CHAPTER 02

Fall Armyworm Scouting, Action Thresholds, and Monitoring

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1. Introduction

This chapter describes several methods for detection of FAW and the use of the FAW incidence data in making treatment decisions (which may sometimes include the decision not to treat). FAW incidence (pest pressure) is one component of the decision-making process. Risk of crop loss is the result of the interaction between pest pressure, plant growth stage, and environmental conditions.

Scouting is covered first because scouting can be readily done by farmers and most directly affects their treatment decisions. Monitoring data complement field-level scouting data and inform crop management decisions. Detailed background information on these topics is followed by protocols for scouting and pheromone trap setup. The information in this chapter should be immediately useful to agricultural professionals (extension, development organization, and private-sector personnel) who advise smallholder farmers, as well as to village-level progressive farmers. It may also be of general interest to technical specialists and policymakers who develop and coordinate local, national, and regional FAW management programs.

We recognize that not all smallholder farmers will formally scout their maize fields. But we recommend that even smallholder farmers use a simplified scouting method to assess the risk of crop damage by FAW before making a control decision. Introducing farmers to scouting protocols, Action Thresholds, and decision support tools such as monitoring provides them with valuable crop management information and will help them develop the skills to more effectively manage pests. Cost-effective management of FAW requires that pest management decision makers consider the pest pressure, the maize growth stage, and the weather, regardless of whether they formally scout their fields.

Finally, we recommend that researchers and pesticide regulators who test the efficacy of interventions for FAW control use a standardized scouting protocol (see **Chapter 3**) in addition to rating plant damage and yield. Scouting data used in combination with a plant damage rating system and yield data provides a more robust assessment of efficacy.

2. Definitions

Terms used for monitoring and surveillance are not standardized across jurisdictions or scientific disciplines (FAO.IPPC 2016; McGrath *et al.* 2018). In some cases, the terms are used as synonyms and in others they have unique meanings. For the purposes of this chapter, the following definitions apply:

- ***Monitoring*** denotes an effort to actively track the presence, population, and movement of a pest within a specified geography. Monitoring activities may be organized and implemented at various scales—most typically by governments, through trained technical personnel who systematically gather data to inform policymakers and practitioners about the presence and severity of the pest across a given area. However, more localized measurements, such as data from farmers with their own pheromone traps, can also be aggregated and incorporated into broader, formal monitoring schemes. Finally, monitoring also has a specific meaning in the context of Insect Resistance Management (IRM), which refers to ongoing, repeated measurement of an insect pest population's susceptibility to a particular toxin (*e.g.*, to a pesticide or a specific insecticidal protein expressed in a genetically engineered crop variety).
- ***Surveillance*** denotes the informal, passive detection of pest presence and other issues. Surveillance is typically performed by farmers at the farm level and assumes no special training or approach. The importance of surveillance should not be overlooked. History shows that farmers in the field are often among the first to identify emerging problems, and when a mechanism exists to collect and track surveillance reports as they arise, this can lead to more rapid response to invasive pests. The collective feedback of thousands of farmers can provide powerful information about the dynamics of pest infestation. One lesson learned from the FAW management campaign in Africa was that many farmers had observed FAW before it was officially reported by scientists. In the future, there will be new pests arriving in farming areas and it is critical that pest control specialists in each country better integrate farmer observations to more effectively manage emerging pests.
- ***Scouting*** refers to an activity conducted according to science-based protocols by a trained individual—typically by a farmer, trained at the farmer field school or extension level, observing his or her own fields for the pest. Scouting allows the farmer to precisely assess pest pressure (*e.g.,* the intensity of FAW infestation) and crop performance in the field. Scouting is typically performed to evaluate both

the economic risk of pest infestation and the potential efficacy of pest control interventions within the immediate field context, with the goal of informing practical crop management decisions at the individual field and farm level. As noted above, however, localized scouting data can also be aggregated and incorporated into formal monitoring schemes at broader geographic scales.

3. Scouting for FAW in Maize

Cost-effective maize integrated pest management (IPM) programs are built on a foundation of good agricultural practices, good-quality (and preferably pest-resistant) seed and, only if needed, conservative use of pesticides. When implemented correctly, IPM lowers pest pressure through conservation biological control, which conserves natural enemies (McCravy 2008; see **Chapter 5**). It is important to scout maize fields on a regular basis to assess the risk of crop loss due to FAW and other pests. If egg-laying pressure is high and the weather is favorable to FAW, additional control measures may be needed to prevent unacceptable crop loss. Proper scouting should also provide farmers with the information necessary to avoid treatments that are not economically justified.

- ✓ **One of the fastest ways to reduce the use of insecticide** and control the cost of FAW management is to use scouting and Action Thresholds to eliminate unneeded insecticide applications.

Farmers frequently ask, "When can I skip an insecticide application without putting my crop at risk?" This chapter will answer that question, providing practical information based on field experience in Africa, the Americas, and Asia. Here, we will explore the following topics:

- ✓ Field scouting, including protocols for detecting FAW larvae of different sizes
- ✓ Guidance on what pesticide application methods to use based on FAW larval size and the growth stage of the maize plants
- ✓ Guidance on when it is advisable to use an effective, low-toxicity insecticide even though it may be more expensive than other options
- ✓ Monitoring systems for FAW
- ✓ Risk assessment data that support "no action" decisions (moth counts and weather forecasts)
- ✓ Strategic combinations of materials and methods that improve the efficacy of control tactics and reduce the cost of FAW management (see Section 8, FAW Management Scenarios)

3.1. Surveillance and Simplified Scouting

There are three approaches to assessing the risk of crop loss due to FAW in a maize field, which are referred to in this manual as *surveillance*, *simplified scouting*, and *formal scouting*. All three approaches are useful depending on the situation, the management goals of the farmer (*e.g.,* maximum grain yield, silage quality, reduction of input costs), and the level of scouting experience. The first two can be done easily by most farmers while formal scouting generally requires some amount of more formal training.

3.1.1. Surveillance

The most informal type of assessment, surveillance, gives an overall sense or first impression of what is going on in the field, and what signs to look for during more formal field scouting. *Signs* are indicators such as feeding scars on maize leaves that provide indirect evidence that FAW is present. When farmers or their advisors arrive at a maize field, they typically spend a few minutes looking around for signs of FAW (and other pests, diseases, and weeds). Information on FAW instar and severity can be quickly obtained by breaking open a few plants and taking note of the plant growth stage (see Section 3.2, Maize Growth Stages).

In some cases, surveillance is a sufficient level of assessment for the farmer to determine whether there is a pest problem in that field. There is, however, a natural sampling bias associated with surveillance because the eye is drawn to FAW "hot spots" (parts of the field that contain a heavy FAW infestation). Sampling bias during surveillance can lead to an overestimate of risk and unnecessary insecticide applications. Thus, we recommend that the farmer or advisor conduct a brief surveillance coupled with scouting, which represents a more systematic approach to risk assessment.

3.1.2. Simplified Scouting

To reduce bias while keeping the time and cost reasonable, scouting is based on sampling techniques. If one were to examine every plant in a one-hectare maize field (as many as 60,000 plants per hectare) at a rate of 5 seconds per plant, it could cost about 83 hours in labor. In contrast, the scouting instructions below recommend visiting five representative field locations per hectare and examining 10 plants per location to determine the average percentage infestation in the field. This should take no more than 15 minutes.

A simplified and useful scouting procedure is described in the training video "How to Identify and Scout for the Fall Armyworm" (https://sawbo-animations.org/708) by Scientific Animations Without Borders (SAWBO; Bello-Bravo *et al.* 2018). Simplified scouting reduces sampling bias and may reduce insecticide use. To perform simplified scouting:

- ✔ Check the field in five representative locations ("stops"). Examine 10 plants at each stop.
- ✔ Record the number of plants (out of 10) that are infested with FAW.
- ✔ Calculate an average of the FAW infestation level across the five stops.
- ✔ If an average of 2-4 plants out of 10 (20-40%) are infested with FAW in the field, consult a local Extension Officer (see Section 5, Action Thresholds).

Simplified scouting is sufficient in many cases, especially when farmers and their advisors are first learning about FAW. After the first growing season, farmers and their advisors are often ready to use a more detailed scouting method. Formal scouting follows the instructions above, but adds two additional procedures: (1) distinguishing between small and large larvae during the vegetative growth stages; and (2) evaluating the risk of yield loss caused by damage to the tassel (which reduces pollen shed and can lead to reduced kernel set and misshapen ears) or to the developing ear, especially when FAW egg laying is high and the weather is favorable to FAW (see Section 7, Decision Support Tools).

Assessing the size of the FAW larvae during vegetative growth is important because it influences spray timing, application method, and insecticide choice (see Section 8, FAW Management Scenarios). During later stages of crop growth, there is a narrow window of opportunity to control large FAW larvae, especially after initial tassel and ear emergence when they can cause substantial yield loss (see Section 4, Formal Scouting).

3.2. Maize Growth Stages

When scouting a maize field, it is important to have a general understanding of the crop growth stage. Maize growth stage does influence the scouting procedures (see Section 4, Formal Scouting) because it determines where to search, what to search for, and which Action Threshold to use (Section 5).

Maize growth stages are divided into the Vegetative (V), Vegetative Tassel (VT), and Reproductive (R) stages. The "V" stage of a maize plant is defined as the number of leaves that have a visible "collar". The maize plant below (Figure 1) has three leaves with visible collars. There are no visible collars on the fourth and fifth leaves. Therefore, this plant is at the V3 stage. Note that determining the maize V-stage precisely is not important. Mistaking a V4 plant for V3 or V5 will not affect your management decision.

The maize vegetative stages are subdivided into the early-whorl (V1-V6) and late-whorl plant (V7-V12) stages (Figure 2). Seedlings are sensitive to foliar feeding by FAW (red arrow at left in Figure 2). In addition, neonate larvae from eggs laid during the seedling stage grow into large larvae that can attack the growth point two weeks later. First tassel (VT) marks the end of the vegetative growth stages and is the stage at which the maize tassel is emerging from the whorl. There are six reproductive (R) stages, R1 (silking) to R6 (physiological maturity) (Nielsen 2019; Larson 2020). It is important to scout carefully after tassel emergence (red arrow at right in Figure 2) and during early ear development (VT-R2). R2 (blister stage) is often referred to as the "brown silk" stage, and its midpoint is about 10 days after silking (Larson 2020).

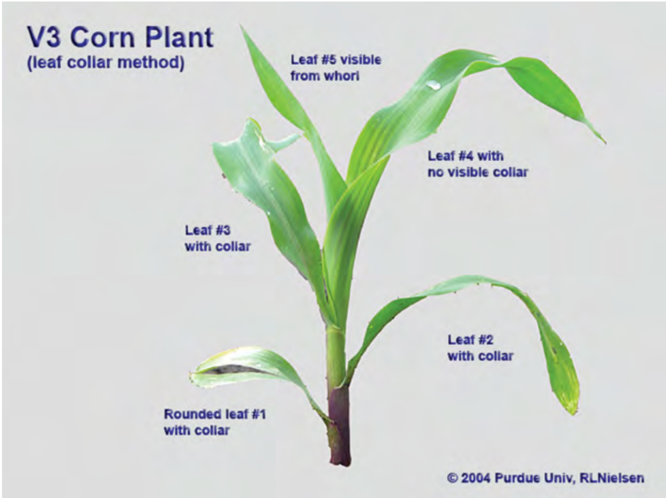


Figure 1. The maize plant displayed here has three (3) leaves with visible collars. There are no visible collars on leaves four and five. Therefore, this plant is at the V3 stage. Photo credit: R.L. Nielsen (Purdue University, USA).

