Food and Agriculture Organization of the United Nations

International Plant Protection Convention

# PREVENTION, PREPAREDNESS AND RESPONSE GUIDELINES FOR *SPODOPTERA FRUGIPERDA*

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Food and Agriculture Organization of the United Nations
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Fall armyworm (*Spodoptera frugiperda*) (FAW) is an insect that can cause unprecedented impacts to crops – particularly maize (*Zea mays;* also known as corn), sorghum (*Sorghum bicolor*), rice (*Oryza sativa*) and other agricultural crops – if not managed properly. The introduction and spread of this pest should be prevented where still possible. It is important to note that, to date, none of the more than 70 countries in which FAW has been detected has been able to eradicate this pest and significant pest populations have established in affected countries.

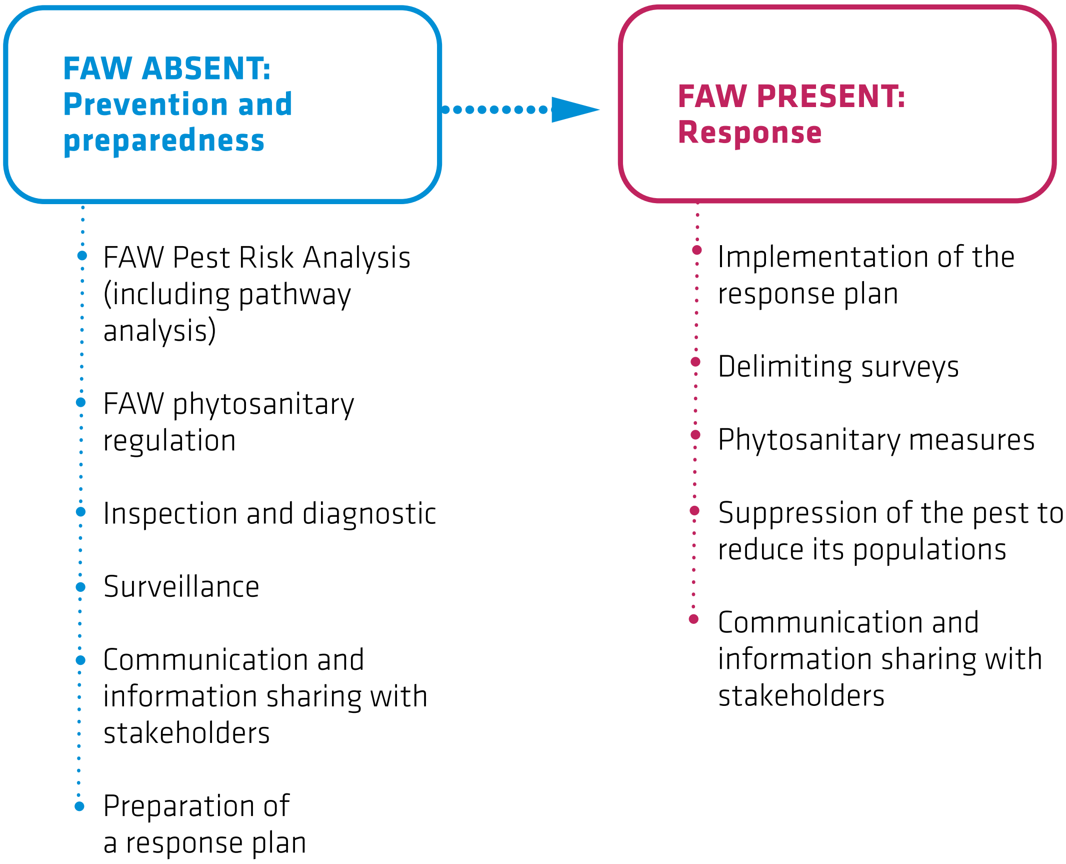
The aim of these guidelines is to help national plant protection organizations (NPPOs) to take suitable actions at the proper time against FAW through timely detection to prevent or slow the spread of the pest and reduce its negative impact. The guidelines are directed at NPPOs of countries where FAW fulfils the requirements to be regulated as a quarantine pest for applying internal quarantine and biosecurity measures.

The guidelines give general information on the distribution and biology of the pest (section 1), followed by technical details of what needs to be included in prevention, preparedness (section 2) and response plans for FAW (section 3). Figure 1 summarizes the actions to be taken by the NPPO.

When the pest is absent, countries should prepare a response plan, as well as a prevention and preparedness plan, so that they are ready if the pest is subsequently detected in their territory.

The guidelines also summarize the elements to be taken into account when drafting a communication plan.

Figure 1: Flow chart of the range of actions when the pest is absent and present



# Contents

# Acknowledgments

This document has been developed by experts of the FAO-IPPC Fall Armyworm Technical Working Group on "Quarantine and Phytosanitary Measures", under the oversight of the IPPC Implementation and Capacity Development Committee. This document was also open to consultation through the IPPC Online Commenting System.

# Abbreviations and acronyms

| | |
|---|---|
| CABI | Center for Agricultural Bioscience International |
| EFSA | European Food Safety Authority |
| EPPO | European and Mediterranean Plant Prtoection Convention |
| FAO | Food and Agriculture Organization of the United Nations |
| FAMEWS | FAW Monitoring and Early Warning System |
| FAW | Fall armyworm |
| IPPC | International Plant Protection Convention |
| IPM | Integrated Pest Management |
| ISPM | International Standards for Phytosanitary Measures |
| NPPO | National Plant Protection Organization |
| PRA | Pest risk analysis |

# Explanatory note

The guidelines refer to relevant International Standards for Phytosanitary Measures (ISPMs) and other guides developed under the auspices of the International Plant Protection Convention (IPPC) Secretariat. The terms used in the guidelines are consistent with ISPM 5 (*Glossary of phytosanitary terms*).

Further information can be found in the series of publications on FAW available at http://www.fao.org/fall-armyworm/resources/en/ and on the dedicated FAW web page maintained by the IPPC Secretariat at https://www.ippc.int/en/the-global-action-for-fall-armyworm-control/. A comprehensive information portal on the pest, maintained by CABI and containing materials from multiple organizations, is available at https://www.cabi.org/isc/fallarmyworm.

