Xanthomonas Wilt of Banana:

Training manual

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[1] https://www.cgiar.org/initiative/plant-health

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Introduction

Xanthomonas wilt is a major banana disease affecting smallholder farms in East and Central Africa. While Xanthomonas wilt disease management practices have been introduced across extensive regions, achieving eradication has proven difficult. Re-emergence of Xanthomonas wilt in managed sites and the transmission to new regions are ongoing problems, often related to incomplete or incorrect implementation of recommended disease management practices.

This manual is designed to provide a basic, to-the-point overview on Xanthomonas wilt of banana, its management and mitigation. The manual focuses on providing practical knowledge on banana Xanthomonas wilt disease management that is directly applicable in field conditions. Throughout four concise modules, we discuss:

- Module 1: What causes Xanthomonas wilt disease and how to recognize it
- Module 2: How to prevent Xanthomonas wilt
- Module 3: Which actions to take to control Xanthomonas wilt when it is detected on a farm
- Module 4: Xanthomonas wilt management in practice: avoiding common pitfalls

All the information provided is based on current scientific research on Xanthomonas wilt carried out by various research organizations, comprising universities, OneCGIAR and NARS, and is presented in an accessible way.

We highlight disease management practices that have already provided positive results in the field (significant reductions in Xanthomonas wilt incidence) with impact at scale. Detailed attention is given to the practical issues smallholder farmers can face when implementing disease management practices and how to best prepare farmers.

Training videos accompany each module, available at **www.crophealth.org/.**

Module 1: What is Xanthomonas wilt

In this first module, we aim to provide a good understanding on what Xanthomonas wilt actually is. First, we briefly introduce which regions are affected by Xanthomonas wilt and what impact the disease has on a farmer. Next, we look more closely at:

- the bacterium causing the disease
- the symptoms it causes in infected plants
- how the disease spreads to different plants, across fields and regions
- which plant species are affected by Xanthomonas wilt (host range)

Research has shown that a good understanding of the disease epidemiology (behavior) forms the basis of understanding how and why disease management works, and can motivate the correct implementation of disease management practices in the field. For example, having a good understanding of how the disease spreads will inform us on how to prevent this spread from occurring.

We will investigate disease management in-depth in the remaining modules (Modules 2-4).

The impact of Xanthomonas wilt

Xanthomonas wilt is a major banana disease impacting banana growing regions across East and Central Africa. Xanthomonas wilt mostly affects smallholder subsistence farms which represent ~90% of the banana production systems in this region. Banana Xanthomonas wilt leads to loss of fruit production and ultimately to the death of infected plants. These losses severely impact the livelihoods and food security of smallholder subsistence farmers. Economic losses further resonate along the banana value chain resulting in substantial losses at national levels.

Xanthomonas wilt was originally reported in Ethiopia as a disease of enset (*Ensete ventricosum*), a distant relative of the banana. Official reports of Xanthomonas wilt on enset date back to 1968, although observations of similar disease symptoms have been made as early as the 1930s. In Ethiopia, the occurrence of Xanthomonas wilt on banana plants was first reported in 1974.

The first observation of Xanthomonas wilt on banana plants outside of Ethiopia were recorded in 2001 in Uganda and eastern DR Congo. The disease has since spread to the rest of the African Great Lakes countries comprising of Rwanda, Tanzania, Kenya, and Burundi (Fig. 1). Xanthomonas wilt is widespread in Ethiopia, Uganda, Rwanda, eastern DR Congo, Western Kenya adjacent to Lake Victoria, and the Kagera region of NW Tanzania.

Xanthomonas wilt currently does not occur outside of East and Central Africa.

Figure 1: Countries affected by banana Xanthomonas wilt, and when its first observation was made.

Causal agent

Xanthomonas wilt of banana is a disease caused by the **bacterium *Xanthomonas vasicola* pv. *musacearum***.

Throughout this manual, we refer to the bacterium as ***Xvm***.

Infection

The *Xvm* bacterium is a vascular pathogen that enters a host plant through wounds that expose internal tissue. Once inside a host plant, the bacteria produce yellow, mucoid colonies that will clog the vascular tissues of the plant through which water, nutrients and food move or are translocated.