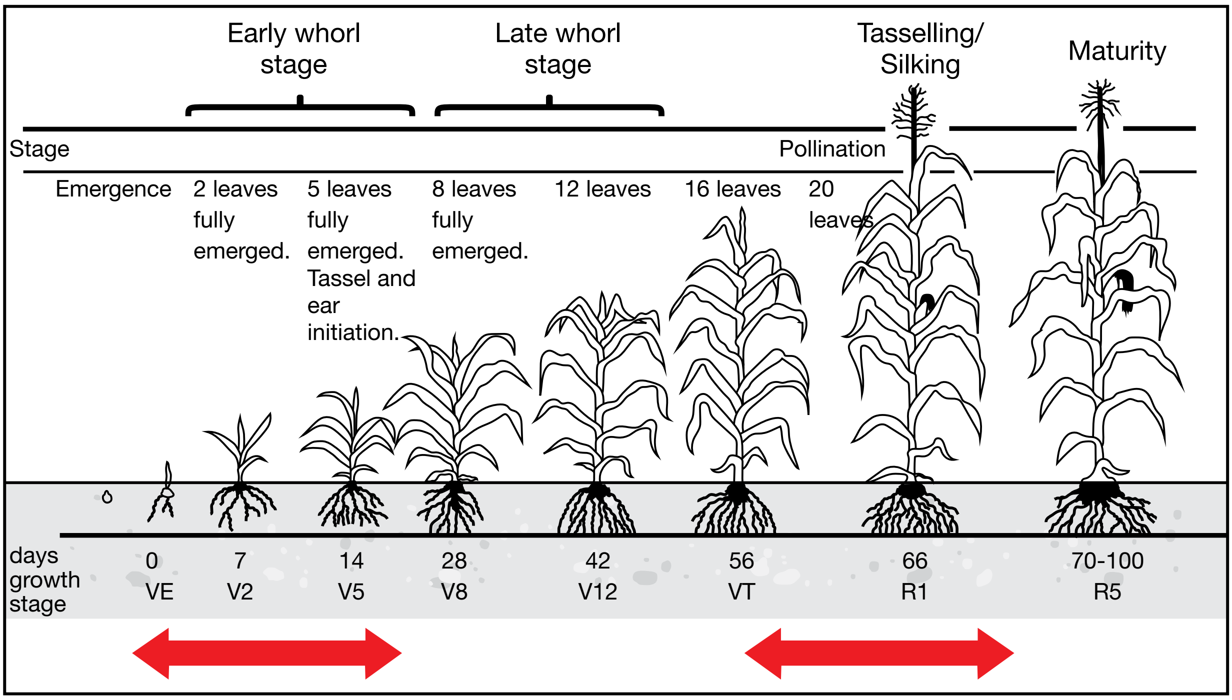


Figure 2. Vegetative (V) and Reproductive (R) stages of maize. (Adapted from Beckingham 2007).

The seedlings (VE-V6) are more vulnerable (red arrow at left) to foliar feeding by FAW than the late-whorl-stage plants (V7-V12).

Risk of crop loss due to FAW (red arrow at right) is high during early ear development (VT-R2).

4. Introduction to “Formal Scouting”

A step-by-step scouting protocol and data worksheet are provided in Section 9. The next few sections provide more detail on the principles and rationale underlying the recommended scouting procedures. Box 1 describes several abbreviations and terms used throughout this chapter.

BOX 1. Terms Used in Scouting

Percentage of Infested Whorls (%IW) – the percentage of plants with FAW larvae in the whorl.

Percentage of plants with Small, Fresh Windowpanes (%SFW) – a windowpane is an area of the leaf that the FAW fed upon but was unable to penetrate fully. Early-instar FAW larval mandibles are not able to fully penetrate the leaf surface and leave a thin, translucent layer of tissue that resembles a windowpane when held up to the sun. (The Davis Scale refers to these as pinholes; see **Chapter 3**, Section 7.1.2.)

Percentage of Infested Plants (%IP) – the percentage of plants infested by FAW. Includes plants with larvae, regardless of size, as well as those with any signs of fresh feeding.

Search arena – The area of the maize plant being searched (*e.g.*, the whorl).

Search target – The insect or sign being searched for (*e.g.*, small or large FAW larvae).

Selective spray – A pesticide application made either to a specific part of a field, to specific plants within the field, or to a specific part of the maize plant. This is generally done when it is clear that just a small number of plants are infested with larvae. The selective spraying described in this chapter is done by walking the entire field but applying the insecticide only to infested plants.

4.1. When to Scout

- Begin scouting when the maize plants are small, soon after emergence. Seedlings are vulnerable to foliar feeding; in addition, FAW sometimes acts like a cutworm, shearing the young seedling at its base. Continue scouting preferably every 7 days but no longer than every 14 days. The best time to apply control measures is at egg hatch when the larvae are small and before they move into the whorl.
- Check the fields carefully after initial tassel emergence and during early ear development. If the weather is favorable to FAW and there are larvae at the base of the developing ears, the risk of crop loss is high. Apply control measures before the larvae penetrate the husk of the developing ear.
- Scout after an insecticide application (following the insecticide label field re entry interval). It may be necessary to re-treat surviving larvae with a selective spray directed at the whorls. The advantage of selective sprays is that they may reduce pesticide use. The disadvantage is that it is possible to miss some infested plants, thus reducing the efficacy of the treatment.
- Scout after a heavy rainstorm. Heavy rainstorms can kill most of the small FAW larvae. Consider delaying a spray decision if rainstorms are likely because a spray might not be needed after a heavy rainstorm. In equatorial climates (tropical), a series of well-timed rainstorms can substantially reduce crop loss associated with FAW, even when egg-laying pressure is high.

4.2. Scouting Patterns

The first step when scouting maize is to choose one of the two basic scouting patterns. In each pattern, sampling is conducted in five representative locations per hectare. Use the “W” scouting pattern when the maize plants are small (Figure 3). Zigzag through the field, stopping and examining plants at five different locations (A-E in Figure 3).

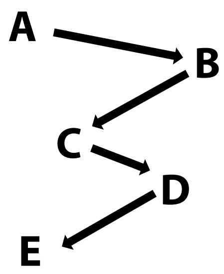


Figure 3. Use the “W” scouting pattern when plants are small. Each of the letters represents a sampling location within the field.

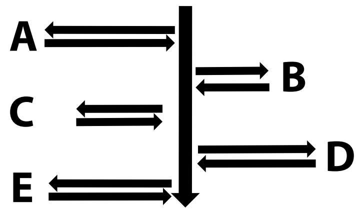


Figure 4. Use the “Ladder” scouting pattern when plants are tall. Each of the letters represents a sampling location within the field.

Use the “Ladder” scouting pattern when the maize plants are tall (Figure 4). Start at the beginning of the middle row. Walk several paces; turn right, stop, and sample. Return to the middle row. Walk several paces; turn left, stop, and sample. Return to the middle row. Repeat until five different and representative locations in the field have been examined (A-E in Figure 4).

4.3. Where and What to Look for During the Vegetative Stages

During the vegetative stages, focus observations on the newest three or four leaves emerging from the center of the whorl (a “whorl” is an arrangement of leaves in the center of the plant when looking at it from the top; see Figure 5). Focusing on the whorl will increase the chances that the feeding damage being observed is “fresh” damage, *i.e.*, indicative of actively feeding larvae.

Figure 5. Whorl of a healthy maize plant. Arrow indicates center of whorl.
Photo credit: Anani Bruce (CIMMYT).

Although one will occasionally encounter FAW egg clusters and larvae, they are usually well-hidden and not so easy to find. It is rare to see 1st- and 2nd-instar larvae (Figure 6). Therefore, during the vegetative stages, look for signs of feeding (described below) rather than eggs or larvae themselves.

Learn to distinguish between the signs of small versus large larvae. Small FAW larvae feeding on the leaves are exposed and more physiologically susceptible to insecticides. Large larvae in the whorl are protected from exposure to insecticides and are more physiologically resistant to insecticides than small larvae. Low-toxicity insecticides (*e.g.*, some microbial or botanical insecticides) are much more effective on small larvae than on larger larvae. Control options for large larvae are more limited. Although large FAW larvae are not generally found on newly emerged maize, it is possible for FAW larvae to enter the field from weeds or a neighboring crop.

Key points

✓ **Target the control of FAW when the larvae are small.**

✓ **Control the FAW larvae before they move into the whorl.**

The FAW life cycle is summarized in **Chapter 1** and described in detail by Capinera (2020).

4.3.1. Small Larvae—Signs of Feeding

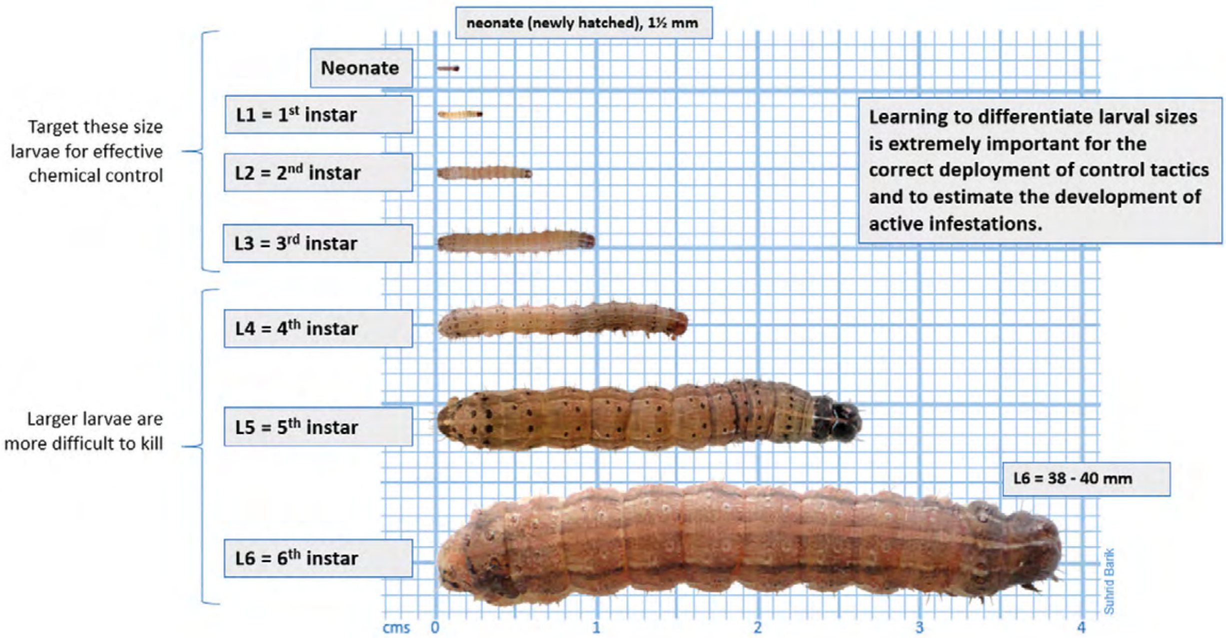


Figure 6. FAW instars (illustrated to scale). Image credit: Suhrid Barik, Corteva.

FAW eggs are laid in clusters. Egg hatch results in clusters of small larvae that in turn feed on leaves, causing clusters of small, sunken, transparent pits or windowpanes (Figures 7 and 8). Small, fresh windowpanes (SFW) indicate egg hatch and the presence of small larvae. If the indicated percentage of plants (see Section 5, Action Thresholds) has clusters of SFW, consider applying control measures.

The feeding pattern depends on the maize variety (level of resistance) as well as the crop maturity and leaf texture. When the leaves are young and tender, small larvae produce small, round windowpanes (about 1.0 mm in diameter; Figure 8). As the leaves get older and more fibrous, small larvae produce small, elongated windowpanes (about 1.0 mm in width; Figure 9).

4.3.2. Large Larvae–Signs of Feeding

Third-instar FAW larvae move down into the whorls. Larger FAW larvae (4th, 5th, and 6th instar) take up residence in the whorl and produce a variety of feeding signs: scraping, cutting and tearing, fecal pellets (frass), and a pattern sometimes called the whorl-feeding sign (Figures 10-14). For the purpose of scouting, all signs of feeding by large FAW larvae are recorded under a single heading: infested whorls (%IW).

Figure 7. Egg hatch results in a cluster of small larvae. Photo credit: Anani Bruce (CIMMYT).

Figure 8. Feeding by small larvae results in clusters of small round windowpanes that are about 1.0 mm in diameter. Photo credit: Dan McGrath.

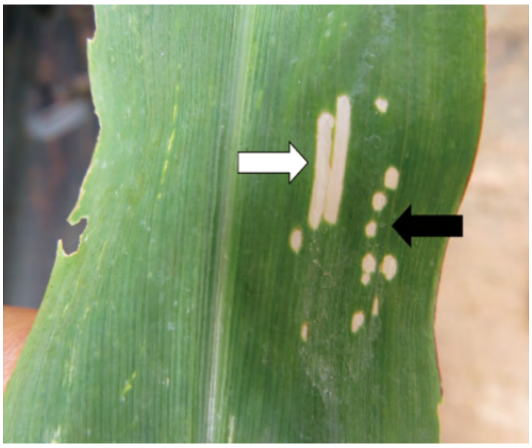


Figure 9. As the leaves mature and become more fibrous, the small windowpanes become more elongated (white arrow), about 1.0 mm in width. Black arrow shows round windowpanes made earlier on leaf. Photo credit: Dan McGrath.

By the time FAW larvae are three centimeters (3 cm) in length (Figure 10), they will complete their life cycle soon. These larvae will leave the maize plants and form their pupae in the soil. When they emerge from the pupae (referred to as eclosion), the moths fly up into the air and are scattered across the landscape by the wind. Controlling 6^{th}-instar larvae, therefore, may be a waste of time and resources. Try to time pest management actions so that treatments are applied when the larvae are small (during instars 1-3 of larval development).

Figure 10. The most useful field mark for large larval identification is the “four dots in a square” pattern on the eighth (8^{th}) abdominal segment (arrow). However, by the time FAW larvae are large enough to identify without a hand lens, they are difficult to control. Photo credit: Anani Bruce (CIMMYT).

Figure 11. Feeding by large larvae produces a sign called scraping (left). Feeding by small larvae produces clusters of small, round windowpanes (right). Photo credit: Dan McGrath.

