larval movement between rows; (iv) increasing natural enemies' abundance by providing extra food sources and shelter (Harrison *et al*., 2019).

The realized benefits of intercropping are dependent on the choice of plants involved in the scheme, as well as the environmental and socio-economic contexts of the field (Hailu *et al*., 2018, Kassie *et al*., 2020). The intercrop should be planted at the same time or earlier than the main crop, so they grow up together, and FAW control appears better where intercrops with abundant vegetative growth are used. Alley cropping can often be an effective strategy, as it enhances the growth of the intercrop, but limits competition with the main crop.

The **push-pull system** is an example of an intercropping system that was found to be effective as a FAW management strategy. In an example of the system widely tested in sub-Saharan Africa, maize is intercropped with silverleaf or greenleaf desmodium (*Desmodium uncinatum* or *Desmodium intortum*, respectively), a trailing perennial legume species that produces volatiles that repel FAW; and Napier grass (Pennisetum purpureum), a perennial grass that attracts FAW (hence the name 'push-pull') (Khan *et al*., 2018, Midega *et al*., 2018). The plants that attract FAW can then become a focus of further management action. There are challenges in mainstreaming adoption of the method, including sourcing seeds for the push or pull plants.

3. Conservation and enhancement of natural enemies

In both its year-round breeding areas and invasive range, numerous natural enemies regulate FAW populations (e.g. Molina-Ochoa *et al*., 2003, Sisay *et al*., 2018, Agboyi *et al*., 2020, Firake and Behere, 2020). These include organisms, such as insects, spiders, nematodes, birds and bats that feed, either as predators or parasitoids, on FAW eggs, larvae, pupae and moths. Pathogenic microorganisms also play an important role in naturally regulating FAW populations. It is possible to conserve and even enhance the abundance and effectiveness of these natural enemies by creating a favourable environment for them in and around fields. This strategy, called conservation biological control, forms the cornerstone of FAW habitat management. Conservation of natural enemies requires **avoiding adverse agricultural practices, such as indiscriminate use of pesticides**, which can harm the beneficial insects, spiders and other beneficial organisms (Jepson *et al*., 2020, Meagher *et al*., 2016, Perfecto 1990, Carmo *et al*., 2010, Torres and Bueno, 2018). Some examples of this strategy include:

3.1   Leaving **strips of wild plants** on the field margin is an example of increasing habitat diversity to enhance natural enemies. This approach increases the availability of supplementary food for natural enemies in the form of nectar and pollen, which in turn increases the numbers of natural enemies and results in lower FAW survival rates (Wyckhuis and O'Neil, 2007; Hay-Roe *et al*., 2016). It is particularly effective if plants that are good nectar sources are planted or sown.

3.2 **Integrating crops with woody perennials** – such as fertilizer trees (e.g. Glircida sepium, Faidherbia albida); trees planted on boundaries or as live fences – and maintaining forest fragments and uncultivated patches of natural regeneration are other ways of increasing habitat diversity for natural enemy conservation. The abundance of insect predators has been found to decline with distance from forest fragments, leading to corresponding increases in FAW infestations. Trees are likely to increase the abundance of vertebrate natural enemies, such as bats and birds, both with good potential as natural enemies of FAW moths (Jones *et al*., 2005, Maine and Boyles, 2015).

3.3 **Protection and provision of natural enemies' nests**. Ants and social wasps are very important predators of FAW. Protecting ant and social wasp nests in and around fields is a simple and effective strategy for FAW control. Unfortunately, farmers often remove these nests because they think they are a menace and do not appreciate the service these organisms provide.

3.4 Food source amendment to attract natural enemies. Ants are important natural predators of FAW larvae. They crawl up the plants, into the whorls, to find and drag out FAW larvae. In Honduras, a traditional practice consisting of spraying sugar water in maize fields enhanced ant populations and reduced FAW damage (Canas and O'Neil, 1998). In Africa, there are some informal reports of farmers using food-based baits (e.g. sugar, meat, fish stock) to attract ants, but there is no documented evidence of the effectiveness. Based on a lack of compelling evidence, the Technical Committee does not endorse utilizing such approaches.

Challenges in mainstreaming conservation biological control methods include the methods' knowledge-intensive nature which may require intensive training; and lack of incentives for farmers to try them. These challenges have limited the adoption rate of these methods. There is also a knowledge gap in the cost-effectiveness of some of these methods.