After infection (i.e. the introduction of the pathogen), **the bacteria gradually spread within the plant**. Often the infection takes place at the plant inflorescence (flowering structures; discussed later on in this module) through insect vectors. From this infection site, studies have shown that the bacteria on average take 5 to 6 weeks to reach the corm (= rhizome) which is below ground. During this period, symptom expression can already occur after 2 to 4 weeks, with first symptoms closest to the infection site and progressing with the movement of the bacteria. Garden tools can also introduce the bacteria with each cut made, and the timing of symptom expression will depend on the location of infection.

Xvm bacteria however do not efficiently spread within and through the underground corm or rhizome. The corm tissues potentially act as a barrier to the movement of these bacteria. As such, the bacteria may not reach all the physically interconnected suckers on a mat. This is referred to as **incomplete systemic spread of the *Xvm* bacteria within a mat** (Fig. 2).

Figure 2: Left to right: Xvm infection at the male inflorescence; Xvm spread within the plant; incomplete systemic spread.

A low density of *Xvm* bacteria can sometimes be detected in healthy-looking suckers on the mat without (initially) causing symptoms. This is known as a **latent infection**, and the asymptomatic (i.e. healthy looking) stems can continue to develop bunches. In some cases, latent infections can develop into the disease (Fig. 3).

Figure 3: Latent infections.

Symptoms

Xanthomonas wilt of banana is characterized by the following symptoms (Fig. 4):

- The leaves of an infected banana plant will start yellowing and wilting. These leaves also tend to snap along the leaf blade as the wilting progresses, and the color will further shift from yellow to brown.
- On flowering plants, a dry rot and blackening of the male inflorescence part will occur (after an insect-mediated infection).
- The fruit will ripen unevenly and prematurely. When cutting the fruit, its pulp will show brown to black stains.
- When taking a cross section of the pseudostem or leaf sheaths, a sticky yellow liquid will ooze out of the vascular tissue [10 to 15 minutes after having made the cut]. This clogging/blocking of the vascular tissue is essentially what causes the plant to wilt and eventually die.
- Some internal pseudostem discoloration might also occur.

Figure 4: Symptoms.

The timing of symptom expression is not exact

The expression of these symptoms can occur as early as 2 to 4 weeks after initial infection, although on average, symptom expression occurs 6 to 7 weeks after infection. This timing has been shown to vary depending on the site of infection within the plant and on cultivar differences.

Low inoculum levels of the *Xvm* bacteria can also cause latent infections and these bacteria are able to survive in parts of the banana mat for over 2 years without expressing symptoms.

A farmer will only know that Xanthomonas wilt infections have entered his or her field once symptoms of the disease start to appear.

How can we be sure we are dealing with Xanthomonas wilt?

Visual detection and recognition of disease symptoms are the main ways a farmer can identify the presence of Xanthomonas wilt on his/her farm. However, how can a farmer be positive that he or she is dealing with Xanthomonas wilt and not some other disease?

The symptoms of Xanthomonas wilt can sometimes be confused with other banana diseases. For example, the yellowing and wilting of the leaves is also an important symptom of Fusarium wilt, a fungal disease (Fig. 5). Xanthomonas wilt symptomatic leaves however have a duller yellow color, while Fusarium wilt affected leaves have a brighter yellow color. Yellowing caused by Fusarium wilt will more typically start at the edge of the oldest leaves and progress towards younger leaves, while for Xanthomonas wilt, leaf yellowing happens more randomly. For Fusarium affected plants, yellow outer leaves will often break at the petiole and will then “hang” around the pseudostem. In contrast, Xanthomonas wilt affected leaves often “curl up”, or snap at the leaf blade level. Banana plants infected by Fusarium will not present the other symptoms typical for Xanthomonas wilt. Accurate Xanthomonas wilt diagnosis through visual inspection should be mainly based on the presence of yellow ooze on cut pseudostem surfaces and fruit pulp discoloration.