Figure 12. Cutting, tearing, and fresh fecal pellets (frass) indicate the presence of large FAW larvae. Photo credit: Dan McGrath.

Figure 13. Damaged leaves expanding out of the whorl produce a series of holes across a "pinch" in the leaf. This is called the whorl-feeding sign. Photo credit: Dan McGrath.

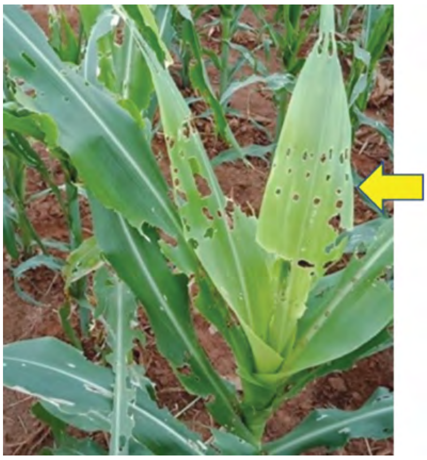


Figure 14. The whorl-feeding sign (arrow) indicates the presence of large FAW larvae. Photo credit: Anani Bruce (CIMMYT).

4.4. Where and What to Look for During the Reproductive Stages

When the tassel first becomes visible (Figure 15), the search arena (where to look) and the search target (what to look for) both change. Examine the base of the developing ears and the leaf axils above and below the ears. Look for larvae, regardless of size, and any signs of fresh feeding. In other words, during the reproductive stages (after tassel/ear emergence), scout to determine the percentage of FAW-infested plants (%IP). Base the %IP on the discovery of any larvae regardless of size and any sign of fresh feeding.

> **Note:** The reason to use this more conservative measure (%IP) is that if FAW attacks the ears, the risk of crop loss is significantly higher.

When the tassel emerges, it pushes the FAW larva(e) out of the whorl. The larvae then migrate to the base of the developing ears and the leaf axils above and below the ears (Figure 16). Eggs that hatch during tassel formation produce large larvae in about two weeks, right about the same time that the ears are filling.

There is a brief period after tassel emergence and during early ear development, *i.e.*, before the FAW larvae penetrate the husks, when application of an effective, low-toxicity insecticide can significantly reduce yield loss. At this plant growth stage, use of a low-toxicity insecticide is particularly important because of the risk to the applicator and the length of time to harvest; see **Chapter 3**. The frequency of ear damage depends on weather conditions and egg-laying pressure. If egg-laying pressure is high at first tassel emergence and the weather conditions are favorable for FAW (warm and dry), the risk of ear damage is high (see Section 7, Decision Support Tools).

FAW larvae sometimes enter the developing ears from the tip. Most of the time, however, FAW larvae either damage the base of the ear or bore through the husk and eat the developing kernels (Figure 17).

Figure 15. When the tassel emerges, it pushes the FAW larvae out of the whorl. The larvae then migrate to the base of the ears and the leaf axils above and below the ear. Photo credit: Anani Bruce (CIMMYT).

Figure 16. When scouting after tassel emergence, gently pull the developing ear away from the stem. Look for larvae at the base of the ears and in the leaf axils above and below the ears. Photo credit: Syed Nural Alam (Bangladesh).

Figure 17. After tassel emergence, the FAW larvae attack the developing ears by boring through the husk. Photo credit: Dan McGrath.

Key points

- ✓ **Scout the maize crop carefully before first tassel emergence and again between the first tassel (VT) and R2 stages.**
- ✓ **Control the FAW larvae before they penetrate the husk and enter the developing ear.**

5. Action Thresholds

There are several types of pest management thresholds including Detection, Economic, and Action Thresholds. All three are useful depending on the goals of the farmer. These concepts are described in detail in **Chapter 1** and are briefly summarized here.

If the mere presence of FAW in a maize field triggers pest control actions, we refer to this as a *Detection Threshold.* In general, use of Detection Thresholds is not advised because they will tend to overestimate the risk to the crop. An *Economic Threshold* is a formal, research-based tool that is used to evaluate the risk of economically significant crop loss, taking into account the pest population, the cost of the control measures, and the value of the crop. While a formal Economic Threshold for FAW may not be available, crop advisors have a good working knowledge of the factors typically used in calculating Economic Thresholds and can use that information to help farmers make management decisions.

An *Action Threshold* is an estimate of the Economic Threshold. It is based on impartial information but informed by practical experience and expert opinion. The Action Thresholds discussed below are based on consensus among most pest management specialists familiar with grain yield and infestation data for FAW in maize in the Americas, Africa, and Asia. For example, recent research at the International Maize and Wheat Improvement Center (CIMMYT) in Eastern Africa shows that under natural, low to moderate FAW damage levels, the yield loss of open-pollinated varieties (OPVs), FAW-tolerant hybrid maize, and FAW-susceptible hybrid maize was between 36% and 57% in the absence of chemical control. Use of hybrid maize in the absence of chemical control doubled yields relative to the OPVs (Prasanna 2019). Similarly, Britz (2020), using artificial infestation of maize plots with 3rd-instar larvae, studied the relationship between FAW infestation level and yield loss and determined that initial infestation levels of 10, 20, 40, and 100% at the V4 stage resulted in yield losses of approximately 16, 34, 49, and 74%, respectively (Britz (2020) and Johnny van den Berg, personal communication).

Table 1. Relationship between FAW infestation level and maize yield loss (Britz 2020), and potential yield protection by insecticide treatment.

		1 ton/ha scenario			3 ton/ha scenario		
Initial Infestation level (%)	Yield loss (%)	Loss from 1 t/ha field (kg)	Protected yield in kg (assuming 90% efficacy)	Value of protected yield (@US$0.21/kg)	Loss from 3 t/ha field (kg)	Protected yield in kg (assuming 90% efficacy)	Value of protected yield (@US$0.21/kg)
10	16	160	144	$30.24	480	432	$90.72
20	34	340	306	$64.26	1020	918	$192.78
40	49	490	441	$92.61	1470	1323	$277.83
100	74	740	666	$139.86	2220	1998	$419.58

Yield loss data from Britz (2020) and Johnnie van den Berg (personal communication)
Cost of maize = 15 Rupees per kilogram ($0.21 USD/kg)
One rupee = 0.014 USD (Feb 16, 2021)

An herbicide-tolerant maize hybrid, DKC78-35R, was used in this trial (Johnnie van den Berg, personal communication). Plants of this hybrid take between 68 and 78 days to 50% tassel and have relative maturity of 120 to 148 days. The inherent level of lepidopteran resistance in this hybrid is unknown (https://www.cropscience.bayer.africa/za/en-za/products/seeds/product-detail-template.html/dkc78-35r-east_west.html).

In Table 1, the data from Britz (2020) are used to illustrate calculation of an Economic Threshold for a particular variety and commercial value of maize, and how it can be used to support an Action Threshold. By estimating the potential loss of yield from a field at a particular level of infestation, one can calculate the cost of that damage. In turn, one can determine whether that loss is more than the cost of a pesticide treatment being considered (the Economic Injury Level; see **Chapter 1**). These calculations also show that for a higher-yielding field, the benefit of a pesticide treatment becomes evident even at relatively small infestation levels. The data are consistent with the Action Thresholds provided below in Table 2. Additional calculations that include costs of actual pesticide treatments are provided in **Chapter 3**, Section 7.1.5. A method for estimating yield by sampling within small plots (crop cutting) is available from the One Acre Fund (https://oneacrefund.org/documents/291/Maize_Yield_Measurement_2018_One_Acre_Fund.pdf).

The FAW Action Thresholds serve two purposes: (1) deciding when to act to prevent unacceptable crop loss, and, equally important, (2) deciding when *not* to act—when one can skip an insecticide application without putting the crop at risk.

Depending on the value of the maize crop, partial FAW control may be sufficient because some crop loss may be economically acceptable.

✓ **The presence of FAW in a crop does not necessarily mean that spraying of a pesticide is economically justified.**

Table 2 describes our recommended plant-age-based Action Thresholds, which are described in more detail in the following sections. During the vegetative stages, Action Thresholds are based on percentages of plants with specific FAW damage/injury signs associated with small (%SFW) versus large (%IW) larvae. During the reproductive stages, thresholds are based on %IP.

Ideally, Action Thresholds would be calculated for each maize variety and possibly confirmed in different world areas. In the absence of a formally calculated economic injury level, the Action Thresholds in Table 2 provide guidance for grower decisions. Section 5.3 describes several factors that can be used to adjust

Action Thresholds for a particular situation. In **Chapter 3,** Section 7.1.5 illustrates cost-benefit calculations for two different yield scenarios and provides instructions for performing these calculations given the expected efficacy of a particular treatment.

Table 2. Action Thresholds based on maize growth stage, FAW feeding signs, and larval size.

Maize growth stage and feeding sign	Growth stage	Plant-age-based Action Thresholds based on larval size	Action
Seedling (early whorl) based on percentage of plants with SFW or IW	V1-V6	20% (10-30%) with SFW or IW SFW indicate small larvae (1st & 2nd instars); IW indicate large larvae (4th, 5th, & 6th instars)	**If 20% or more of the plants have SFW or IW, consider treating (see recommendations below for different larval sizes)**
Late-whorl-stage plant based on percentage of plants with SFW or IW	V7-V12	50% (40-60%) with SFW or IW SFW indicate small larvae (1st & 2nd instars); IW indicate large larvae (4th, 5th, & 6th instars)	**If 50% or more of the plants have SFW or IW, consider treating (see recommendations below for different larval sizes)**
Tassel and early ear development based on %IP	VT-R2	**IF SPRAYING AT THIS STAGE, USE PRODUCTS WITH LOW HUMAN TOXICITY AND ONLY IF THE RECOMMENDED PPE IS AVAILABLE.*** 20% (10-30%) Percent infested plants	If %IP is 20% or more, and appropriate pesticides and PPE are available, consider treating (see recommendations below)

SFW, small, fresh windowpanes; IW, infested whorl; %IP, percent infested plants; PPE, personal protective equipment
* Particular caution must be taken during late sprays owing to the height of the plants and the risk of applicator exposure.

5.1. Action Thresholds for the Vegetative Stages (Before Tassel Emergence)

During the vegetative stages, use the scouting procedure (as in Section 9.1) to estimate the percentage of plants infested by FAW and the predominant size of the larvae. Before making a spray decision, consider the environmental conditions. A heavy rainstorm, for example, will kill most of the small larvae. If a heavy rainstorm is expected, delay the spray decision until after the rainstorm. Scout again after the rainstorm.

Seedling (early whorl stage = VE-V6):

20% (range 10-30%) of plants have SFW (small, fresh windowpanes) and/or IW (infested whorls)

- If the field exceeds the Action Threshold and most larvae are small (detected as SFW), apply a recommended foliar broadcast spray (see **Chapter 3**).
- If the field exceeds the Action Threshold and most larvae are large (detected as IW), apply a selective spray directed into the whorl of the infested plants.
- If the field exceeds the Action Threshold and both small and large larvae are detected, there are multiple overlapping generations of larvae. It may be necessary to apply a recommended broadcast spray to control the small larvae, re-scout the field, and follow up with a selective spray directed into the whorl to re-treat the large larvae that survived the first insecticide application (see Section 8, FAW Management Scenarios). NOTE: Do not re-enter the field sooner than the re-entry interval listed on the label.

  Note: This approach "resets the larval developmental clock" by killing both older and younger larvae. Thus, the next spray decision can be made based on the density of small larvae. This is the ideal situation because small larvae are easier to control.

Late-whorl-stage plants (V7-V12) are more resilient and better able to compensate for FAW leaf damage. Therefore, the plant-age-based Action Threshold is higher (less conservative) during the late-whorl plant stage than during earlier stages. It should be noted that FAW feeding on tassels and pollen can cause significant damage to maize kernel set in the developing ears.

Late-whorl-stage plant (V7-V12):

50% (range 40-60%) for SFW (indicating small larvae) and/or IW (indicating large larvae)

As the late-whorl plant stage comes to an end, scout carefully. Check the regional moths counts, if available. Check the weather forecast, if available. Watch out for the combination of high moth counts (high egg-laying pressure) and warm, dry weather. If necessary, apply an insecticide to reduce the number of larvae infesting the whorls as the maize plants begin to tassel at the end of the late-whorl plant stage.

5.2. Action Threshold for the Reproductive Stage (After Tassel Emergence)

After tassel emergence, the situation and the scouting protocol change (see Section 9.2). The plant-age-based Action Threshold is set lower (more conservative) during the reproductive stage because if FAW larvae are present during early ear development, the risk of crop loss is high.

The decision to apply a pesticide spray on developing ears is based on the %IP. In other words, if there are larvae at the base of the developing ears (regardless of size) or any signs of fresh feeding, the risk of crop loss is high.

Tassel and early ear development to brown silk stage (VT-R2):

20% (range 10-30%) based on %IP

A well-timed rainstorm can kill most of the FAW larvae (if small), significantly reducing the risk of ear damage. Moth counts and the weather forecast are particularly useful when making an ear-spray decision (see Section 7, Decision Support Tools).