4. Augmentative and classical arthropod biological control

Augmentative biological control consists in repeated releasing (inundation) of natural enemies (in this case, parasitoids or predators) that are already present in the area. This requires the use of natural enemies that (1) are easy to mass-produce and (2) kill the target pest before they cause serious damage. In the case of FAW, the egg parasitoids *Trichogramma* spp. and *Telenomus remus* have already been extensively studied and are occasionally used in the Americas (e.g. Cave, 2000; Figueiredo *et al*., 2002, Figueiredo *et al*., 2015, Salazar-Mendoza *et al*., 2020). *Telenomus* remus most efficiently exploits FAW

egg masses but it is more expensive to produce, whereas Trichogramma spp. are cheap and easy to produce but are less efficient to parasitize the lower layer of the egg masses. These egg parasitoids are presently being considered and tested in Africa and Asia (Liao *et al*., 2019; Tefera *et al*., 2019; Kenis *et al*., 2020; Laminou *et al*., 2020), as well as parasitoids of young larvae, such as Cotesia icipe (Sisay *et al*., 2019), and various predators, such as true bugs and lacewings (e.g. Xu *et al*., 2019; Keerthi *et al*., 2020). While the above approaches hold promise, they depend on investment in rearing facilities and knowledge-intensive marketing system that are absent in many countries.

Classical biological control consists in the inoculative introduction of an exotic natural enemy, usually from the area of origin of the target invasive pest, for permanent establishment and control. This method has often been successful to provide an area-wide control of invasive pests, such as the cassava mealybug, the mango mealybug and many others, leading to huge benefit-cost ratios. Various parasitoids and predators attack FAW in its area of origin (Molina-Ochoa *et al*., 2003). However, in classical biocontrol projects, the risk of non-target effects on native insects needs to be considered and only a few parasitoids (and no predators) are sufficiently specific to FAW to be considered for introduction in the newly invaded regions. Some of these species are presently being studied in quarantine laboratories at CABI and the International Institute of Tropical Agriculture (IITA), for example. The scope of classical biological control is not the individual farm level, but a regional scale as it benefits the entire producer communities. Thus, unlike profitability evaluations of pesticide applications at field level, the economic value of such interventions is quantified in a benefit-to-cost analysis over a time horizon where the benefits are chiefly calculated as avoided costs enabled by biological control.

5. Routine scouting

The practices mentioned above are meant to shore up both plant and environmental health in general and lend resilience over the whole cropping system against pest outbreaks. Farmers need to carefully evaluate all control options, including whether a pesticide or biopesticide is needed, cost effective, and sustainable. In accordance with IPM principles, routine scouting and an agro-ecosystem analysis should guide the decision, using selective and low-risk pesticides, and always as a last option. FAO Guidance Note 2 describes a scouting protocol for FAW. Routine scouting and agro-ecosystem analysis provides information on current level of fall armyworm populations and damage, crop health, population levels of natural enemies and their functions in suppressing fall armyworm.

Economic action threshold (EAT) is a common decision-support tool to guide the need for synthetic pesticide application. On its own, EAT relies on at least three types of information: cost and efficacy of control, yield loss associated with a certain level of pest population or plant injury, and the monetary value of yield being protected by the control action.

Both the cost of control and monetary value of yield saved are highly region-specific and should be calculated using local values. Relatively low farmgate prices for the yield, for example, can render pesticide application cost-ineffective. The control efficacy can depend highly on weather, application technology and its long-term effects on the natural enemy populations (see paragraph 6.2 below). Association between yield loss and pest population or plant injury depends highly on the varieties being used, crop age and health, levels of natural enemies in the field, and weather. All of these variables need to be accounted for in the economic threshold. With all of these limitations, it is important that the economic action threshold is estimated specifically for a given agro-ecosystem/socio-economic setting and be updated regularly to reflect changes in the price and agronomic trends. Farmers and agricultural advisors need to be trained in understanding how EATs are calculated and in making their own local calculations. If EATs are reached, farmers and agricultural advisors should be trained to analyse the agro-ecosystem to check the situation of other correcting factors (such as presence of natural enemies, pathogens, and weather) to reach a decision based on an agro-ecosystem analysis.

6.Biopesticides

6.1   **FAW mating disruption.** This is achieved by strategically releasing FAW sex pheromones in the field. Inundating the environment with FAW sex pheromones disrupts mating location by FAW moths and, consequently, reduces mating successes, resulting in reduced offspring. More studies are needed to investigate the efficacy of this tactic against FAW. Costs for existing mating disruption options in the market need to be factored in when making a decision to apply this tactic.

6.2   **Microbials and botanicals.** A number of microbial and botanical pesticides, such as neem extract, Azadirachta indica, Bt (Bacillus thuringiensis), entomopathogenic fungi, such as Beauveria bassiana and Metarhizium anisopliae, and entomopathogenic virus, such as SfNPV, can be effective against FAW (see Bateman *et al*., 2018, Bateman *et al*., 2021, Jepson *et al*., 2020 and Rioba and Stevenson, 2018 for lists of biopesticide active ingredients with known efficacy against FAW). Some biopesticides are target-specific, with relatively low environmental persistence. These properties make these biopesti-

cides especially relevant for sustainable management of FAW, where available and affordable for farmers.