Supporting technologies can be used at the field level to verify disease detection. For example, the **smartphone application Tumaini** (currently available on Google Play Store) is able to detect and distinguish between symptoms of five different banana diseases, including Xanthomonas wilt, and one pest. By taking images of disease symptoms using a smartphone, this app can help farmers to accurately detect Xanthomonas wilt. We will provide more information on this smartphone application and on disease detection in Module 3.

Figure 5: Left column: Xanthomonas wilt; Right column: Fusarium wilt.

Other bacterial wilts [such as Moko and Blood disease] can cause similar symptoms to those of Xanthomonas wilt, but these wilts are currently not known to occur in Africa.

Modes of disease transmission

The *Xvm* bacteria need a transmission pathway to move from one banana plant to the next, between different fields or across regions. Here we show mechanisms of both naturally occurring transmission and human-induced transmission, and of local and long-distance spread.

Local spread

Insect vectors

Insect vectors [e.g. bees, fruit flies,..] are the primary mode of natural transmission of Xanthomonas wilt from one inflorescence to another. When these insects come into contact with the yellow bacterial ooze that is formed in infected plants, they can transmit bacterial inoculum from an infected plant to a healthy plant.

The primary sites where insects naturally come into contact with bacterial ooze are the fresh wounds formed on the **male part of the inflorescence**. The fresh abscission (natural detachment of bracts, flowers or fruits) sites on the rachis (stalk) where male flowers and bracts were attached form wounds from where bacterial ooze can leak out (Fig. 6). Transmission via the female inflorescence is rarer, as here the bract scars dehydrate more rapidly leaving a shorter time period for transmission to occur. The nectar itself contains only low inoculum levels.

Figure 6: Left: Ooze visible on a rachis with open wounds where male flowers and bracts fell off, via which insects can pick up bacterial inoculum. Right: insects on male bud.

The species composition and behavior of the insect population will directly impact how frequently these infection sites are visited and how far they carry the bacteria. For example, fruit flies will only travel the distance of a few neighboring plants during their lifespan, whereas wasps and bees will travel further increasing the distance of disease transmission. In addition, farms at higher altitudes and lower temperatures will be less affected by insect-mediated transmission simply due to lower insect population numbers and activity.

Contaminated tools

The use of farming tools unknowingly contaminated with *Xvm* bacteria is one of the main human-induced mechanisms for disease transmission. Farming tools (such as hoes, knives, or machetes) will become contaminated by working on diseased banana plants (Fig. 7). The tool blade can come into contact with sap or bacterial ooze from the infected banana plant and will carry bacterial inoculum. Consecutive management of diseased and healthy plants using contaminated tools leads to direct transmission between plants on a farm.

Contaminated tools also serve as a transmission pathway between farms as tools are often shared within communities, or even across large distances through hired labor. Traders often use their own tools in regions where they buy bunches and can thus also transmit the disease over long distances.

The *Xvm* bacteria have been shown to survive on non-stainless steel and stainless steel for up to 6 and 20 days, respectively.

Figure 7: The use of potentially-contaminated cutting tools.

Infected planting material

The use of asymptomatic infected planting material is the second main human-induced mode of Xanthomonas wilt transmission.

Most farmers source new planting material in the form of suckers from their own farm or from neighboring farms. While using symptomless suckers, latent infections of Xanthomonas wilt could be present. This introduces a risk of transferring diseased planting material into healthy fields.

Similarly, transferring asymptomatic infected planting material over longer distances (e.g. when planning to introduce new cultivars) can spread the disease to new regions.

Other types of local spread

Local trade

The *Xvm* bacteria may be spread through the trade of banana bunches (Fig. 8). Additionally, banana leaves used as wrapping material for other products can also transfer bacterial inoculum.

Birds and bats

Similarly to insect-mediated transmission, natural transmission can also occur through nectar-collecting and fruit-eating birds and bats, although this type of spread is generally less common.

Roaming domestic animals

Roaming farm animals eating from standing plants or from plant debris decomposing on the farm can transfer bacterial inoculum between plants, although this is again less common.