✓ **If the weather is warm and dry and moth counts are high at tassel formation, check carefully for FAW at the base of the developing ears and the leaf axils above and below the ears.**

5.3. Factors Affecting Action Thresholds

As noted in the introduction to this section, the Action Thresholds presented here are based on worldwide experience, including from Asia, and provide a starting point for the decisions farmers in Asia need to make now. For crop advisors and others wanting to provide more tailored advice to farmers, the following factors can influence Action Thresholds and should be considered:

- A key variable is the maize variety's performance under insect pressure. Typically, that information is available from the seed dealer. For example, farmers planting maize varieties that do not carry resistance to FAW would generally use the lower value in the action threshold range while farmers planting maize varieties known to be tolerant to FAW would use the higher end of the range. See **Chapter 4** for more information on host plant resistance.
- Moth counts may give an indication as to the overall FAW pressure in the area (see Section 6).
- Heavy rainfalls can reduce the incidence of FAW (see Section 5.3.1).

5.3.1. Action Thresholds and the Weather

Risk of crop loss due to FAW depends on pest pressure, the maize plant growth stage, and the weather. It is widely known that FAW is sensitive to low temperatures. In addition, small FAW larvae immediately after egg hatch are highly sensitive to rainstorms that dislodge and destroy them (Varella *et al.* 2015).

Scouting and an action threshold may indicate high pest pressure, but a spray decision should also take into consideration the weather patterns and the probability of a rainstorm. If egg-laying pressure is high during the seedling stage, for example, one might decide to apply a control measure on the basis of %SFW. However, a well-timed rainstorm can kill most of the FAW larvae (if small), significantly reducing the risk of crop loss regardless of egg laying pressure. The same is true of ear damage. Heavy rainstorms during tassel and early cob formation can significantly reduce the risk of ear damage. This is particularly true in tropical (equatorial) climates where rainstorms can occur on a regular basis throughout the maize growing season. Ear damage is less common in tropical climates. Ear damage is more common in temperate climates and highly variable in subtropical climates.

✓ **Consider the probability of a rainstorm before making a spray decision. If infestation is close to the lower end of the Action Threshold range and rain is imminent, the farmer might choose to delay spraying and re-scout the field a few days after the rain event.**

6. Monitoring and Pest Population Dynamics

6.1. Introduction

Monitoring provides a higher-level view of pest populations in a geographic region and can be organized at various scales. FAW monitoring systems vary a great deal from country to country. The approach used depends, in part, on where the country stands in terms of FAW colonization (Section 6.2). Some countries in Asia are in the early stages of colonization while Africa has been dealing with the FAW since 2016 or earlier. In the Americas, FAW is an endemic pest of maize.

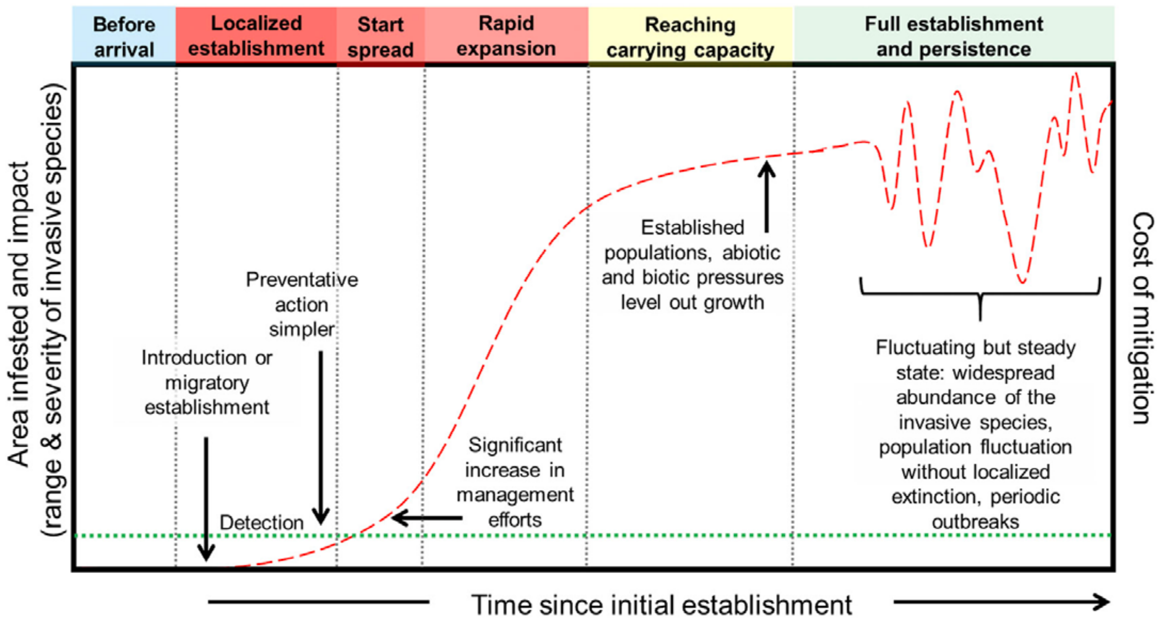
There are two styles of pheromone-based FAW monitoring systems. The most common system, the High-Density Trapping System (HDTS), uses a high density of traps, perhaps thousands, across a country. The HDTS is primarily used to detect the arrival and spread of FAW, often with the hope that new infestations can be discovered early and eradicated to prevent establishment of the new pest. An HDTS may also be used as an educational platform, alerting farmers that FAW has arrived and engaging the farming community in learning about the new pest. On the downside, HDTSs are expensive to establish and maintain; for example, lures must be regularly replaced (see trap descriptions in Section 10). In addition, the traps often capture species other than FAW. It should be noted that the skill level needed to accurately identify a FAW moth in the traps and to recognize contaminating moth species is considerable.

The other system, the Low-Density Trapping System (LDTS), uses a lower density of traps, often on the order of one or a few per thousands of square kilometers. In the USA, LDTSs are used to detect changes in the level of FAW egg-laying pressure from year to year and within a growing season, although moth counts are not always indicative of the number of larvae in the field. The LDTS is used to provide pest management decision support for farmers and their advisors and to detect populations as they migrate into new areas each season (see Section 7: Decision Support Tools). LDTSs are much less expensive to establish and maintain than HDTSs. In addition, an LDTS is usually managed by a university or other institution, where there are likely to be experts and equipment (*e.g.*, microscopes) to facilitate identification of FAW and other pests found in the traps.

6.2. Stages of Colonization

Following introduction into a new region, FAW populations expand according to a normal population colonization curve (Figure 18). Early during the colonization process, FAW infestations may be small and scattered. The first arrival of FAW often goes unnoticed. Delayed detection is usually due to a lack of systematic and comprehensive sampling to detect invasive species. Failure to listen to surveillance reports from farmers is also a factor. As described elsewhere in this manual, FAW's arrival in Asia was both anticipated and detected relatively early, and India's decision to make detection public allowed many countries to begin monitoring for FAW before its arrival to pre-emptively prepare response plans that could be rapidly implemented.

In the years immediately following introduction or migration of FAW into a given area, its establishment is localized, and the pest is most effectively controllable. Following an initial generation(s) in the localized establishment stage, as the population begins to spread, egg-laying pressure can be quite high. Farming communities suddenly realize the full potential of FAW and put a great deal of pressure on their Ministry of Agriculture to "do something." This is generally when governments establish HDTS networks, though because of the rapid growth of the pest population, this is also when management efforts to mitigate FAW will significantly increase in terms of cost and effort. Such a period of rapid expansion was observable following FAW's arrival in India—within two years, FAW had been detected as far to the east and south as Indonesia (Gustianingtyas *et al.* 2021). Given FAW's high range of dispersal (Day *et al.* 2017), and despite individual countries' efforts to mitigate FAW's impact on a preemptive basis, this rapid spread was not overly surprising.



Stages of invasive species management

Preven-tion	Early control (if possible)	Containment (if possible)	Reaching carrying capacity	Full establishment and persistence
• Pre-emptively raise awareness of stakeholders • Monitoring and surveillance	• Implement early and aggressive control measures • Attempt to contain populations before migration (may not be feasible for highly mobile species such as FAW)	• Raise public awareness • Scouting • Work to slow speed of spread • Begin IPM regimes	• Intensify IPM regimes and underscore the importance of conservation biological control • Continued population monitoring	• Ensure IPM approaches are supported and implemented • Continue to underscore the importance of conservation biological control and cultural management • Make use of weather forecasting to aid in IPM and pesticide application decisions

Figure 18. Colonization curve describing the pattern of insect arrival and localized establishment, rapid expansion (exponential growth), and full establishment (at carrying capacity) common to FAW and many other invasive species. Prevention and containment may not be possible for highly migratory pests such as FAW. Source: Timothy Krupnik (CIMMYT).

After several years, abiotic (climate, weather, wind patterns) and biotic factors (availability and concentration of preferred host plants, host plant resistance, density-dependent insect diseases, and natural enemies) begin to regulate and shape the dynamics of the FAW population. The ecosystem approaches the carrying capacity for the species and the population begins to stabilize, though periodic or localized outbreaks are still possible (Koffi *et al.* 2020). The eventual steady-state population level for FAW across Asia is unknown at this time, but in the tropical and subtropical areas of the Americas the FAW is a persistent yearly pest requiring annual control. Regardless of the specific phase of the pest in a given region, the aim of a FAW invasive species management program is to move as quickly as possible to integrate the pest into an IPM framework for maize.

Despite the importance of monitoring, especially in the early stages of a pest invasion, enthusiasm for maintaining HDTS networks often falters after a few years. Many farmers (and system actors as a whole) experience "pest alert fatigue." International development groups eventually withdraw their support for pheromone traps because supplies and the personnel to maintain them are exceedingly expensive. At this point, governments either abandon monitoring altogether or shift to a more cost-effective LDTS (see Sections 6.3-6.6). Emphasis shifts from monitoring of an invasive pest to decision support for management of an established endemic seasonal pest.

6.3. Low-Trap-Density Monitoring of FAW in North America

Experience in the Americas and Africa has shown that LDTS networks can accurately detect regional moth count trends that are useful to pest management decision makers. Once established in a region, FAW egg-laying pressure varies from year to year. The University of Kentucky, USA, provides an LDTS example that demonstrates typical FAW population dynamics in a temperate maize-production area. The example is based on a single pheromone trap, continuously maintained by the University of Kentucky Entomology Department for 14 years (Figure 19). For reference, Kentucky has a land area of approximately 104,658 km^2 (about 2/3 the size of the country of Bangladesh, which has a land area of 148,470 km^2).

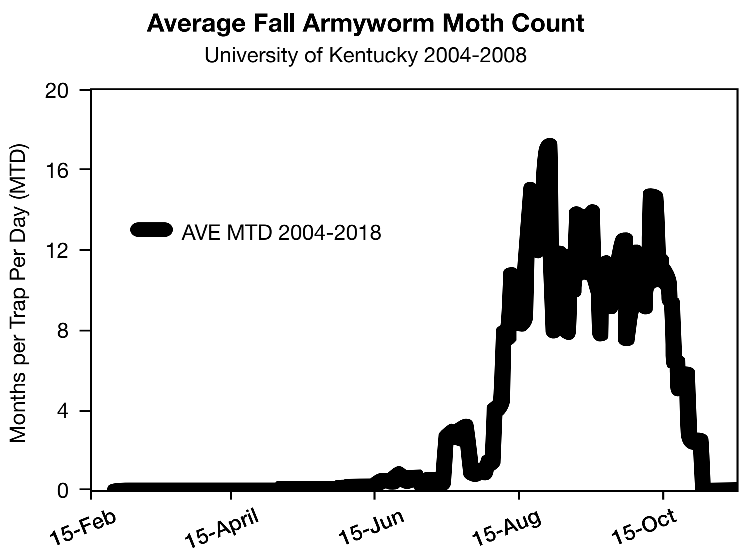


Figure 19. Average number of moths per day, Kentucky USA. The average moth count on a given calendar date was based on data collected from 2004 to 2018. Graph produced by Dan McGrath using data obtained from https://ipm.ca.uky.edu/faw (University of Kentucky College of Agriculture, Food and Environment 2020).

In Kentucky, migratory FAW moths begin to arrive each year in mid-July. The moths are carried north by the wind from endemic populations further south in states of Florida and Texas. Moth counts peak in Kentucky in September and October, late in the North American maize-growing season. This is why *Spodoptera frugiperda* is called the "fall" armyworm: in North America, where it was first observed, FAW arrives in the Fall season. As the weather turns cold in November, the population dies out.

The total number of FAW moths captured each year in Kentucky varies (Figure 20). In years with very low insect pressure, fewer than 100 moths were captured over an eight-month period (approximately 230 days), which is less than 0.44 moths per trap per day (MTD; Figure 21). In high-pressure years, close to 2,000 moths or even more were caught over an eight-month period, which is about 8.7 MTD or more (Figure 22).