# 1. Distribution and biology of the pest

## 1.1 Distribution of the pest

The Food and Agriculture Organization of the United Nations (FAO) has maintained a map of the worldwide spread of FAW since 2016 (see http://www.fao.org/fall-armyworm/monitoring-tools/faw-map/en/) and the European and Mediterranean Plant Protection Organization (EPPO) maintains a referenced list of the pest status of countries across the world (see https://gd.eppo.int/taxon/LAPHFR/distribution).

Fall armyworm originates from tropical and subtropical regions of the Americas and is present across those regions. It has recently spread across sub-Saharan Africa and Asia, parts of the Near East and Northern Africa (NENA) and parts of Oceania. As of April 2021, it is only present in Canary Island in Europe, and absent or of limited distribution in some countries in NENA and in the Pacific.

As part of their national reporting obligations, contracting parties to the IPPC should update the pest status of their territories – including for FAW – on the International Phytosanitary Portal (www.ippc.int).

## 1.2 Biology of the pest

Detailed factsheets for *Spodoptera frugiperda* are provided by several organizations, including CABI (2020), EPPO (2020a) and the University of Florida (Capinera, 2017). In addition, a poster and a video on the life cycle of the pest are provided by FAO and CABI (2019a), respectively. General information only is provided below.

- **Taxonomic position:** Animalia: Arthropoda: Insecta: Lepidoptera: Noctuidae.
- **Plant hosts:** Fall armyworm is highly polyphagous, with its larvae recorded feeding on more than 350 plants from more than 75 families (see details in section 2.4).
- **There are two FAW genotypes based on the host-plant preference:** FAW is composed of two commonly recognized strains, the so-called "corn strain" (*Sfc*) and the "rice strain" (*Sfr*). There are no distinguishable morphological characters to differentiate between *Sfc* and *Sfr*, and identification is currently achieved via molecular diagnostics. Introgression has been detected between different populations.
- **Developmental temperature range:** Fall armyworm is a tropical and subtropical species and its optimal developmental temperature has been reported to range from 23.9 to 32.2°C (Barfield, Mitchell and Poe, 1978). The annual minimum temperature is important for FAW, as it is unable to enter diapause and will not survive below a certain temperature. This minimum temperature for development has been variously reported as 10°C (Wood, Poe and Leppla, 1979), 9.5–10.9°C (Busato *et al.*, 2005), 12.74 – 13.16°C (Ali, Luttrell and Schneider, 1990) and 13.8°C (Hogg, Pitre and Anderson, 1982).
- **Egg-laying capacity per female:** Females are highly fecund. They are capable of laying up to eight egg masses per generation, with the number of eggs in each egg mass ranging from just a few (e.g. nine) to more than 700. A single female may lay over 1 500 eggs during her lifetime (Luginbill, 1928; Capinera, 2017).
- **Number of generations per year:** At its optimal temperature, FAW could achieve six to eight generations per year. Its development cycle can be completed in about 28 days under optimal development temperature conditions, with this extending up to 90 days under colder temperatures (Luginbill, 1928; Sparks, 1979; Vickery, 1929).

- **Long-distance natural spread:** The adult FAW moth is a strong flyer and, with the assistance of prevailing wind, has been reported to travel at least 100 km per night (Johnson, 1987). Adult FAW moths have been known to travel 1 600 km in 30 hours from Mississippi in the United States of America to southern Canada (Rose, Silversides and Lindquist, 1975). Wind-assisted dispersal is a potential pathway of long distance natural spread. FAW therefore has a remarkable dispersal capacity, a feature that is understood to have evolved as part of its life history strategy (Johnson, 1987).
- **Pathways of introduction:** Larvae and pupae of FAW can be transported with traded commodities, especially in parts of plants such as vegetables or fruits, and sometimes on herbaceous ornamentals (Seymour, Roberts and Davis, 1985; Cock *et al*., 2017). In addition, the adults or eggs could potentially gain entry to a country as a hitchhiker pest on international flights, for instance via tourists luggage (Cock *et al.*, 2017; Early *et al*., 2018). Wind-assisted natural dispersal is another potential natural pathway of introduction (Cock *et al.*, 2017).
- **Resistance development:** FAW readily develops resistance to conventional pesticides used for its control. See the Arthropod Pesticide Resistance Database maintained by Michigan State University (2020) for the pesticide resistance status of FAW. An analysis of genes related to pesticide and Bacillus thuringiensis (Bt) resistance showed that the risk of FAW developing resistance to conventional pesticides is very high (Zhang *et al.* 2019).

# 2. Prevention and preparedness plan: **when the pest is still absent**

Figure 1 above summarizes the actions to be taken when the pest is absent, through a prevention and preparedness plan. A prevention and preparedness plan sets out all the activities to be undertaken while FAW is absent from the territory, namely, pest risk analysis (PRA), updating of phytosanitary regulations (including the potential for response measures), inspection and diagnostics, and surveillance to be reported to the IPPC Secretariat through National Reporting Obligations.

## 2.1 **Pest risk analysis**

Pest risk analysis is the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it" (ISPM 5). Pest risk analysis should be undertaken in accordance with ISPM 2 (*Framework for pest risk analysis*) and ISPM 11 (*Pest risk analysis for quarantine pests*). It includes analysis of the pathways by which the pest of concern may enter. Countries are encouraged to conduct a comprehensive PRA when the pest is still absent.

According to the European Food Safety Authority (EFSA) pest risk assessment (EFSA Panel on Plant Health *et al.*, 2018), FAW could enter new countries through international trade. Being a polyphagous pest, it was intercepted on commodities entering Europe and could continue to arrive on several products, such as sweet or hot peppers (*Capsicum* spp.), eggplant (*Solanum melongena*), African eggplant (*Solanum macrocarpon*), African scarlet eggplant (*Solanum aethiopicum*), asparagus (*Asparagus officinalis*), maize (*Zea mais*), and cut rose flowers (*Rosa spp.*). The pathway models in the EFSA pest risk assessment indicate that sweet or hot peppers are the most likely pathway for entry of FAW into the European Union, even though peppers are not the preferred hosts. Adults or eggs of FAW can also travel as stowaway on international flights. This is confirmed by interceptions of FAW egg masses found in various parts of aircraft coming from Central and South America (Cock at al., 2017).