Soil: limited survival

Xvm bacteria only show short survival periods in soil in the absence of the host plant. An experimental study showed survival times of maximal 90 days in moist soil and 30 days in dry soils. No dormant stage of the *Xvm* bacteria in soil (or dried out plant debris) have been detected. Accordingly, soil-related dispersion of the *Xvm* bacteria is of limited importance.

Figure 8: various types of local spread.

Long-distance spread

The spread over long distances is generally human-induced, through

- movement of infected planting material,
- trade of bunches,
- the use of contaminated tools and equipment by traders,
- the use of contaminated tools and equipment by hired laborers.

Naturally occurring transmission is less common, possibly through bats and birds with a large flying radius.

Once an infection occurs at a new site or region, local modes of disease transmission will enable the disease to become established at this site.

Host range

Banana and plantain (*Musa* spp.) and enset (*Ensete ventricosum*) are the only known natural hosts of the bacteria *Xanthomonas vasicola* pv. *musacearum*, although the level of tolerance and susceptibility has been observed to vary between cultivars.

Susceptibility to infection
All cultivated bananas grown in affected regions in Africa are susceptible to the pathogen. Banana cultivars can vary in their susceptibility to insect-mediated infection due to differences in inflorescence morphology. We will learn more about this in the next module (section ‘disease-escaping cultivars’).

Tolerance and resistance
Once infected, not all banana genotypes react the same way, and different cultivars can be more susceptible or tolerant. Tolerant cultivars have the ability to sustain the effects of the disease without severe symptom expression, or without dying. Although relatively few studies are available, some genotypes show reduced symptom expression and severity, for example *Musa acuminata* subsp. *zebrina*, and Yalim belonging to the subspecies *banksii*.

On the other hand, resistant cultivars have a capacity to prevent or reduce the development of the disease. Disease resistance has been identified in the wild banana cultivar *Musa balbisiana*, in which no disease symptoms are expressed.

Short-term alternative hosts
Xvm bacteria have also been found to infect [through artificial inoculations] alternative hosts including the perennial species *Canna indica* and sugarcane, and annual crops such as maize and sorghum.

These species could play a [minor] role in the short-term survival and possible perpetuation of the *Xvm* bacteria within landscapes.

Module 2: Preventive measures

The prevention of Xanthomonas wilt is a critical aspect of disease management. Preventive practices are those practices that can prevent healthy banana plants, healthy fields or disease-free regions from becoming infected with *Xvm* bacteria .

These practices should be applied by farmers tending to disease-free fields to prevent new introductions of the pathogen into their fields, and by farmers already dealing with infected banana plants on their farm to prevent the spread to remaining healthy plants in the field or to neighboring farms.

In this module, we present practices that have been scientifically shown to significantly reduce the risk of infection and spread. The three main practices are:

- **early removal of the male bud of flowering plants**
- **disinfecting gardening tools**
- **using clean planting material**

Farmers can further opt to cultivate **disease-escaping cultivars**, substantially reducing the risk of infection through insect vectors.

Finally, we will present some upcoming technologies in the prevention of Xanthomonas wilt:

- **development of resistant cultivars**
- **early warning systems**

De-budding of the male inflorescence

In Module 1, we learned that insects are an important vector spreading the *Xvm* bacteria. Insects moving between the inflorescences of different banana plants can transfer bacteria from an infected plant to a healthy plant.

The male bud is the primary disease transmission and infection site for insect spread of *Xvm*. *Xvm* bacteria have been isolated from the sap and ooze seeping from cushions to which the male flowers were attached and at the scars made by the fallen bracts.

The timely removal of the male bud, often referred to as de-budding, prevents the formation of the primary infection site for insect vectors and thus prevents insect vector transmission of Xanthomonas wilt.

The emphasis on 'timely' is important. De-budding should be done shortly after the formation of the last fruit cluster on the bunch. Delaying de-budding even just two weeks has been shown to substantially increase the risk of transmission.

The male bud should be removed using a forked wooden stick, by twisting the male bud (Fig. 9). Contact with the rachis should be avoided to prevent contamination of the wooden stick with bacterial ooze. Machetes or other metal tools should not be used, because they increase the risk of bacteria transmission when moving between plants. A forked wooden stick also enables farmers to easily remove male buds that are out of reach.