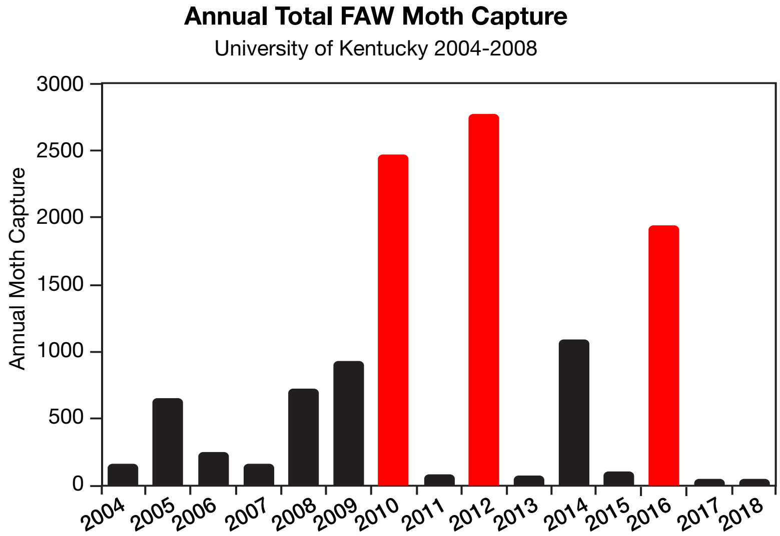


Figure 20. Total FAW moths captured in each year from 2004 to 2018, Kentucky, USA. Red indicates high FAW pressure.

Graph produced by Dan McGrath using data obtained from https://ipm.ca.uky.edu/faw (University of Kentucky College of Agriculture, Food and Environment 2020).

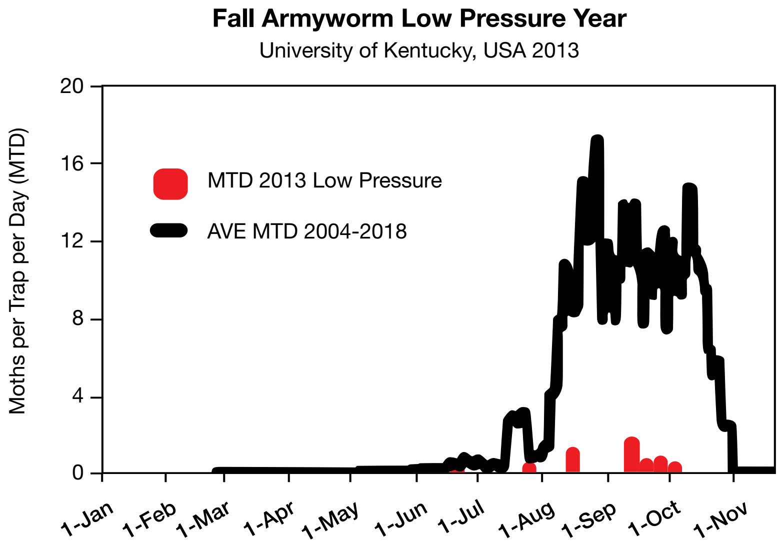


Figure 21. FAW moth counts during 2013 (red columns), a low-pressure year, University of Kentucky, USA. Graph produced by Dan McGrath using data obtained from https://ipm.ca.uky.edu/faw (University of Kentucky College of Agriculture, Food and Environment 2020).

Regional monitoring systems using LDTS networks are used throughout North America to report fluctuations in FAW populations from year to year (http://www.pestwatch.psu.edu). Using these decision support tools provides opportunities to significantly reduce insecticide use in low-pressure years.

6.4. Low-Trap-Density FAW Monitoring in Ghana and Moths Per Trap Per Day (MTD)

Regional FAW LDTSs were pilot tested in four maize production areas of central and northern Ghana during 2017. The Brong Ahafo region covers 39,557 km^2 (15,273 mi^2) and has a subtropical climate. At the beginning of the 2017 growing season, 10 extension officers in the Brong Ahafo region each chose one maize field in their area, set up a *Heliothis*-style pheromone trap (see Section 10), began

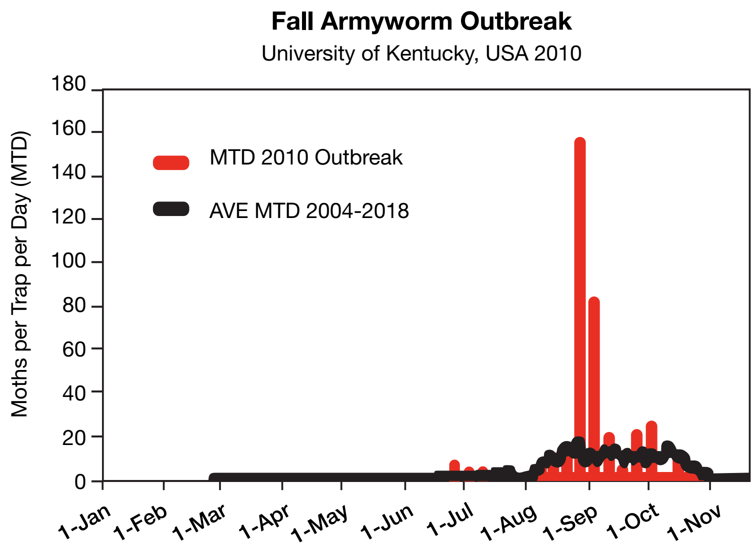


Figure 22. FAW moth counts during 2010 (red columns), a high-pressure year, University of Kentucky, USA. Graph produced by Dan McGrath using data obtained from https://ipm.ca.uky.edu/faw (University of Kentucky College of Agriculture, Food and Environment 2020).

scouting the field about once per week, and reported the data to a regional coordinator. The average regional moth count (Figure 23) was based on the 10 sampling sites.

Across the monitoring sites and throughout the maize season, the trap-check interval varied from 6 to 12 days. In order to calculate the regional average daily moth count, the total number of moths in a trap was divided by the days since the trap was last checked and reported as the MTD. (When reported on a regional basis, the MTD is also called the regional moth count.) As in North America, current experience suggests that MTDs in the range of 0.1-0.2 are low pressure while MTDs of 1.0 and above are high pressure. Further research is needed to establish nuances within these ranges, but this rough guideline should aid practitioners in their spray/no-spray decision-making process.

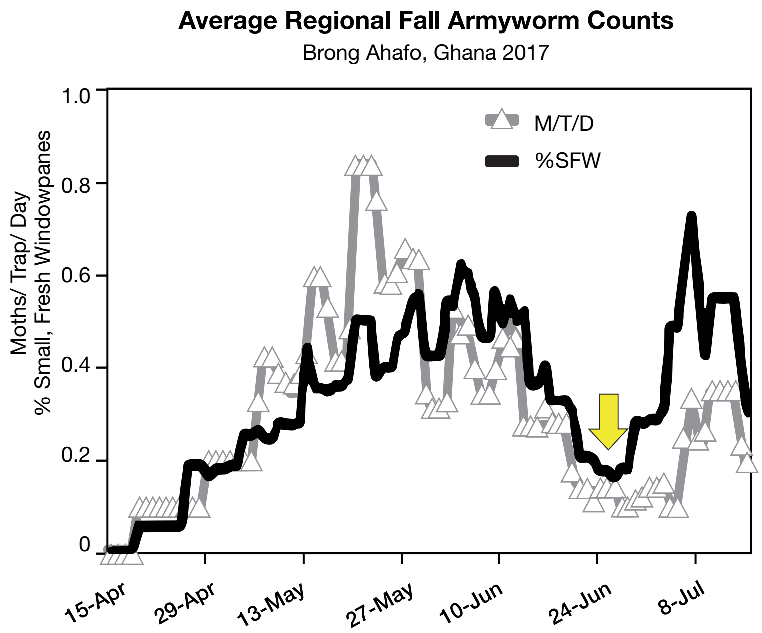


Figure 23. Average numbers of moths per trap per day (MTD) and frequencies of small, fresh windowpanes (SFW) collected from 10 monitoring sites in the Brong Ahafo Region of Ghana, 2017. For SFW, values indicate the proportion of plants with SFW (*e.g.*, 0.4 = 40% of plants had SFW). Adapted from McGrath and Ahlidza (2018).

In Brong Ahafo, the moth count rose steadily at the beginning of the rainy season as maize fields were planted. In late June, there were heavy rainstorms and moth counts declined (yellow arrow in Figure 23). The moth count tapered off as the rainy season came to an end and the maize was harvested.

As shown in Figure 23, average regional MTD counts, which indicate egg-laying pressure, were correlated with SFW percentages, which indicate egg hatch. Thus, the field scouting data appeared to validate the MTD data.

The average regional moth counts in the Brong Ahafo approached 1.0 MTD in late May. Maize fields that were planted in early to mid-April had 70% cob damage at harvest (McGrath and Ahlidza 2018). Maize that was planted in May and tasseled in June had very little cob damage. The LDTS network (one trap per 3,995 km^2) was sufficient to detect regional FAW moth count trends.

6.5. Low-Trap-Density Monitoring in Ethiopia

Low-density monitoring systems were also pilot tested in Ethiopia in four maize-producing regions during 2018 and 2019. Results below are from the Amhara Region, a subtropical maize-production area that covers 154,709 km^2 (59,734 mi^2). Sixteen Ethiopian extension officers established and maintained universal bucket-style pheromone traps (see Section 10) and reported moth counts on a weekly basis to a regional coordinator.

FAW moth counts in the Amhara rose slowly at the beginning of the rainy season as farmers began to plant maize (Figure 24). Moth counts peaked in mid-November and began to taper off as the maize was harvested and the rainy season came to an end.

In early January of 2019, the average regional moth count (yellow arrow in Figure 24) fell below 0.3 MTD. Field scouting confirmed that egg-laying pressure was low (McGrath and Chali 2019). Large (6th instar) FAW larvae from an earlier egg-laying period infested about 5% of the maize plants, which were in the V8 stage (late-whorl stage). This was consistent across several fields in the area.

Based on field scouting data and an Action Threshold and supported by the average regional moth count, farmers were advised to (1) scout their fields to confirm the low level of infestation and (2) look for opportunities to reduce insecticide use. We pointed out that only 5% of the plants were infested with 6th-instar larvae, and that the large larvae were within hours of pupation. Most of the farmers decided to spray anyway, but they only treated the infested plants using a selective spray, directing the spray nozzle into the whorl of the infested plants. This may have reduced the volume of insecticide applied.

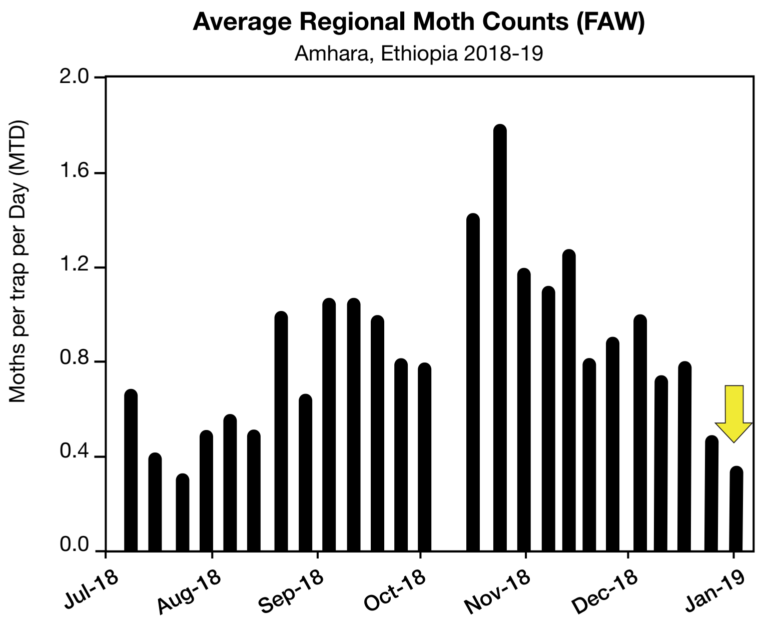


Figure 24. Average FAW moths per trap per day (MTD) in the Amhara Region of Ethiopia during 2018-19. Adapted from McGrath and Chali (2019).

The LDTS network in Ethiopia (one trap per 7,700 km^2) was sufficient to detect FAW moth count trends on a regional scale. Low egg-laying pressure was confirmed by field scouting. The combination of scouting data and moth count data was useful to the farmers, because they were considering a no-spray decision (see Section 8.3).

6.6. Low-Trap-Density Monitoring in Asia

Governments across Asia now recognize the widespread presence of FAW, and many have established pheromone trap networks to track the arrival and spread of FAW in their countries. Hundreds of farmers and extension officers are engaged in these projects.

Figure 25 shows the rise and fall of moth counts (based on pheromone trap captures) and the rise and fall of plants with clusters of SFW (based on field scouting) across Bangladesh during the Rabi (winter) maize-growing season of 2019-2020 (that particular Rabi season was unusually cold for Bangladesh). The average moth and windowpane counts were based on observations of more than 750 fields maintained by the Department of Agricultural Extension in the primary maize growing areas of the country. Averages from three traps per monitoring site were used to calculate a mean per site. Trap density was therefore three per monitoring site over an area of approximately 1,564 km^2 (293 mi^2). All data are available and open-source at the website: https://faw-monitor.firebaseapp.com/.