A physiologically-based population dynamics model of Spodoptera frugiperda (Gilioli *et al.*, 2021a) has been applied to explore the potential risk posed by FAW to Europe (Gilioli *et al.*, 2021b). Results show that the species can establish in Europe with 3-4 generations per year in the coastal areas of the Mediterranean basin and in some warmer inland areas of southern Europe. The species can generate transient populations in southern and in central Europe that can reach, during the favourable season, population abundance representing a risk to susceptible crops.

A pathway analysis for Australia indicates that the majority of FAW interception records in Australia are from fresh asparagus, which could contain eggs and larvae. Sweet or hot peppers, bitter melon (*Momordica* spp.), African eggplant , eggplants, maize (excluding seeds and grain) and cut flowers are also likely pathways for FAW on imported commodities (Australian Government, 2020).

Given the high rate of natural spread of FAW, it is highly likely to enter countries by natural dispersal. Indeed, FAW may continue to spread within northern Africa and could relatively easily enter southern European countries (particularly the Andalusia region in Spain and Sicily in Italy) through migration. In the Pacific, FAW has been detected in the north-west region of Papua New Guinea that borders the Bismarck Sea (Madang Province, May 2020; Tay *et al.*, in prep.), and in New Caledonia (January 2021; FAO 2021). With the detection in New Caledonia (16/12/2020), invasion of other Melanesia countries is considered likely by the Pacific Community.

FAW was detected in more than 70 countries and none has been able to eradicate this pest and significant pest populations have established in these affected countries.

## 2.2 **Phytosanitary regulations**

Following the PRA, the regulated status of this pest should be updated, if needed, as well as the list of commodities subject to phytosanitary import requirements and other preventive measures, and the measures applicable and other priority activities.

In the European Union, FAW is a quarantine pest under the Commission Implementing Regulation 2019/2072 (Annex II, part A; European Commission, 2019a). It is also considered a priority quarantine pest under the Commission Delegated Regulation 2019/1702 (European Commission, 2019b). In addition, there are some specific phytosanitary import requirements regarding this pest on some plants (which should be reflected by an additional declaration on the phytosanitary certificate). These requirements are permanent until further notice on plants such as chrysanthemums/ chrysanthemum (*Chrysanthemum* spp.), carnation (*Dianthus* spp.) and geranium (*Pelargonium* spp.) (Annex VII to Implementing Regulation 2019/2072, point 25). These requirements take the form of provisional emergency measures for fruits of sweet or hot peppers, bitter melon, African scarlet eggplant , African eggplant and eggplants, and plants – other than live pollen, plant tissue cultures, seeds and grains – of maize originating in third countries other than Switzerland, as per the Commission Implementing Decision 2018/638 (European Commission, 2018) amended by the Commission Implementing Decision 2019/1598 (European Commission, 2019c).

In Australia, the NPPO has implemented its regulation through the PRA process for high-risk FAW host plants and included FAW on the National Priority Plant Pest List as a priority target for surveillance, inspection, diagnostics and stakeholder awareness (Australian Government, 2020).

## 2.3 Inspection and diagnostics

Inspection and diagnostics should be put in place to detect and identify the pest. All stages of the pest can be detected visually, with a hand lens for early stages, and specimens can be collected by hand or a sweep net (adults). In addition to inspection, pheromones traps are useful at borders to detect any accidental introduction. To identify specimens found, further confirmation is needed through morphological characteristics or molecular diagnostics. Adults can sometimes be found and collected by hand, especially in a commodity that is transported or stored in cool conditions. Eggs can be found on all above-ground plant parts, mostly on the underside of leaves.

### Inspection

Inspection is defined as official visual examination of plants, plant products or other regulated articles to determine if pests are present or to determine compliance with phytosanitary regulations. "Official" being defined as established, authorized or performed by a national plant protection organization (ISPM 5). Phytosanitary inspections of consignments that are likely to be pathways for the entry of FAW (e.g. of plants of maize, fruit of sweet or hot peppers, fruit of eggplants; EFSA, 2018) should be conducted at the point of entry. Cock *et al.* (2017) assumed that introduction of FAW into Africa was through travellers luggage, therefore inspections of luggage in high risk locations should be conducted. When conducting an inspection, methods should be consistent with ISPM 23 (*Guidelines for inspection*) and ISPM 31 (*Methodologies for sampling consignments*).

The IPPC guide on *Import verification* (FAO, 2015a) also contains useful information. The sample size (in terms of the minimum number of individuals selected from the lot or consignment to be examined) should be determined taking into account the statistical background provided in ISPM 31. Where FAW is regulated in but not yet reported from the area of import, the objective should be to aim to detect an infestation level of one percent or more with a confidence level of ≥ 99 percent.

Targeting of quarantine border inspections should be based not just on the FAW pest status of the exporting country but also on the host commodity (such as cut flowers or asparagus). Countries are encouraged to conduct comprehensive PRA and to keep up-to-date information on FAW distribution and the pest status of individual countries by referring to the International Phytosanitary Portal and relevant papers and journals. The North American Plant Protection Organization resource and training module on risk-based sampling also contains useful information (NAPPO, 2020).

Morphological keys and the bibliography allow adult moths to be identified with a high degree of confidence, based essentially on the genitalia. However, border interceptions should rely on a combination of keys and pathway considerations as There are risks of misidentification (see section on Diagnostics).

Identification leaflets on FAW are available, for example the ones developed by FAO and CABI (2019b, c), the Australian Grains Research & Development Corporation (GRDC, 2020), CottonInfo (2020), the Indian Institute for Maize Research (Firake *et al.*, 2019) and the Quebec Ministry of Agriculture, Fisheries and Food (Ministère de l'agriculture, des pêches et de l'alimentation du Québec) (RAP–MAPAQ, 2018). Such identification leaflets should also be made available to field staff.

For visual examination of consignments, plant-health inspectors should be equipped with some of the important tools such as (a torch, knife and magnifying lens (10×)). The place where the inspection is conducted should be well lit. The visual examination should begin with an overall examination of the commodity. Visual examination of the container and packaging should be conducted to determine if any eggs, larvae, or adults are present on any of the surfaces.

Any part of the plant sample with characteristic symptoms of lepidopteran feeding damage should be removed for further thorough examination. Destructive sampling of a number of randomly selected consignment samples (e.g. corn cobs, cut flower bunches, asparagus bunches) may be conducted to look for larvae which may have bored into the commodity (plant material). Plant damage symptoms caused by lepidopteran stem-borers (foliar and ear damage) and *Helicoverpa armigera* (ear damage) can be easily mistaken for those caused by FAW. Symptoms caused by larvae are not specific to *Spodoptera* spp. but generic for most primarily foliage feeding Lepidoptera species.