Figure 9: Insects on the male bud, and male bud removal using a wooden stick.

Tool sterilization

The use of farming tools potentially contaminated with *Xvm* bacteria plays a critical role in the spread of Xanthomonas wilt. Farming tools need to be disinfected routinely to prevent disease transmission (see Fig. 10).

Tool sterilization methods

Cleaning tools using a 20% solution of **household bleach** (sodium hypochlorite, NaOCl, 3.5%) is very effective in removing *Xvm* inoculum and thus sterilizing the tool blade. While the method is fast and easily implemented, household bleach is not always easily accessible in remote areas, or can be too expensive for poorer households. Household bleach is also prone to adulteration which can affect its efficacy.

Gardening tools can also be effectively sterilized by **inserting the blade into fire**. The duration that the blade should be left in the fire is generally recommended as 20-40 seconds, although recent research shows heating up to 1 minute is required to clear all bacteria. Repeated heating of tool blades can nevertheless damage the metal blade. This damage to tools and the cost of replacement can be very discouraging to farmers to continue with tool sterilization for disease prevention. During the dry season, maintaining an open fire also increases the risk of an uncontrolled fire spreading on the plantation.

Alternatively, a tool blade can be **inserted into boiling water** for 1 minute. This method is similarly effective in sterilizing tools.

The use of **laundry soaps/detergents with cold water** has recently been shown to be a good alternative to bleach, attaining similar sterilizing levels. This method is easily implemented, with the added benefit that laundry soaps and detergents are cheaper than household bleach and generally already used within a household (even in remote areas).

Figure 10: Sterilising tools

Maintaining a fire nearby for direct insertion of a blade, or for continuously boiling water, can be time-consuming and cumbersome. As most farmers work with a single machete or knife, they may not have the time or patience to apply these techniques. Keeping a bucket with diluted household bleach or soap/detergent nearby can be easier in use and faster.

What doesn't work...

Other methods, including insertion of the tool into hot or cold ash, repeatedly and forcefully inserting tools into the soil, washing with cold water, the use of botanicals for their antibiotic properties, or the use of solar radiation, have proven less effective and are not recommended.

Infrequent use of gardening tools also cannot ensure a sterile blade, as the *Xvm* bacteria have been shown to survive for up to 6 and 20 days on non-stainless steel and stainless steel, respectively.

When and how often do tools need to be sterilized?

Farmers are advised to routinely disinfect tools when pruning or harvesting on different mats.

Critically, only clean tools should be used on healthy banana mats. To reduce the time needed to sterilize a tool in infected fields, farmers can be advised to first perform the necessary work on healthy plants, and to subsequently cut all diseased plants consecutively. Disinfection is not needed in between cutting infected plants. Tool sterilization should still be performed when moving from one apparently healthy plant to the next, since asymptomatic diseased plants could be present in the field.

Note: When farmers work together or hire labor, they should ensure that all tools brought in from outside their farm are effectively sterilized before use.

Clean planting material

When setting up new banana fields, or when replacing uprooted infected banana plants or mats, it is critical to use clean planting material to prevent bringing in *Xvm* inoculum and (re-) infecting a field.

Most farmers rely on suckers or rhizome pieces sourced from their own field or from neighboring farms. This introduces a risk of transferring diseased planting material into healthy fields. New planting material should ideally be sourced from disease-free banana fields, or at least from healthy-looking banana mats. Symptomless banana mats can still carry *Xvm* bacteria in the form of latent infections. Newly planted symptomless suckers should regularly be monitored for potential symptom expressions.

The use of symptomless suckers should however be avoided when moving at larger spatial scales. Since a disease-free status of these suckers cannot be ensured, the transmission to new regions where Xanthomonas wilt is not present or prevalent brings with it a high risk of disease introduction. The selection of clean planting material from recognized disease-free sources should be prioritized.

Note: Ideally, clean planting material is sourced from officially certified sources, in the form of tissue-culture derived plantlets, macro-propagation derived plantlets, or suckers from clean mother gardens (Fig. 11). However, banana seed/planting material certification programs are basically non-existent for bananas in Eastern and Central Africa, and no regulated or practical framework is available for smallholder farmers.