Some biopesticides can be prepared by farmers. For example, when dead caterpillars that were killed by virus, fungi or bacteria are observed in the field, they can be collected, taken home, ground (or put through a blender), and strained. The liquid that strains through may be full of fungal spores, bacteria, or virus particles that can be diluted and sprayed back into infested plants. This can be a cheap, effective natural biopesticide. It is possible to spray only into the whorls of infested plants, so as not to waste the natural pesticide.

There may be health risks inherent in preparing homemade biopesticides. Neem aqueous extract has been shown to have low chronic and sub-chronic toxicity and generally low acute toxicity (Boeke *et al*., 2004). However, the home preparation process may involve a mixture of active ingredients and other compounds with variable concentrations; and hazardous exposure of the person preparing the biopesticide may be high (Dougoud *et al*., 2019). Thus, care must be taken in wearing appropriate protective clothing when preparing homemade biopesticides. Cost/benefit studies have found that homemade neem extract can be profitable in other cropping systems (e.g. rice, wheat) (Dougoud *et al*., 2019) and a similar study needs to be done on maize.

Commercial biopesticides are available in some countries. It is important to stress the value of user education on the biopesticide application and modes of action to increase efficacy and develop realistic expectations among farmers (Constantine *et al*., 2020).

7. Risk reduction of pesticides use

A number of important considerations for the use of chemical control in FAW's year-round breeding areas include:

7.1   **Harmonize the use of all approaches and technologies with conservation of natural enemies and other beneficial organisms such as pollinators.** Indiscriminate use of conventional and some botanical pesticides can disrupt natural enemy-pest populations in FAW habitat, leading to increases in the abundance of FAW. To avoid this scenario, if the need for pesticides has been ascertained after careful consideration, deploy a selective pesticide that affects the target pest only and not FAW's natural enemies (Jepson *et al*., 2020, Torres and Bueno, 2018).

The use of seed treatment is only warranted in high risk areas and where it is economically feasible. Some active ingredients used as seed treatments on maize may pose risks to pollinators, especially via dust drift during planting.

Risk mitigation measures such as ensuring the use of high quality seed coating during seed dressing process, high quality drilling equipment during planting process are highly recommended for pollinator protection.

7.2   If the use of pesticides is deemed necessary due to FAW populations, after a careful agro-ecosystem analysis, for example, **select products with the lowest risk to humans, the environment and non-target organisms from the list of available registered products that are effective against FAW**. Table 4 from Jepson *et al*., (2020) on p. 27 gives indications of efficacy, as well as human and environmental risks of active ingredients commonly used against FAW.

7.3   **Ensure proper use** of the selected products, including biopesticides, for approved applications and **comply with international standards** (Guidance on Pest and Pesticide management, FAO 2010; FAO/WHO International Code of Conduct on Pesticide Management).

7.4   **Rotate pesticides or biopesticides** using products with different modes of action to avoid development of insecticide resistance among FAW populations. Studies on FAW populations in Africa, and Asia and the Pacific showed that individuals in the invading populations are resistant to some organophosphate and pyrethroid active ingredients (Zhang *et al*., 2020, Guan *et al*., 2020).

TABLE 4. Pesticides in current use in Africa against fall armyworm (*Spodoptera frugiperda*)
(from Jepson *et al*., 2020)

	Efficacy unknown	Poor-to-fair efficacy (<70 percent to <80 percent control)	Good-to-excellent efficacy (80-100 percent control)
Highly hazardous pesticides	Fipronil, methamidophos, monocrotophos, phorate	Carbofuran, carbosulfan (obsolete substance), dichlorvos, imidacloprid, thiamethoxam, trichlorphon	Beta-cyfluthrin, cyfluthrin, methomyl
High-risk pesticides to health and environment requiring maximum PPE with engineering and behavioural mitigations	Cartap hydrochloride	Abamectin, benfuracarb, carbaryl, chlorpyrifos, diazinon, dimethoate, fenitrothion, malathion, pirimiphos-methyl, profenofos, thiocarb	Acephate, gamma-cyhalothrin, lambda-cyhalothrin, cypermethrin, deltamethrin, diflubenzuron, emamectin benzoate, fenvalerate
High-risk pesticides to health and environment requiring double-layer PPE and either eye or respiratory protection, or both	Pyridalyl	Acetamiprid	Bifenthrin, alpha-cypermethrin, beta-cypermethrin, indoxacarb
Lower-risk pesticides to health requiring single-layer PPE, but high environmental risk	--	--	Lufenuron, novaluron, spinetoram, spinosad, teflubenzuron, triflumuron
Lower-risk pesticides to health and environment requiring single-layer PPE	Pyriproxifen	*Bacillus thuringiensis* serovar kurstaki, Beauveria bassiana, Metarhizium anisopliae	*Azadirachta indica, Bacillus thuringiensis* serovar aizawai, chlorantraniliprole, flubendiamide, methoxyfenozide, *Spodoptera frugiperda* nuclear polyhedrosis virus (SfNPV), pyrethrum

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