If suspected *S. frugiperda* are detected, specimens should be sent to the designated laboratory to confirm the species identity. Before being sent to the laboratory, larvae should be boiled and then placed in 70 percent ethanol for morphological identification or should be placed in 95–100 percent ethanol for molecular identification, and adults placed either in wrapped paper inside hermetic containers (taking care to preserve the wings, which are fragile) or in ethanol. Wing patterns and colours will not be preserved in ethanol. If the inspector suspects the presence of exotic *Spodoptera* species, especially *S. frugiperda*, the lot or consignment should be detained under official control.

## Diagnostics

The diagnostic activities for the identification of the species should be carried out by the laboratory of the NPPO or by another laboratory under the authority of the NPPO. ISPM 27 (*Diagnostic protocols for regulated pests*) and the IPPC *Guide to delivering phytosanitary diagnostic services* (FAO, 2016a) provide useful general information on diagnostics.

A diagnostic protocol covering *Spodoptera littoralis*, *Spodoptera litura*, *Spodoptera frugiperda* and *Spodoptera eridania* has been approved and published by EPPO (2015), including morphological and molecular identification.

Morphological identification is best carried out on adult stages if it is to be reliable. However, experts with experience on this genus may make an identification to species level based on the morphology of immature stages (in particular late instar larvae), with due consideration of the context. The morphological identification of the eggs is not possible.

Molecular identification can be relatively time-consuming, especially if a DNA-sequencing facility and service provider are not readily accessible. In this case, morphological identification from larvae or adult moths by an experienced person can potentially help with timely confirmation of suspect specimens. Reliable identification of *S. eridania*, *S. frugiperda*, *S. littoralis* and *S. litura* can be readily achieved via well-established molecular tests such as sequence identity confirmation. Guidance on when a molecular test is recommended is provided in the EPPO diagnostic protocol, in the sections on morphological identification of the different stages and species. The identification of *S. eridania*, *S. frugiperda*, *S. littoralis* and *S. litura* can also be performed using four simplex real-time polymerase chain reaction (PCR) test that can be combined into a single method based on TaqMan chemistry (Van De Vossenberg and Van Der Straten, 2014).

Molecular diagnostics based on the partial mitochondrial DNA cytochrome c oxidase subunit I (*mtCOI*) gene has been the most widely used approach for species confirmation, this also allowing the differentiation of "rice" and "corn" host preference (i.e. *Sfr* and *Sfc*). A loop-mediated isothermal amplification (LAMP) test has been developed in South Korea (Kim *et al.*, 2020). Another LAMP test to support diagnosis of FAW at the border and in surveillance is being developed by Agriculture Victoria in Australia (Australian Government, 2020).

Species-level morphological identification is possible for late instar larvae but is more difficult and usually requires consideration of contextual information, including the type and extent of damage. There are risks of misidentification with at least three other *Spodoptera* species – *S. eridania*, *S. littoralis* and *S. litura* – that must be discounted to confirm identification of FAW. Larvae of (primarily) Poaceae-feeding species, like *S. cilium*, *S. exempta* and *S. mauritia*, *S. exigua* but also *S. ornithogalli*, are easily confused with *S. frugiperda*. Larvae of several other noctuid genera, for instance *Agrotis*, are highly similar to *S. frugiperda*. Early larval stages of most other noctuid species are very difficult to distinguish morphologically from those of FAW.

## 2.4 Surveillance

Surveillance is an official process which collects and records data on pest presence or absence by survey, monitoring or other procedures (ISPM 5). ISPM 6 (*Surveillance*) and the IPPC guide on *Plant pest surveillance* (FAO, 2016b) are useful general references to be consulted. EFSA Pest survey card on *Spodoptera fugiperda* (EFSA, 2020) could also be consulted.

### Host range and part of host affected

Fall armyworm is extremely polyphagous. A recent review suggests it has been recorded on over 350 host species from more than 75 families, although it prefers for monocotyledons, mainly Poaceae, and also for Asteraceae and Fabaceae (Montezano *et al.*, 2018). A detailed host list is provided by EPPO (2020c). Fall armyworm causes substantial damage to crops of maize, rice, sorghum, cotton (*Gossypium* spp.), soybean (*Glycine max*) and sugarcane (*Saccharum officinarum*) around the world and its range extends to potatoes (*Solanum tuberosum*), tomatoes (*Solanum lycopersicum*), cucurbits (Cucurbitaceae) and several other vegetable and fruit crops (Casmuz *et al.*, 2010). Damage can severely reduce production, particularly when FAW is present in high population numbers. Fall armyworm can be found on almost all types of commodities of plants or above-ground plant parts. Fruits can also be infested by eggs or, more often, by larvae. Young seedlings are usually targeted as larvae emerge at the beginning of the growing season, but mature plants are also attacked as larvae age. Larvae begin feeding in the whorl and feeding extends to leaves, stems and reproductive parts; larger larvae may cut the plant at the base. Effects on plants in the natural environment are less well known.

### Symptoms and pest damage

The larval stage is the only life stage that causes crop damage. Feeding begins after hatching, though the damage from young larvae on leaves is superficial. The larvae are mainly external feeders, especially in or on young plants, while later-instar larvae can completely destroy all plant parts including stems, branches, leaves and reproductive structures (Czepak *et al.*, 2019; EPPO, 2020a). In Zea mais, as the larvae move into the whorl they begin feeding more, and as they develop they skeletonize the leaves. If the plant is older, larvae may travel to the cob or fruit and feed on the developing seeds. It is noteworthy that plant damage due to FAW infestation does not necessarily result in yield loss; pest injury can be inflicted to a certain degree without resulting in significant loss in yield (Juarez, Twigg and Timmermans 2004). In addition, plant damage incurred at some growth stages does not translate to yield loss.

Symptoms of the presence of larvae are holes in fruits or leaves along with the presence of excrement. Early stages are likely to be found by scraping the epidermis of the underside of the leaves, but this is not always the case: for instance in cut flowers such as rose, larvae tend to migrate to the flowers very soon after hatching. Symptoms caused by the larvae are not specific to *Spodoptera* but are generic for most, primarily foliage-feeding, lepidopteran species. Under natural conditions, pupation takes place in the soil where the pupae are difficult to detect. However, pupae can occasionally be found in commodities without soil, since fully grown larvae will always pupate, regardless whether or not soil is present.