Figure 11: Left to right: Tissue-culture derived plantlets; macro-propagated plantlets; clean mother gardens.

Disease-escaping cultivars

Several banana cultivars / genotypes are less susceptible to insect-mediated *Xvm* bacterial transmission due to differences in their inflorescence morphology.

In module 1, we showed that certain genotypes do not form the vulnerable infection sites for insects-mediated transmission because they lack the male inflorescence, while in others the infection site is not exposed because the male flowers and bracts are persistent and/or form dry wounds after abscission. These cultivars are referred to as 'disease-escaping cultivars' (Fig. 12).

Selection of these cultivars can be part of a preventive strategy. De-budding will in this case no longer be necessary. The sterilization of gardening tools and the use of clean planting material are still necessary when cultivating disease-escaping cultivars.

A farmer's selection of specific banana cultivars will not only depend on disease-escaping traits, but mostly on crop production traits (e.g. yield, type of fruit, …). However, even incorporating a higher diversity of cultivars, increasing the presence of disease-escaping cultivars, could reduce the risk of establishment and spread of Xanthomonas wilt.

Figure 12: Dwarf Cavendish with persistent bracts and flowers.

Upcoming advancements in preventive strategies

Development of resistant cultivars

Research on the development of bacterial wilt resistant banana cultivars is ongoing. Genetic engineering for resistance has produced promising results, both through transgenic and cisgenic crop modification.

[transgenic: genetic material transferred between two species; cisgenic: genetic material transferred between genotypes within a species]

The availability of genetically modified, resistant cultivars should not be expected in the short-term. The research is still ongoing and comprehensive risk assessments and safety evaluations are needed. Additionally, most countries in eastern and central Africa do not have an established regulatory basis regarding genetically modified crops which can further delay implementation.

With genetic engineering, the transfer of genes for useful agronomic traits across species can be facilitated. In this case, the useful gene is related to disease resistance, which can be enhanced by

- expressing resistance genes,
- expressing antimicrobial genes, or
- expressing defense genes.

Without going into further detail (beyond the scope of this manual), by engineering the expression of these genes in a banana cultivar, disease-resistant cultivars may be developed.

Genome engineering:

CRISPR-Cas9 genome editing provides the capability of creating precise alterations in the plant genome.

Recently, robust CRISPR-Cas9 genome editing of banana has been established and first advances toward targeted genome manipulations for Xanthomonas wilt resistance have been made. The mechanisms are beyond the scope of this manual.

Early warning systems

Risk assessments and strategies for early warning systems are being developed and field tested. If a community can be informed in a timely manner on an increased risk of disease introduction or transmission in their area, the community as a whole can be encouraged to consistently implement preventive measures.

Risk assessments are based on:

- current disease incidence data
- epidemiological models

Epidemiological models combine an empirical or mechanistic understanding of disease transmission with current data on disease incidences, and provide predictions on the risk of disease entry/establishment/spread for a specific area.

The availability of current disease incidence data can be a bottleneck. Data collection is generally done through surveillance by trained staff across specific regions of interest, but detailed long-term monitoring across large spatial scales is difficult to achieve. The use of mobile phone applications by farmers to verify disease incidence on their farm could substantially improve the accessibility of up-to-date disease incidence data.

Mobile phone applications currently in use:

- Tumaini [Downloadable from the Google Play Store]
- ICT4BXW [https://www.ict4bxw.com/]

Data generated by the mobile phone applications should be mapped and insights on the geographical spread of the disease should be translated into early warning messages to national plant protection organizations (NPPOs) and application users in, and adjacent to, infested regions.

The assessed risk predicted by epidemiological models could then be communicated to farmers through the same mobile phone applications, effectively warning of increased risk in a timely manner.

Current state of implementation: Smartphone applications are available for disease recognition and reporting. Mapping of disease incidence and risk within these applications is currently in a proof-of-concept stage. Early warning systems linked to the mapping platform should be up and running by the end of 2023.