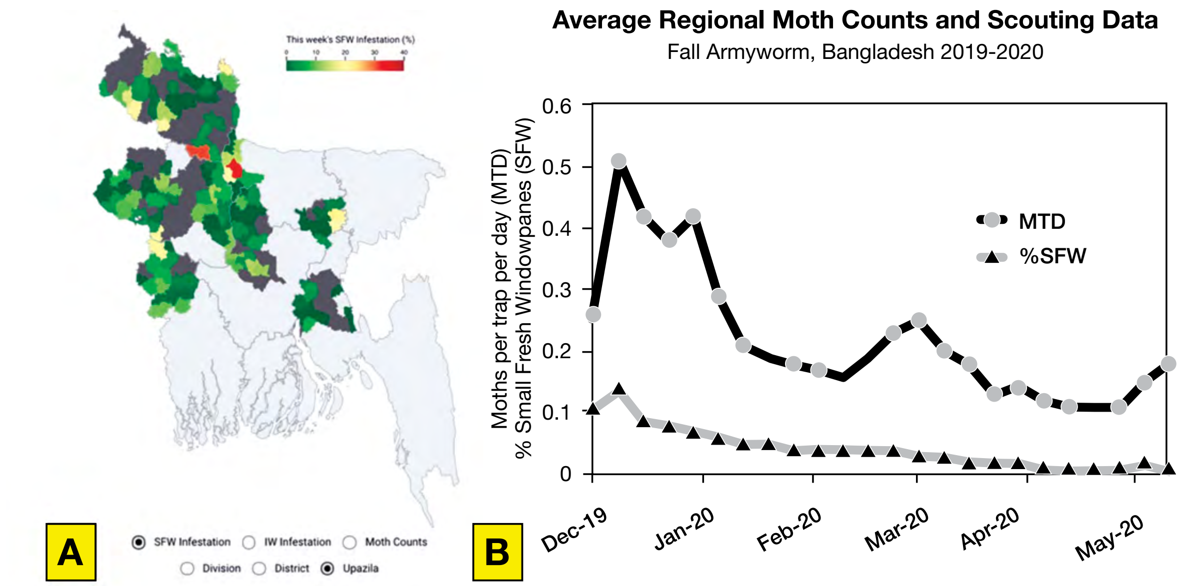


Figure 25. (A) Areas monitored for FAW in Bangladesh. (B) Average moth counts and frequencies of plants with small, fresh windowpanes during the 2019-2020 Rabi Season in Bangladesh. MTD, moths per trap per day; %SFW, percentage of small, fresh windowpanes. Source: Department of Agricultural Extension and CIMMYT, Bangladesh, available at: https://faw-monitor.firebaseapp.com/

The average MTD and the average %SFW told the same story. At the beginning of the Rabi planting season of maize (late November), egg-laying pressure was moderate. Moth counts peaked in December at about 0.5 MTD (3-4 moths per week). The percentage of plants with small larvae (based on SFW) approached the Action Threshold for seedling maize, but both moth and windowpane counts tapered off as the season progressed. By the time the maize plants began to tassel (mid-January), moth counts were low, at or below 0.2 MTD (less than one moth per day). At harvest, which begins in late March, there was essentially no cob damage. This is good news, as it indicates that sometimes insect pressure is low enough not to require aggressive treatment.

The trapping effort by the Bangladesh Extension officers indicates that there may be times in the future when FAW egg-laying pressure is low and farmers should consider reduced insecticide use. There may be times when more environmentally friendly, moderately effective materials and methods would be an appropriate and safe choice including microbials (*e.g.*, *Bacillus thuringiensis* serovar *kurstaki*), botanicals (*e.g.*, Neem oil), and biological control agents (*e.g.*, *Spodoptera frugiperda* nucleopolyhedrovirus). However, the maize crop must be checked carefully at first tassel emergence. If egg-laying pressure is high and the weather is warm and dry at that stage, switch to a highly effective, fast acting, low-toxicity insecticide.

Once FAW has become established, Asian countries may consider restructuring their monitoring systems to use a less expensive LDTS strategy. Average regional moth counts could serve as an important decision support, especially for farmers who are looking for opportunities to reduce pesticide use and control the cost of FAW management.

6.7. Monitoring for Changes in Resistance or Host Range

As detailed in **Chapter 1**, FAW exists as two strains, Corn/Maize-strain (C-strain) and Rice-strain (R-strain), which have identical morphology but differ in genetic characteristics and host preferences. Current evidence indicates that FAW in Asia is behaving as a C-strain with respect to host preference, and that the R-strain found in America may not have invaded Africa or Asia. Nevertheless, it will be important to investigate any instances of FAW feeding on millet, rice, or other crops preferred by R-strains.

Evidence from several studies (see **Chapter 1**) indicates that FAW in Africa and Asia carry alleles for resistance to synthetic pesticides. There is currently little evidence for the presence of resistance to *Bt* proteins in FAW from Africa or Asia, but this too requires continued monitoring.

7. Decision Support Tools

With training and experience, farmers or their advisors can scout a planting of maize, apply an Action Threshold, and make an informed pest management decision without moth counts or a weather forecast. Moth counts (see Section 7.1) and weather forecasts (Section7.2) should, therefore, be considered supplemental "decision support tools". The following sections explain how these decision support tools can be used in conjunction with field scouting data.

7.1. Moth Counts

Moth captures (in pheromone traps) indicate egg laying and may be the first indication that FAW is present. The presence of high moth counts should certainly prompt careful field scouting if it is not already being done on a regular basis. Moth counts (egg laying) and clusters of SFW (egg hatch) are highly correlated (see Section 6, Monitoring).

There is a narrow window of opportunity (a few days) to effectively control FAW damage after egg hatch and before the larvae move into the whorl. Once FAW larvae mature and move into the whorl, control options are limited. Moth counts can prompt timely field scouting and timely intervention, *i.e.*, when the larvae are small (1^{st} and 2^{nd} instar).

There are several potential sources of moth count data including local (field-side), area-wide (village or neighborhood), regional, and even national sources. Local or field-side trap counts are useful, but it may not be economically feasible for every farm, much less every planting, to have its own pheromone trap. Average regional moth counts, where they are available, can provide an accurate assessment of FAW egg-laying pressure.

It takes a few years before one can be confident in interpreting the moth counts for a given area. Keep historical moth count records and review this information at the end of each maize-growing season. Farmers and advisors who do this will grow more confident in the ability to discern whether moth counts are above or below average.

Based on experience so far with FAW in Africa, Asia, and the Americas, we can offer the following estimates as a starting point for interpreting average regional moth counts.

- ✓ **If the average regional moth count is 1.0 MTD or higher (seven moths per week or higher), the FAW egg-laying pressure is relatively high. Confirm this with field scouting.**
- ✓ **If the average regional moth count is 0.2 MTD or lower (approximately one moth per week), FAW egg-laying pressure is relatively low. Confirm this with field scouting.**

The high moth count guidance may seem low (1.0 MTD). Unlike many other lepidopteran insects, FAW moths rarely show up in pheromone traps in large numbers. One moth per day or seven moths per week is a significant number of FAW moth captures.

In addition, keep in mind that this advice is based on average regional moth counts. FAW moth density is usually patchy (uneven) across the landscape. The regional average integrates across high, medium, and low moth count patches. When the average moth count in a region rises above 1 MTD, regular scouting is necessary because a FAW outbreak is likely.

- ✓ **Average regional FAW moth counts will remain relatively low, even during an outbreak. One or more moths per day is significant.**
- ✓ **If both moth counts (MTD) and scouting data (%SFW) are low, look for opportunities to avoid or minimize insecticide use.**
- ✓ **If traps are improperly placed, such as being covered in tall maize, there may be no moths in the field trap even though a significant percentage of plants are infested with FAW. A poorly maintained or poorly placed trap produces misleading results. Under these conditions, field-level trap counts may be poorly correlated with field damage.**

Moth counts support no-spray decisions by increasing the confidence of farmers (or their advisors) in their scouting data. If the percentage of maize seedlings with %SFW is low and moth counts are low, a farmer may be more comfortable making a no-spray decision.

Average regional moth count trends prior to and during the growing season, if they are available, support community-based FAW management decisions.

- ✓ **High moth counts should prompt preparation for FAW control including, if time permits, the procurement of insecticide-treated seed.**
- ✓ **If one is using a short-residual botanical insecticide (*e.g.*, neem), high moth counts should prompt preparation of spray solution.**
- ✓ **If the farming community is practicing area-wide mating disruption, high moth counts should prompt area-wide deployment of FAW pheromone dispensers.**

7.2. Weather Forecasts

A heavy (and well-timed) rainstorm will kill most of the small 1st- and 2nd-instar FAW larvae feeding on the leaves. Rainstorms, however, do not control large FAW larvae established in the whorls.

In rainfed (non-irrigated) maize culture, FAW damage depends on the sequence of planting and rainfall. When rain moistens the soil at the beginning of the season, farmers often plant maize. What happens next is critical. In tropical areas where there are regular heavy rainstorms throughout the maize-growing season, FAW damage may be insignificant. FAW damage is sometimes heavier in subtropical maize-producing areas when the weather is dry and warm as the maize begins to tassel. If the weather is dry during the late vegetative stage, the risk of ear damage is higher.

The weather forecast, if available, should be considered when assessing risk of crop damage in a FAW-infested field. If rain is forecast or storm clouds are gathering on the horizon, consider delaying an insecticide application decision. Scout the field again following a rainstorm. The field may require only a selective spray (directed at the whorl) to control larvae that survived the rain, or may not need a spray at all.

7.3. Four-Step Risk Assessment with Decision Support

If moth counts and a weather forecast are available, use them. This is especially important when trying to reduce insecticide use.

An experienced individual should be able to scout a field (one hectare, five stops) in about 15 minutes and make a well-informed spray decision. Risk assessment with decision support takes four steps.

Before reaching the field …

1) Check the average regional moth count (if available)
2) Check the weather report (if available)

Upon arriving at the field…

3) Check the pheromone trap (if available)
4) Scout the field (see Section 9) and apply an Action Threshold

- ✓ Following a yes-spray decision, scout again in 7-14 days (after the label re-entry interval).
- ✓ Following a no-spray decision, shorten the scouting interval.

8. FAW Management Scenarios

The following scenarios are based on field experience in Africa and Asia. They are not meant to be prescriptive; rather, they are designed to give the practitioner a sense of how to apply field scouting data and decision support in making a pest management decision.

Good agricultural practices (GAP) do make a difference. They produce a more resilient, fast-growing maize crop that can better compensate for foliar feeding. Yield loss associated with foliar feeding by FAW is more prevalent when soil fertility is low (Clavijo 1984). Good soil fertility does not, however, prevent ear damage. Regardless of how well the crop is growing, scout fields carefully after first tassel emergence and during early ear development.

Once a farmer has made the decision to apply an insecticide, the choice of insecticide and the application method are based on the size of the larvae (small vs. large) and the maize growth stage (early vs. late). The following descriptions provide some general guidance. Details on pesticide efficacy and safety are presented in **Chapter 3**.

Foliar broadcast sprays are a relatively expensive application method because the active ingredient is applied across the entire field. A broadcast application with an effective insecticide will control small FAW larvae, but is unlikely to control large FAW larvae once they are established in the whorl. The most effective approach for controlling FAW in maize is to control the larvae before they move into the whorl.

If the %SFW is high and the %IW is low, a broadcast application should work.

Selective sprays directed at the whorl only treat the visibly infested plants. In some cases, this may reduce the volume of pesticide applied per hectare. Farmers should choose the most effective insecticide(s) they can afford, when they are trying to control large larvae.

Tassel or ear sprays are rare and should be based on careful scouting. Tassel and ear sprays may be required less often in tropical locations where heavy rainstorms occur throughout the production season. Risk of ear damage is the highest when the weather is warm and dry (no rain) and the average regional moth count (egg-laying pressure) is high.

If FAW larvae are discovered at the base of the ears, risk of yield loss is high. The risk of applicator exposure, particularly through the skin, is also high because the maize is tall. Choose a low-toxicity insecticide that is highly effective on FAW (*e.g.*, chlorantraniliprole, spinosad, spinetoram, emamectin benzoate). These insecticides are relatively more expensive than older insecticides, but they are a good value when a tassel or ear spray is needed.

The risk of applicator intoxication depends on insecticide choice, the height of the maize plants, use of personal protective equipment (PPE), and applicator practices. If the appropriate level of PPE is not available (see product label and **Chapter 3**), it is recommended to hire a professional spray service provider.

We recognize that FAW moth counts and weather forecasts are not widely available to smallholder farmers. Farmers who do have access to such information should use it, but farmers can successfully control FAW even without those data.