Recovery of plants is dependent on FAW population numbers, but where infestation is high, the damage from larvae is often too extensive and plant death is common. In maize, FAW destroys silks and tassels, limiting the plants' ability to fertilize. Damage in a field attacked by FAW has been compared to that of hailstorm damage (CABI, 2019a) and feeding damage will often lead to secondary infections such as from fungi.

The FAW Monitoring and Early Warning System (FAMEWS) app and global platform provides a way to pool and visualize surveillance information (see below).

### Detection surveys

A detection survey is a survey conducted in an area to determine if pests are present (ISPM 5). Detection surveys should be conducted regularly to rapidly identify individuals or populations of FAW which have been accidentally introduced or have spread naturally.

These detection surveys can be conducted by collecting FAW samples by trapping or visual inspections for identification.

There are many FAW surveillance protocols available; for example, the FAO and CABI (2019b) instructions, the protocols outlined by Kearns *et al.* (2020), and the EFSA FAW surveillance guidelines (Kinkar, Delbianco and Vos, 2020) that detail specific objective-oriented considerations. The Australian Government provides detailed operational instructions on selecting a site, placing and maintaining a trap, submitting samples and managing data (Britton and Greenwood, 2020; see also Government of Western Australia, 2018). Field scouting protocols can also be found in the FAO Farmers Field Schools guide for FAW management (FAO, 2018).

Adults of *S. frugiperda*, specifically females but also 'older' males having lost part of the scales, have a non-descript external appearance. They may be overlooked easily if mistaken for common noctuid species, especially in areas where the presence of *S. frugiperda* is not (yet) expected. This may hamper early detection in the field, if growers are not aware of the possible introduction of S.frugiperda (e.g. through natural dispersal). Together with the fact that also the larvae are easily misidentified, this is the reason why surveying with pheromone traps in areas neighbouring areas where *S. frugiperda* is present is extremely important.

### Trapping

In the field and in production-, storage-, handling- and other facilities, adults can also be detected with the aid of light traps and pheromone traps. Pheromone traps allow adult males to be caught, although this may include non-target species. Light traps are species-nonspecific and catch both female and male adults.

*Sensitivity and specificity.* Trap–lure combinations can differ significantly in both sensitivity and specificity, depending on strain and geographical variation within FAW populations. Intraspecific variation in FAW is well recognized and there are corresponding strong, intraspecific variations in the composition and response to pheromones. This became apparent in central and South America, when there were poor responses to traps containing lures from North America (Andrade, Rodriguez and Oehlschlager, 2000; Malo *et al.*, 2001).

Subsequent sex-pheromone characterization has revealed considerable differences between North and South American populations (Batista-Pereira *et al.*, 2006), and lure compositions have been adjusted for use in these regions. Recent research from populations in Togo has also shown differential responses to trap–lure combinations (Meagher *et al.*, 2019).

Given this variability, it may be necessary to conduct field trials of trap–lure combinations for early detection to optimize trapping success for previously unmonitored populations. These trials should be carried out in areas where the pest is already present, and therefore this information can be used for early detection in areas that are still free of the pest.

*Lures.* Although FAW lure composition varies, it can be refined easily within known populations through comparative studies. All lure types trialled for FAW in various studies around the world have captured FAW moths, but the efficiency has varied and as an early-detection indicator in low populations this efficiency may be crucial to meeting programme objectives. These lures cannot be used for in-crop monitoring. Because there would not be a correlation between the number of moths trapped adjacent to a host crop and intensity of FAW infestations in the crop. Ref: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0089255.

Lures should be replaced every three to five weeks, depending on the weather as heavy or prolonged rain or strong winds may degrade the lures' efficacy faster. Lures are dispensed on a rubber septum, which is hung in the selected trap design and pierced to release the pheromone.

*Traps.* The trap height is commonly 1.5 m but always just above the canopy level of the grasses. Traps are placed at a minimum of 20 m apart for monitoring. Most trap types are likely to be suitable during the dry season. However, to be effective across seasons they must also be durable during the high rainfall events of the wet season, which is when high numbers of moths are likely to be present. The trap types described below have been used successfully in various places around the world, but durability and cost vary. Both trap type and lure composition influence by-catch numbers. Overall bucket traps (preferably yellow – Gilson *et al.*, 2018) are the most suitable for FAW monitoring and delta traps are the most effective for FAW detection surveys. However, the design of the trap is very likely to need refining to withstand high rainfall events.

### Visual examination

Visual examination is an examination using the unaided eye, lens, stereoscope or other optical microscope (ISPM 5).

The larvae of FAW are nocturnal and commonly feed deep in the parts of plants where they cannot be easily seen, making visual surveillance time-consuming. Nevertheless, the plants should be examined visually for FAW if any of the following conditions apply:

- the damage includes skeletonizing of leaves or large borer-type holes;
- the damage occurs overnight;
- the damage occurs after rainfall or irrigation events.

The damage caused by FAW is not specific to this species but is similar to that of other foliage-feeding lepidopterans. Nevertheless, when FAW is present, large amounts of frass that resembles sawdust when dry are obvious and skeletonizing of leaves is common. Depending on the crop, surveillance may require plant parts such as new leaves to be pulled apart; in maize, for instance, the whorl, ear, cob and tassels should be examined for damage.

### Survey locations

Trapping surveys for FAW should be conducted in regions where the pest has not been detected previously and could establish (endangered areas according to the PRA conducted) or in regions where migratory populations can be expected. This can be supported by surveillance in those parts of the region with susceptible crops. If entry of FAW is thought to be most likely by human action (travel, trade), surveys should concentrate on points of entry of freight and travelers. Countries bordering on countries/areas where FAW is present, and if natural spread is thought to be most likely, surveys should concentrate on the border area. Also locations where imported commercial commodities may be handled, selected or repacked, and inferior quality may be discarded pose a higher risk for entry.

### Survey timing and frequency

According to the best estimates for entry by natural pathways, winds blowing FAW adults into an area are most likely to occur during the wet season in tropical areas. However, FAW is likely to reproduce all year round in tropical areas and is likely to take advantage of wet microclimates, including irrigated areas, during the drier months. Trapping surveillance in tropical areas should therefore be conducted all year long, although trapping may be periodic, rather than continuous, depending on logistical constraints. Visual surveillance should coincide with the growing season and high rainfall or irrigation events.