Module 3: Control measures

When Xanthomonas wilt infections have been detected on a farm, disease control measures need to be implemented. Two main strategies are recommended for controlling Xanthomonas wilt, namely complete diseased mat uprooting (CDMU) and single diseased stem removal (SDSR). Both practices center around the removal of infected plants, and thus of *Xvm* bacterial inoculum, from the affected field and are combined with preventive measures [tool sterilization, early de-budding, and the use of clean planting material] to reduce the risk of disease transmission.

In this module, we present the background and practical implementation of both control practices

- **complete diseased mat uprooting (CDMU)**
- **single diseased stem removal (SDSR)**

We discuss the advantages and disadvantages of each practice, the implementation issues a farmer might experience, and which practice is most suitable in different situations.

Other methods of infected plant removal exist. For example, infected banana mats can be destroyed by injecting herbicide. These methods are generally not recommended [environmentally unfriendly, might affect browsing ruminants] and will not be discussed in detail in this manual.

Firstly however, we start with **the detection of Xanthomonas wilt in the field**. Because, without accurate detection, we cannot move to effective disease control.

Early detection and the accurate diagnosis of Xanthomonas wilt

Early detection and the accurate diagnosis of Xanthomonas wilt are critical first steps in disease management.

Accurate diagnosis

Accurate diagnosis allows for a targeted selection of control practices. Symptoms can be confused with other biotic or abiotic stresses, and careful verification is needed before implementing control practices

Visual assessment of symptoms is the most practical way for smallholder farmers to diagnose Xanthomonas wilt. If unsure about the symptoms of Xanthomonas wilt at this stage, please refer to module 1.

Supporting technologies can be used at the field level to assist in verifying disease detection. The use of smartphone applications distributed by CGIAR research institutes are currently the most practical means for farmers to verify their diagnosis of Xanthomonas wilt in the field.

The smartphone application Tumaini (Fig. 13; freely available on Google Play Store) is able to detect and distinguish between symptoms of five banana diseases, including Xanthomonas wilt, and one pest. By taking images of disease symptoms using a smartphone, Tumaini can help farmers to accurately detect Xanthomonas wilt. A run-through of this application is provided in the accompanying training video.