- ✓ In one of the case studies below, moth counts were used as a decision support for a farmer who was considering a no-spray decision.
- ✓ In another case study, rain clouds observed on the horizon were used, in part, to support a delay-spray decision.

8.1. Scenario One: High Cash-Value, No Scouting Data

Under most circumstances, calendar-based spray schedules are discouraged, but under exceptional circumstances, they might be considered. For example, under FAW outbreak conditions, a farmer growing a high-value maize crop (such as a seed company growing a hybrid maize seed production field) may be justified in using a calendar-based spray schedule. Plan on applying six insecticide sprays at a 14-day interval starting two weeks after planting and continue until brown silk (R2). Rotate the chemical family based on mode of action [MOA] (see Insecticide Resistance Action Committee [IRAC] recommendations in **Chapter 3**, Pesticides) every two sprays. A six-spray program using a rotation of effective insecticides will control cob damage even during an FAW outbreak (McGrath and Ahlidza 2018).

This is an aggressive and expensive spray program that might be used in a maize seed production field operated by a commercial seed company. It is possible that less than six applications will be needed. Scout the field and use an Action Threshold prior to each application.

- ✓ Timely and sequential application of effective insecticides at a 14-day interval keeps resetting the FAW “developmental clock” and enables treating the FAW population when the larvae are small. The insecticide applications are, therefore, more likely to be effective.
- ✓ As the plants move into the reproductive stage, it is important to reduce the possibility of FAW larvae moving to the base of the developing ears.
- ✓ Rotate the chemical families every 30 days (about every two sprays) to slow down the development of insecticide resistance.

8.2. Scenario Two: Moderate Cash-Value, Seedling Stage

Scouting Data:

- Maize growth stage: V2
- %SFW: 14%
- %IW: 0%
- Average regional moth count: Not available

Field Notes: “good moisture and soil fertility, plants growing well”

In this case, the maize plants were at the seedling stage (VE-V6). Field scouting showed that FAW egg-laying pressure was moderate; 14% of the plants had clusters of SFW. Few, if any, larvae had advanced to the 3rd or 4th instar. None had moved into the whorl.

✓ Remember that SFW are indicative of FAW egg hatch and the presence of small larvae.

This maize planting with 14% SFW was not quite at the seedling Action Threshold of 20% (Table 2). However, the Action Threshold is a range from 10% to 30% depending on the risk perception of the farmer or advisor. No moth count data were available, so the farmer did not know if the egg-laying pressure was rising or falling.

A conservative decision would be to apply a recommended foliar insecticide as a broadcast spray to kill the small FAW larvae before they move into the whorls. However, soil fertility was high and the plants were growing well (field notes). A weather forecast was not available, but rain clouds were gathering on the horizon and it looked like a heavy rainstorm was coming. The farmer decided to delay their decision and scout the field again after the rainstorm.

✓ Heavy rainstorms may kill most of the small FAW larvae (1st and 2nd instar) feeding on the leaves.

✓ Less than total FAW control during the vegetative stages may be acceptable because some crop loss at this plant stage may be economically acceptable.

8.3. Scenario Three: Moderate Cash-Value, Late-Whorl Plant Stage

Scouting and Moth Count Data:

- Maize growth stage: V9
- %SFW: <1%
- %IW: 21%
- Average regional moth count 0.1 MTD

Field Notes: "mostly 6th instar FAW larvae were observed"

In this case, the maize plants were waist-high and in the late-whorl stage (V7-V12). Egg-laying pressure was low based on field scouting (<1% of plants with SFW). The farmer (or their advisor) had access to the regional FAW moth count. The moth count was also low, a second confirmation that egg-laying pressure was low.

Twenty-one percent (21%) of the maize plants had IW. The 6th-instar larvae were from a previous egg-laying period, a residual population (survivors) following an earlier insecticide application.

✓ Remember, FAW has six larval instars. The first and second instar larvae feed on the leaves. The 3rd instar moves into the whorl. The fourth, fifth, and sixth instar occupy the whorl and sometimes come out to feed at night.

✓ Remember, the signs of feeding by large FAW larvae include scraping, cutting and tearing, frass, and the whorl-feeding-sign (Section 4.3.2). For the purpose of field scouting and application of an Action Threshold, all signs of feeding by large FAW larvae are recorded as IW.

A planting of maize with 21% IW is not at the Action Threshold for late-whorl-stage plants (30-50%; see Table 2).

✓ Remember that large, rapidly growing maize plants can tolerate and compensate for a significant amount of foliar feeding. As a result, the plant-age-based Action Threshold is higher (less conservative).

The whorl damage in a few of the plants was severe. The farmer was alarmed and prepared to spray the field again. Upon examination, the scout found that the majority of the whorl feeders were large, 6th-instar FAW larvae. FAW Action Thresholds often exclude larvae that are greater than three centimeters long (>3.0 cm), because it is not cost effective to control them (Figure 10). They are within days of pupation. At the V9 stage, first tassel is a few days away. The scout advised the farmer to skip this insecticide spray but keep scouting. The farmer rejected the advice and sprayed anyway. However, the farmer decided to selectively spray rather than spray the whole field. The farmer applied a spray directed at the whorl, spraying only the infested plants.

8.4. Scenario Four: Moderate Cash-Value, Cob Stage

Scouting Data:

- Maize growth stage: VT to R1
- %IP: 30%
- Average regional moth count: Not available

  Field Notes: “A lot of plants have FAW larvae at the base of the developing ears. The larvae have not yet begun to penetrate the husks.”

In this case, the maize plants were in the reproductive stage after first tassel. Thirty percent (30%) of the plants were infested with FAW. Based on %IP (Table 2), the Action Threshold for ear-stage maize is 20% (10-30%). There were FAW larvae at the base of the developing ears, but they had not yet begun to penetrate the husks. The weather was warm and dry.

- ✓ Remember, scouting after tassel emergence is focused on the discovery of any larvae or any sign of fresh feeding (%IP).
- ✓ Remember, if there are FAW larvae at the base of the developing ears, the risk of crop loss is high.

Since the applicator’s risk of exposure to insecticide is high when the maize plants are tall, the farmer chose to use a highly effective and low-toxicity insecticide (chlorantraniliprole). Although it was expensive, the farmer thought it was a good value.

The farmer hired a local spray service provider who wore a complete set of PPE. The applicator directed the spray at the ears and the leaf axils above and below the ears.

8.5. Scenario Five: High FAW Pressure, Subsistence Farmers

For smallholder farmers growing maize to feed their families, the crop has significant value. Subsistence farmers, however, may be cash poor, and pest control can be a significant input cost. Smallholder farmers often ask, “Can I get away with just one FAW spray?” The answer is, “It depends.” The decision should be based on field scouting and an Action Threshold.

In an emergency, smallholder subsistence farmers may purchase a small amount of a recommended, less expensive FAW insecticide available in the market. However, cheap insecticides tend to be older ones for which generic versions are available (Haggblade *et al.* 2021). Many of these less expensive insecticides tend to be highly toxic to people and only moderately effective on FAW.

- ✓ It is especially important that the subsistence farmer scouts the field when the plants are small. Seedlings are vulnerable to foliar feeding. FAW seedling damage can depress yield if good agronomic practices are not followed.
- ✓ It is equally important to treat the field while the FAW larvae are small. Small larvae are more susceptible to insecticides. Apply the insecticide when the larvae are small, before they move into the whorl.

In terms of applicator safety, when the maize plants are small, the applicator can walk down an alley and reach across the closest maize row, spraying the next row over to their side. This prevents them from walking through wet, recently sprayed foliage.

A percentage of the larvae may survive the less effective insecticide and move into the whorl. Although late-whorl-stage maize plants can tolerate more foliar feeding than seedling maize, and thus have a higher Action Threshold, most farmers should focus on controlling FAW when the larvae are small rather than wait for the appearance of large FAW larvae and damaged plants. It is very difficult to control large larvae buried in the whorls.

In many cases, depending on the weather and the egg-laying intensity, one or two sprays will be sufficient. Heavy rainstorms kill many of the 1st- and 2nd-instar FAW larvae. However, the farmer should take a careful look at the base of the developing ears between the first tassel (VT) and brown silk (R2) stages. If there are larvae at the base of the developing ears, the risk of significant crop loss is high. Farmers should consider using an effective, lower-toxicity insecticide to protect the ears (*e.g.*, 5% emamectin benzoate).

Example: One- or Two-Spray Program:

- **One broadcast spray at the seedling stage, based on field scouting and an Action Threshold using %SFW.**

  Ignore the large larvae and their dramatic feeding signs during the late-whorl plant stage. It is difficult and expensive to control the large larvae anyway.

- **One spray on developing ears using a highly effective, low-toxicity insecticide based on field scouting and an Action Threshold using %IP.**

  If the weather is favorable to FAW (dry and warm) and the egg-laying pressure (moth count) is high, expect some yield loss.

9. Protocol: Scouting a Maize Field for FAW

9.1. Scouting Instructions – Vegetative Stages

See Section 4.3 for detailed descriptions and photos.

Upon arriving at a field, make a preliminary assessment (surveillance):

- ✓ Determine whether the field has been recently sprayed with pesticide. If yes, check the re-entry interval before proceeding into the field.
- ✓ Determine the growth stage of the maize plants.
- ✓ Determine which insect pests and what size larvae are present.
- ✓ Determine which signs of insect feeding are present.
- ✓ Note whether there has been a heavy rainfall recently.

Step One: Choose a scouting pattern.

Use the “W” scouting pattern when the maize plants are small. Zigzag through the field, stopping and examining plants at five different locations within the field (A-E in Figure 3).

Use the “Ladder” scouting pattern when the maize plants are tall. Start at the beginning of the middle row. Walk several paces; turn right, stop, and sample. Return to the middle row. Walk several paces; turn left, stop, and sample. Return to the middle row. Repeat until five different and representative locations in the field have been examined (A-E in Figure 4).

Step Two: Walk into the field and begin scouting about 5 meters from the edge, avoiding the border rows. Move through the field at a steady, moderate pace.

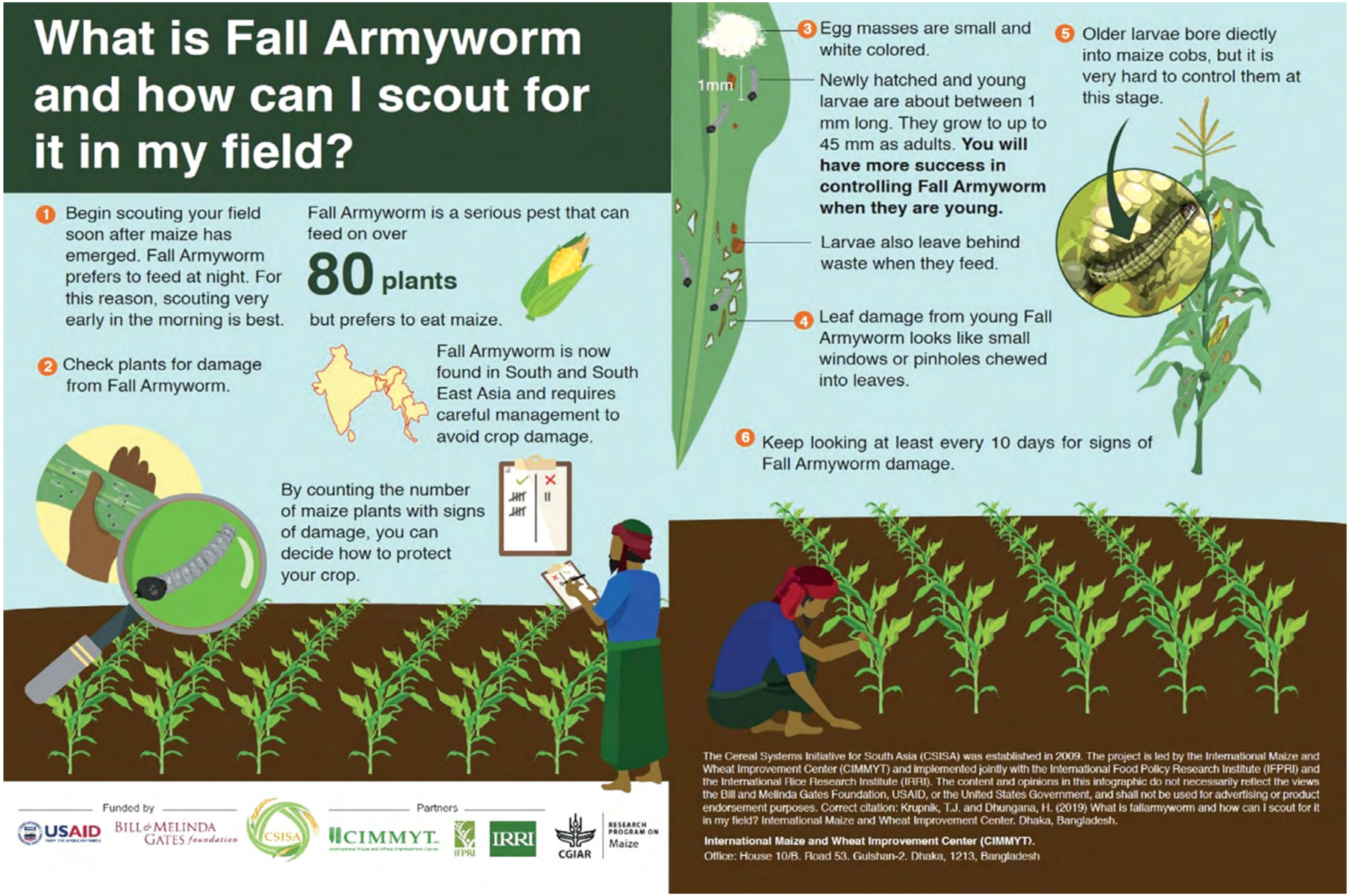


Figure S1. First pages of an infographic providing a brief summary of scouting procedures for growers. Source: CIMMYT, Bangladesh (Krupnik and Dhungana 2019). See **Chapter 7** for links to this and other FAW infographics in English, Bangla, and Lao.