In cooler regions where seasonal incursions are expected, trapping and visual surveillance should coincide with migratory patterns in the FAW populations.

### General surveillance

In addition to detection surveys, useful information on FAW presence can also be obtained by conducting general surveillance. General surveillance is a process whereby information on pests of concern in an area is gathered from various sources (ISPM 6). A citizen-science programme may be coordinated to encourage relevant stakeholders and the general public to watch out for FAW, as done in Australia. Simple FAW identification and information resources may be provided to importers, growers and home gardeners to encourage them to report suspected cases of FAW and hence help authorities to identify and report FAW incursions (e.g. Australian Government, 2020). See also section 2.5. More detailed information and training programmes should be offered to those involved in the production and handling of herbaceous and horticultural crops to promote and support the reporting of cases of suspected FAW presence.

### The FAMEWS mobile app

The FAW Monitoring and Early Warning System (FAMEWS) mobile app (FAO, 2020a) is an application provided by FAO for smartphones. It can be used as a tool in both detection and delimiting surveys (see section 3.1), and could be used every time a field is scouted and pheromone traps are checked for FAW. It also allows surveillance information to be pooled and visualized.

The app has the following parts:

- data entry – to collect, record and transmit:
  - basic farm data
  - scouting data (collected manually or using artificial intelligence)
  - trap data
  - immediate advice from field officers to stakeholders (farmers, growers, industry representatives);
- integrated pest management (IPM) education;
- digital library;
- chat to share experiences;
- expert resources.

Data are entered by making selections from drop-down lists. For each item, a useful explanation is provided to help the user enter accurate data. In some cases, this explanation includes photos – for instance of different pests and natural enemies. The app is intuitive, easy and fast to use. It is currently available in 29 languages.

The FAMEWS mobile app is mobile app is available for free download on smartphones. This tool is currently being improved and upgraded by FAO.

## 2.5 Communication and information sharing with stakeholders

Communication is a critical element in monitoring FAW effectively pre-incursion and in managing FAW effectively once its presence has been detected. The *IPPC guide to pest risk communication* (FAO, 2019a) and the IPPC guide on *Managing relationships with stakeholders* (FAO, 2015b) provide guidance to NPPOs on identifying and engaging with stakeholders and on developing pest risk communication strategies, including guidance on the key goals and concepts of pest risk communication, the factors that may influence its success and the principles of good pest risk communication.

NPPOs are highly encouraged, even when the FAW is still absent, to publish their FAW prevention, preparedness, and response plans on their websites.

A stakeholder awareness programme, particularyfor farmers and growers is beneficial, and should include information on how to identify FAW, what should be done if FAW is suspected, how to report to the NPPO and other relevant information that might be required. For example, communications and awareness materials from the Australian NPPO, have been developed to meet different stakeholder needs and, include NPPO information on FAW (official scientific and national-response information), jurisdictional information (operational and technical information, provided by states and territories to industry and farmers, on surveillance, management and reporting), and industry information (targeted industry information, resources and reference materials provided by affected industries – such as grain, cotton and horticulture – to support their specific industries). For the EPPO region, a datasheet and a poster are available for NPPOs to raise awareness about FAW (EPPO, 2020a and EPPO, 2020b).

# 3. Implementation of the response plan: **when the pest is officially detected and confirmed**

The response plan sets out the phytosanitary measures that are to be applied to contain or limit the spread of FAW once the pest is officially detected and confirmed, as shown in Figure 1. These include delimiting surveys, preventive measures, phytosanitary measures and measures to suppress the pest population and its spread. The response plan should be implemented immediately once FAW is officially found in a new territory. The prevention and preparedness plan should also continue to be implemented for the parts of the country where the pest is still absent.

## 3.1 **Delimiting surveys**

A delimiting survey is a survey conducted to establish the boundaries of an area considered to be infested by or free from a pest (ISPM 5).

If FAW is detected during detection surveys or if a report of a suspected case of FAW is verified, a programme of delimiting surveys should be put in place to establish the boundaries of the infested area. A distance of 100 km is usually considered an adequate cost-effective compromise for the radius of the area to be investigated, depending on the data available on the mobility of the insect (which varies depending on climatic conditions). In the territory falling within this area, the phytosanitary authorities should conduct surveys through inspections and trapping, fovouring, the areas cultivated with susceptible crops, in particular with maize, sorghum and rice but at the same time guaranteeing homogeneous coverage of the entire area.

## 3.2 **Phytosanitary measures to be implemented once FAW is officially detected**

The following phytosanitary measures should be implemented once FAW is officially detected.

- If FAW is detected in an imported consignment, the infested commodity should be immediately destroyed or treated to prevent the spread of the pest. All lots of the same consignment should be checked and, if necessary, treated or destroyed. The NPPO should notify the relevant national and international levels bodies of the pest interception. Cold storage as incubation for 3 hours at -2°C to 5°C kills more than 80% of FAW females (Luginbill, 1928).
- If FAW is detected in a site that poses a high pest risk, such as storage places for imported plants including vegetables, the source of the infestation should be traced, and the infested plants or vegetables destroyed or treated. It is important to check all plants including vegetables present on the site that may have been infested by the pest. An accurate specific surveillance programme should be implemented around the site to ensure that the pest has not already spread to the surrounding environment. Specific surveillance is a process whereby information on pests of concern in an area is obtained by the NPPO over a defined period (ISPM 6) and can include detection surveys.
- If FAW is detected in places of production or in the wild, pesticide treatments or other control measures should be applied and surveys should be intensified on maize and other host plants throughout the country.
- If the pest is not yet widespread throughout the country, the NPPO may officially establish a demarcated area (infested area + buffer zone (ISPM 5)) in which phytosanitary measures are implemented and the rest of the country may be considered as a pest free area (ISPM 4 (*Requirements for the establishment of pest free areas*), ISPM 10 (*Requirements for the establishment of pest free places of production and pest free production sites*), FAO, 2019b). A declaration of a pest free area should be supported by the results of detection surveys and similarly maintained. Given the great flying capacity of FAW, it is very difficult to define the radius of the buffer zone; the NPPO could consider entire provinces or administrative districts as areas where the pest is considered to be present.

**Caution:** Fall armyworm has a high rate of spread of more than 100 km in one night; it is very polyphagous and can be easily confused with other pests. These factors render its early detection difficult. Biological factors such as high reproductive rates and short generation time have made the eradication of FAW impossible. Eradication of FAW was attempted in Taiwan and Brunei, involving total destruction (cut and burn) of infested maize crops, but this was unsuccessful in preventing resurgence of FAW. In Australia, eradication of FAW was deemed not feasible (e.g. see FAO, 2020b) following rapid detection of FAW at multiple sites (EPPO, 2020d). Eradication has also been deemed not feasible in New Caledonia (IPPC, 2021). Governmental agencies therefore swiftly transitioned to advising industries and state government agencies to mitigate and manage the pest via chemical control as a short-term solution, and to invest and develop IPM strategies for long-term, ecologically responsible solutions. It is important to note that, to date, none of the more than 70 countries in which FAW has been detected has been able to eradicate this pest and significant pest populations have established in these affected countries.

## 3.3 Suppression of the pest to reduce pest populations

Suppression is the application of phytosanitary measures in an infested area to reduce pest populations (ISPM 5). Phytosanitary measures include legislation, regulation or official procedures, some of which have been discussed in other sections.

Potential suppression methods are summarized in Table 1.

A more comprehensive analysis of suppression methods and evidence for their effectiveness is available in relation to Outcome 2 of the FAO Global Action (see FAO, 2020b). It is emphasized that IPM is the preferred overall approach for suppression, but that different methods will be appropriate in different situations. Choosing which method to use where and when, at national, local or farm level, is critical to effective IPM. Those decisions are not discussed here but should be based on appropriate surveillance or monitoring. In order to meet the phytosanitary import requirements of importing countries, a systems approach may be appropriate, as detailed in ISPM 14 (*The use of integrated measures in a systems approach for pest risk management*).

Any suppression method being considered for use can be evaluated against several criteria.

- **Cost-effectiveness.** At the simplest level, the cost of control must be less than the value of crop loss avoided for it to be worthwhile. Opportunity and other costs may also need to be considered.
- **Efficacy**. Results demonstrating a positive effect in controlled trials in an appropriate context are desirable, though not always available.
- **Safety**. Control methods, particularly pesticides, can be hazardous to human and environmental health. Safety should be considered even during the selection and prioritization of methods to be implemented. If a relatively hazardous method is to be used, recommended precautions should be followed to mitigate human and environmental health risks. Inherent in this consideration is compatibility among methods. A suppression method that is hazardous against terrestrial arthropods, for example, may be inherently incompatible with the use of biological-control methods.
- **Availability**. The availability of regulated products such as seeds of pest-resistant or pest-tolerant varieties and plant protection products is initially determined by their registration status, and only products registered for a particular situation should be considered. Even registered products may not be widely stocked if distribution is expensive or the perceived market is small. The availability of other inputs, such as seeds of companion or intercropping plants may also be a constraint.
- **Scalability**. The scalability varies between methods according to their commercial potential (for certain technologies) or complexity and potential trade-offs (for certain practices).

Reference documents include the International Maize and Wheat Improvement Center (CIMMYT) guide to IPM for FAW in Africa (Prasanna *et al.*, 2018), the FAO guide to integrated management for FAW on maize (FAO, 2018) and the FAO FAW Guidance Notes 9 and 11 on sustainable management of FAW (FAO, 2020c, 2020d).

In addition, general guidelines for the development of a regional IPM strategy are being drawn up in collaboration with the FAO FAW Technical Committee (TWG 1-6) (FAO, 2021).

Table 1: Main categories of suppression methods, with some of their advantages and disadvantages.

| Method | Advantages | Disadvantages |
|---|---|---|
| **Pest-resistant or -tolerant host plants**<br>Conventionally bred plant varieties and transgene-based varieties | No active intervention is required for conventionally bred plant varieties<br>Compatible with other suppression methods<br>Reduced pesticide usage | Few conventionally bred resistant varieties available<br>Transgenic crops (including maize) not available in all countries<br>Resistance to some Bt genes in transgenic maize<br>Well-planned resistance pest management strategies need to be developed for transgenic crops |
| **Agronomic practices**<br>Planting time adjustments, weed management, soil-health management, changes to plant nutrition, companion cropping, intercropping, crop rotation and other habitat management practices to suppress FAW populations | Low risk to humans, non-target organisms and the environment<br>Some require no financial expenditure<br>Can encourage natural enemies of FAW | Can be labour intensive<br>Effects may depend on the context and environmental conditions<br>May not fit with usual production practices |
| **Conservation biological control**<br>Habitat management practices to conserve and encourage existing natural enemies | Low risk to humans, non-target organisms and the environment | Knowledge intensive and context-specific<br>Some opportunity or other non-financial costs |
| **Augmentative biological control**<br>Mass production and release of natural enemies of FAW (mostly egg parasitoids) | Low risk to humans | Economically sustainable production and distribution of natural enemies not easily achieved<br>Need to ensure mass releases do not have negative impact on non-target organisms |
| **Microbial pesticides**<br>Pesticides based on bacteria, viruses and fungi | Generally lower risk to humans, non-target organisms and the environment than synthetic pesticides<br>Generally less build-up of resistance to microbial pesticides than to synthetic esticides | May be slower acting that synthetic pesticides<br>Not all products are widely available<br>Need to consider national regulations |
| **Botanical pesticides**<br>Pesticides based on plant extracts, particularly neem (azadirachtin) | Generally lower risk to humans, non-target organisms and the environment than synthetic pesticides | May be slower acting than synthetic pesticides<br>Not all products are widely available |
| **Chemical pesticides**<br>Synthetic pesticides, registered for use against FAW applied as a seed treatment or to growing plants (many modes of action are effective against FAW when applied appropriately) | Act rapidly<br>Generic products can be low cost<br>Widely available | Many, especially cheaper generics, are hazardous to humans, non-target organisms (including beneficial insects) and the environment<br>Necessary personal protective equipment is often not available<br>Seed treatments may not last very long<br>Resistance to some pesticides is known in different populations of FAW in native and introduced ranges<br>Can facilitate secondary pest outbreaks<br>May lead to altered natural enemy communities |

Further information is available in FAO (2018, 2020c, 2020d), Jepson *et al.* (2020), Prasanna *et al.* (2018) and Rwomushana *et al.* (2018).