Step Three: Stop and examine 10 plants in a row.

- ✓ Focus the search (search arena) on the newest three to four (3-4) leaves emerging from the whorl.
- ✓ Record the number of plants (out of 10) that have small, fresh windowpanes (SFW) and/or signs of fresh feeding by large larvae, indicating infested whorls (IW).
- ✓ Note which kind of feeding (SFW or IW) is more prevalent. The feeding sign, SFW or IW, is a clue to the size of the FAW larvae infesting the plant.

Step Four: Move to the next stop. Examine 10 plants **in a row**. Record the number of plants (out of 10) that have SFW or IW. Repeat the process at five locations per hectare.

Step Five: After examining five different locations per hectare, exit the field. Obtain two data points per field:

1) The percentage of plants that have SFW or IW.

2) The most common kind of feeding (SFW or IW).

Step Six: Make a spray decision based on the plant-age-based Action Threshold (see Section 5, Action Thresholds), the size of the larvae, and the weather. If most of the larvae are small and a rainstorm is expected, consider delaying your decision. Scout the field again the day after the rainstorm.

9.2. Scouting Instructions – Reproductive Stages

See Section 4.4 for detailed descriptions and photos.

Step One: Use the ladder pattern to scout the field. Enter in the middle of the field (middle alley).

Step Two: Walk into the field about 5 meters (to avoid the field-edge effect). Turn right and walk several paces perpendicular to the middle row. Stop and examine 10 plants **in a row**.

- Gently pull the developing ear away from the stem and examine the base of the ear.
- Briefly examine the leaf axils above and below the ears.
- Record the number of plants (out of 10) that have any larvae (regardless of size) or **<u>any sign</u>** of fresh feeding.

Step Three: Walk back to the middle. Walk several paces down the middle row. Turn left and walk several paces perpendicular to the middle row. Stop and examine 10 plants in a row.

Step Four: Walk back to the middle row. Walk several paces down the middle row. Turn right. Repeat the process at five locations per hectare.

Step Five: Exit the field. Calculate the percentage of infested plants (%IP). Use a plant-age-based Action Threshold to make a spray decision (see Section 5, Action Thresholds).

See Figure S1 for an example of an infographic summarizing scouting procedures.

FAW Scouting Worksheet

Location____________________ **Planting Date:**____________ **Pheromone Trap Type:**____________________
Name: ______________________________ **Phone**: ____________________________

Moth Trap & Weather Data	**Scouting #___**							**Scouting #___**							**Scouting #___**						
Today's date:																					
Date last checked:																					
Days since last checked:																					
FAW moth count:																					
FAW moths/trap/day (MTD):																					
Average Regional FAW (MTD):																					
Maize growth stage:																					
Insecticide Application (Date):																					
Rainstorm (Date):																					
Rainstorm Forecast (yes/no):																					
Field Scouting Data	**Vegetative (V1-V12): Examine the three to four (3-4) newest leaves emerging from the whorl.**																				
Five Stops	A	B	C	D	E	Sum	%SFW + IW	A	B	C	D	E	Sum	%SFW + IW	A	B	C	D	E	Sum	%SFW + IW
#Plants w/ small windowpanes (SFW) or infested whorls (IW):																					
Most common sign (SFW or IW):																					
Field Scouting Data	**Early Reproductive (VT-R2): Examine, tassel, base of cobs, & leaf axils above and below the cobs.**																				
Five Stops	A	B	C	D	E	Sum	%IP	A	B	C	D	E	Sum	%IP	A	B	C	D	E	Sum	%IP
#Plants w/larvae or any feeding:																					

Notes:			

Vegetative Stages (VE-V12): SFW (Small, Fresh Windowpanes = egg hatch & small larvae); IW (Infested Whorls = scraping, cutting, tearing, frass, & whorl-feeding sign = large larvae).
Early Reproductive Stages (VT-R2): %IP (Percent Infested Plants = any larvae plus any sign of fresh feeding)

10. Protocol: Pheromone Trap Setup and Maintenance for a Low-Density Network

10.1. Introduction

The most cost-effective way to produce a FAW moth count is to establish and maintain a low-density pheromone trap network (see Section 6). It is not necessary to establish a pheromone trap on every farm, much less every field. The purpose of the low-density trap network is to detect high and low egg-laying intensity and inform pest management decisions.

Most of the time, we think of pheromone trap networks as an early-warning system, detecting pest outbreaks and generating "pest alerts." It is equally important, however, to detect low-pressure periods and provide decision support when a farmer is considering a no-spray decision. When a farmer or farm advisor scouts a field and finds that the FAW larval counts are low, average regional moth counts validate and support the no-spray decision. There are few larvae in the field and few incoming moths, so no insecticide is necessary. The farmer or advisor should check the field again the following week.

10.2. Instructions for Setup and Maintenance

Establish pheromone traps at least one month before planting maize. Place the traps in or next to the maize fields so that the scent of the pheromone is carried across the tops of the plants by the wind.

As the wind blows through and around a pheromone trap, it picks up and carries the scent downwind. The length of a pheromone plume is 50-100 meters, though plume length varies according to the pheromone chemistry and other factors (Adams *et al.* 2017). The male FAW moth follows the scent-trail or "plume" back to the trap. The length of the pheromone plume determines, in part, the effectiveness of the trap and the area that is sampled.

Hang the trap from a long pole (3-4 meters). For seeding maize, start with the trap approximately 1.0 meter off the ground. As the plant grows taller, raise the trap so that its base is always 30 centimeters above the top of the plants (Figure S2).

Figure S2. As the maize plant grows tall, raise the trap up so that the base of the trap is always above the top of the plants. Photo credit: Dan McGrath.

Although some manufacturers claim that their lures "work" for several months, all lures lose strength over time. As a result, moth counts diminish over time. This can mislead a pest manager, suggesting that moth counts are low or declining when, in fact, they are not. The details of each type of trap use vary, but for most types, lures should be replaced every three to four weeks and stored in a freezer until use.

Trap maintenance is important. If the scout fails to replace the pheromone lure every 3-4 weeks, the trap attracts fewer moths as the lure loses strength. If the scout fails to raise the trap as the plant grows taller, the pheromone is not carried downwind across the top of the plant and the trap attracts fewer moths. If the plant plugs, blocks, or buries the trap, fewer FAW moths can access the trap. Note that poor maintenance leads to false and misleading moth counts.

10.3. Pheromone Trap Styles

There are a variety of pheromone traps that can be used for monitoring FAW populations. When choosing a trap, consider not only the cost, but also the durability of the trap. Consider the strength and weakness of the trap (Figures S3-S8). Some inexpensive pheromone traps are disposable after one use. Other more expensive traps can be used for five to twenty (5-20) years.

Figure S3. Delta traps are inexpensive and disposable. The male FAW moths are attracted to the lure and get stuck on the sticky bottom board. The sticky bottom has to be replaced when choked with dead moths or dust, sometimes as often as once per week. This raises the maintenance cost. Photo credit: T. Tefera, B. Sisay & J. Simiyu (*icipe*, Addis Ababa, Ethiopia).

Figure S4. Funnel traps are inexpensive, and the bags are disposable. The moths are attracted to the lure at the top of the funnel, then flutter down and are trapped in the bag. The biggest weakness of this trap is that the moths knock their wing-scales off in the bag. This makes it much more difficult to identify the FAW moths. Photo credit: Sharanabasappa Deshmukh (UAHS-Shivamogga, India).

To use a universal bucket trap (Figure S6), unwrap the insecticidal strip and place it in the bottom of the trap. Do not handle the strip with bare hands: use gloves or some other tool. An insecticide strip should last for three to four months after which it should be replaced. If the moths are still alive, fluttering around, and knocking off their wing-scales when you check a bucket trap, the insecticide strip may need to be replaced. Do not store extra insecticide strips with food. Place them in a sealed airtight jar and store in a cool, dark place.

Figure S5. Water traps are relatively inexpensive. They can be reused for a couple of seasons. The moths are attracted to the lure hanging above soapy water, then flutter down and drown. The water removes wing-scales, making moth identification difficult. It is challenging to adjust the height of the water trap, keeping it above the plants. Many farmers put the traps on the edge of the field. Photo credit: Tim Krupnik (CIMMYT).

Figure S6. Universal bucket traps are moderately expensive, but they can be reused for about 5 years. The moths are attracted to the lure suspended above the funnel, then flutter down into a dry chamber below. Inside the chamber is an insecticide strip. The moths die rapidly and retain their wing-scales., which helps with identification. Insecticide strips must be replaced every 3-4 months. This increases maintenance costs. Photo credit: T. Tefera, B. Sisay & J. Simiyu (*icipe*, Addis Ababa, Ethiopia).

Figure S7. Heliothis net traps are expensive but they can be reused for 5-10 years. The male moths are attracted to the lure suspended at the bottom of a large opening, then flutter up into a small funnel where they are trapped.

Because of the size and design of the trap, the traps are more sensitive than most other trap types. They detect moths even when the population density is low. These are one of the most popular traps in the USA for monitoring insect pests in maize fields. Photo credits: Dan McGrath.

Figure S8. Hartstack wire-mesh traps are expensive, but they can be reused for 15-20 years. They detect moths even when the population density is low. These are one of the most popular traps in the USA for low-density pheromone trap networks and regional monitoring systems.

The moths are attracted to the lure suspended at the bottom of a large opening. They fly up into a trap at the top. Wing-scales are preserved, making it easier to identify the FAW moths.

Photo credit: Copyright and Courtesy of Purdue University and Kira Albright.

10.4. Checking the Trap

FAW pheromone lures will attract the target moth species, *Spodoptera frugiperda*, but may also attract closely related moth species. It is important, therefore, to identify and count both the FAW moths and any contaminating moth species when checking a trap. Do not just count the moths in the trap and assume all those trapped are FAW moths.

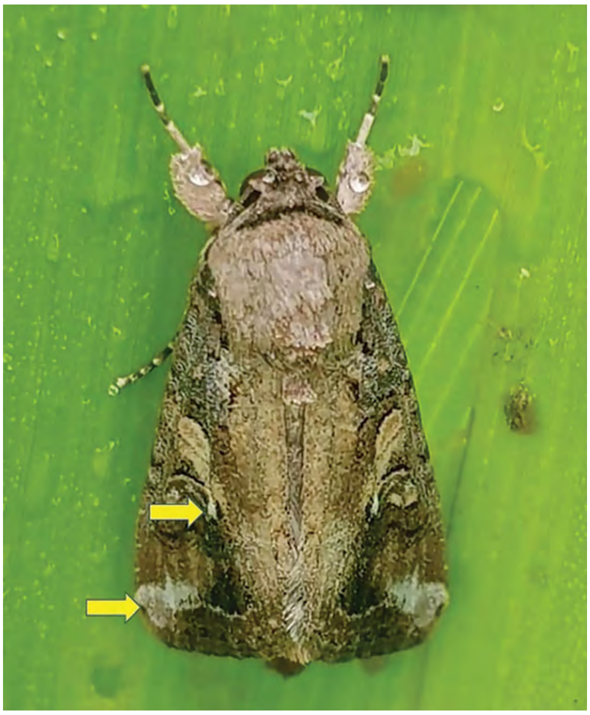


Figure S9. Male *Spodoptera frugiperda* (FAW) moths have a wingspan of 32 to 40 mm. In the male moth, the forewing is shaded gray and brown, with triangular white spots at the wing tip and near the center of the wing. Photo credit: B.M. Prasanna (CIMMYT).

If the FAW moths have blown in on the wind from another location, they will be damaged and hard to identify. Likewise, if the FAW moths have lost their wing-scales in the pheromone trap, they will be difficult to identify. Use "partial" field identification marks and body size to identify FAW (Figure S9). Look for field identification marks that should not be there, to eliminate contaminating moths (*i.e.*, moth species with field marks that do not occur on FAW moths).

- ✓ Check and empty the trap every week.
- ✓ Live moths may crawl up the sides of the trap. Pinch the thorax of the moths between your thumb and forefinger to freeze the wing muscles.

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