## 3.4 Communication and information sharing with stakeholders

Once FAW is detected, a dedicated communications team and a spokesperson from the NPPO should be appointed to draft a communication plan.

Communication strategies will need to quickly adapt to address the urgent need for clear, timely, consistent, relevant and science-based information targeted to the needs of different stakeholders. Building trust and credibility through inclusive dialogue and participation is critical from the beginning, particularly as the arrival of FAW presents a complex and new threat to farmers. Sound and consistent advice that can support farmers in managing FAW is critical. Identification of the different stakeholders involved and their needs is essential so that communication modes can be appropriately targeted. In the example of the Australian FAW response, the NPPO and government agencies needed to support stakeholders and growers by providing technical advice, coordination and support. but it was found that the on-the-ground response and management of FAW was better implemented and delivered at the industry and grower level. The communications plan should, therefore, always consider the specific context. Clear advice for preparing a FAW preparedness plan and communication strategy in the event of an outbreak is available in CABI (2019b). See section 2.4 and Annex 1 for further information.


EFFECT OF INTERCROPPING
MAIZE WITH LEGUMES TO
CONTROL FAW IN MAIZE
TRT - 05
1. MAIZE
2. MAIZE - MUNGBEAN
3. MAIZE - BLACKGRAM
4. MAIZE - SOYBEAN
5. MAIZE - COWPEA
REP - 04
D.OP - 28-12-2018

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# APPENDIX 1

## Checklist to draft and implement prevention, preparedness and response plans for fall armyworm (*Spodoptera frugiperda*)

### A.
### While fall armyworm (FAW) is still absent from the country, prevention, preparedness and response plans should be drafted, and the prevention and preparedness plan should be implemented

Actions to be taken include the following:

- Conduct a pest risk analysis (PRA) for FAW in the country of the national plant protection organization (NPPO), which can be based on published PRA documents conducted in areas with similar characteristics.

- Include *Spodoptera frugiperda* in the list of quarantine pests in the national phytosanitary regulation.

- Identify (i) a reference laboratory to confirm the pest species identity, and (ii) an official FAW diagnostic protocol published by relevant plant protection authorities or scientific communities (e.g. Van De Vossenberg and Van Der Straten, 2014; EPPO, 2015). Include national diagnostic protocols and procedures in prevention, preparedness and response plans to ensure consistency of identification methods (morphological or molecular). Multiple laboratories may be used to provide FAW identification and diagnostics, but all need to be working from nationally consistent diagnostic protocols.

- Draft FAW prevention, preparedness and response plans with relevant NPPO staff at national and local levels and in consultation with relevant stakeholders (e.g. producer organizations; seeds organizations; harvest and transformation centres for crops, fruits and vegetables; and sellers of crops, fruits and vegetables). Inform such stakeholders about the impacts and status of the pest and any other relevant information related to the plans. Stakeholders may also be actively engaged in surveillance and in the implementation of phytosanitary measures. The IPPC guide on *Managing relationships with stakeholders* should be consulted (FAO, 2015b).

- Define clearly the roles, responsibilities and command structure of those who are to implement the plan. Emergency plant-pest response plans and organizational arrangements will vary from country to country but should be consistent with other animal and plant quarantine and biosecurity plans for the country in question.

- Establish national FAW response and management units to plan, coordinate and manage the FAW response activity across policy, technical and operational functions.

- Organize training courses for NPPO staff, particularly on surveillance activities and phytosanitary measures, to ensure proficiency in implementing the plans.

- Conduct general surveillance through public education and awareness-raising initiatives addressed to stakeholders, particularly maize producers as maize is the most attractive crop for FAW. Conduct specific surveillance by detection surveys for FAW, based on visual examination and the use of pheromone traps.

- Develop and implement an awareness programme for small stakeholders and growers.

- Check the availability of plant-protection products and biological-control agents considered to be most effective against FAW as reported in the published, peer-reviewed, scientific literature (e.g. Jepson *et al*., 2020). In the event of shortfalls in availability, the NPPO should urge the relevant bodies to advance the production or import, the registration, and the marketing of whatever is needed to implement effective, safe, economically sustainable and low-environmental-impact control, such as the use of lower-risk pesticides (Jepson *et al*., 2020).

- Secure financial resources to provide a general annual budget for implementing the FAW prevention, preparedness and response plans. In some cases, it may not be practical to wait for annual funding budgets, in which case national FAW funding may need to be part of an emergency budget and resourcing arrangements to activate rapid and immediate responses.

- Coordinate and exchange information with regional and neighbouring countries to help regulation of trade pathways posing a pest risk and of potential natural-pathway routes.

- Organize simulation exercises with all stakeholders to promote good operational preparedness, identify gaps in the response plan and raise awareness at government, industry and local levels.

## B.
## Once an outbreak is officially detected in the country, the response plan should be implemented

An outbreak is defined as "a recently detected pest population, including an incursion, or a sudden significant increase of an established pest population in an area" (ISPM 5).

Activities to be undertaken include:

- Comply with the national reporting obligations of the International Plant Protection Convention (IPPC) and share the outbreak information with the IPPC Secretariat and other relevant bodies (e.g. Europhyt for European Union countries).
- Activate the national FAW response and management units described above.
- Appoint a dedicated communications team and a spokesperson from the NPPO, and draft a communication plan.
- Implement all activities of the response plan as necessary, including the communication plan listed above.
- Revise and update the FAW prevention, preparedness and response plans to adapt to the situation.

## IPPC

The International Plant Protection Convention (IPPC) is an international plant health agreement that aims to protect global plant resources and facilitate safe trade.
The IPPC vision is that all countries have the capacity to implement harmonized measures to prevent pest introductions and spread, and minimize the impacts of pests on food security, trade, economic growth, and the environment.

## ORGANIZATION

- There are over 180 IPPC contracting parties.
- Each contracting party has a national plant protection organization (NPPO) and an Official IPPC contact point.
- 10 regional plant protection organizations (RPPOs) have been established to coordinate NPPOs in various regions of the world.
- The IPPC Secretariat liaises with relevant international organizations to help build regional and national capacities.
- The Secretariat is provided by the Food and Agriculture Organization of the United Nations (FAO).

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