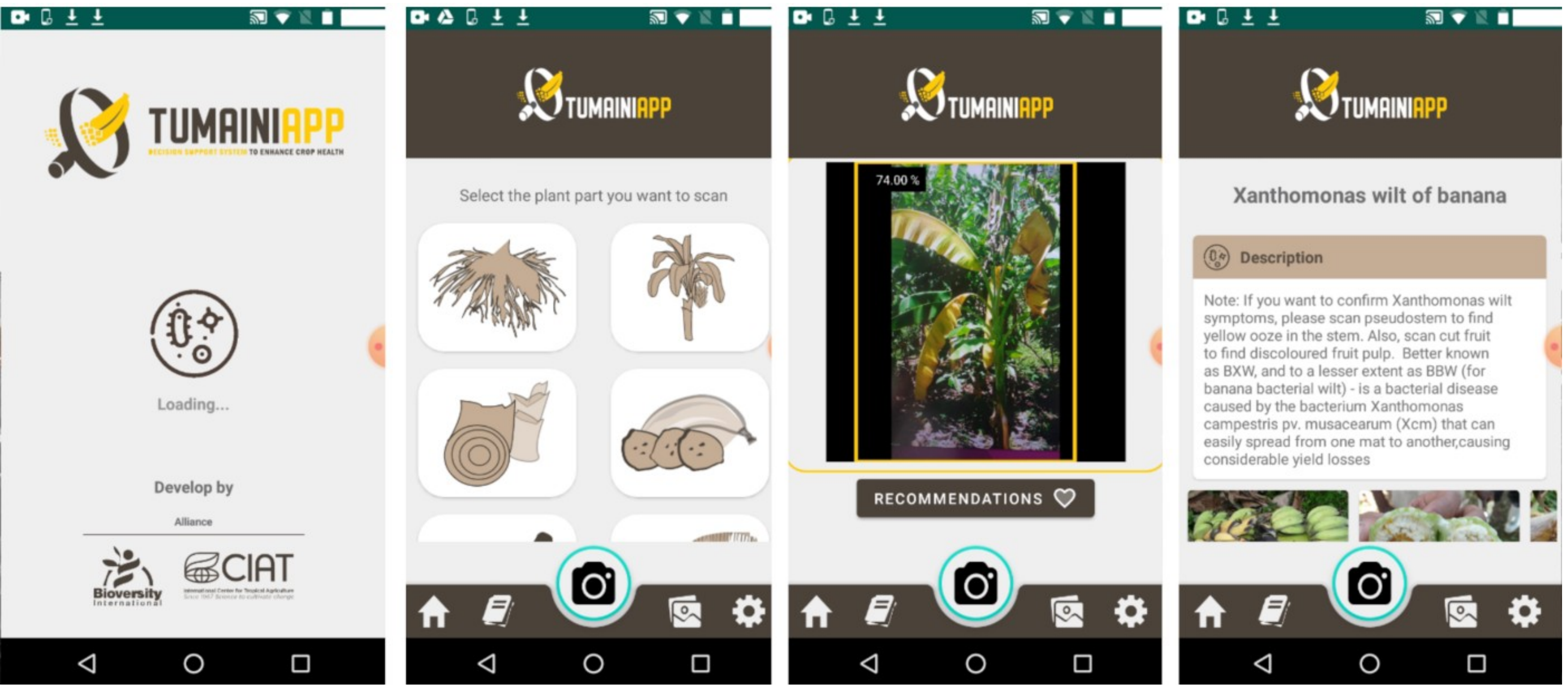

Figure 13: Stages from the Tumaini application.

Other diagnostic tools exist to confirm the presence of Xanthomonas wilt (including microbiological, serological and molecular diagnostic methods) although these techniques are generally not available to farmers outside of research studies, and are beyond the scope of this manual.

Early detection

Early detection allows for early action. Detection at the first signs of new infections will:

- ease the application of control measures (few plants to control),
- achieve fast disease subsidence rate, and
- reduce the risk of further disease transmission.

Early detection calls for consistent monitoring on a plant-by-plant basis at regular intervals. Weekly or bi-weekly field inspections are generally recommended based on the average length of time between infection and symptom expression.

Complete Diseased Mat Uprooting

Complete Diseased Mat Uprooting (CDMU) is the original recommended control package in which the entire infected mat is uprooted and destroyed, and new banana plants are replanted using clean planting material.

Methodology

Infected mat uprooting

When applying CDMU, the entire banana mat needs to be uprooted, including the rhizome and all attached stems (Fig. 14). The affected area should remain bare for two months to ensure no *Xvm* bacteria have survived in the soil. After this two-month period, new banana suckers can be planted using clean planting material (as discussed in Module 2 – Preventive measures).

Disposal of the infected mat

The uprooted infected mat should be transported to the edge of the field, and left to decompose on a compost heap. When transporting the debris to the compost heap, the mat should be transported in large pieces, to avoid ooze leakage onto the soil. Each additional cut in a pseudostem or leaf sheath will expose additional bacterial ooze that could potentially lead to infections within the field, if e.g. picked up by insects or browsing animals. At the compost heap site, the debris may be cut into smaller pieces, to speed up plant decay. If the plant debris is cut, it is highly recommended to cover the compost heap with other plant debris or a small layer of soil to avoid contact of insects or animals with the bacterial ooze. The *Xvm* bacteria luckily do not survive well in decaying plant material (generally less than 35 days) and the decomposing plant debris will not remain a source of infection for long.

Figure 14: CDMU

[The uprooted infected mat could alternatively be buried in a designated hole at the edge of the field. This will ensure no insects or browsing animals can pick up and transmit bacterial ooze. Burying is however very labor-intensive, and composting is often preferred.]

Preventive measures

All preventive measures discussed in Module 2, including the early removal of the male bud, tool sterilization and the use of clean planting material, remain essential components of the CDMU control package. Namely, even when infections have been detected on a field, the correct/rigorous implementation of preventive measures will prevent the remaining healthy mats in the field from becoming infected, and will also prevent the spread to neighboring fields.

Advantages of the CDMU control package

CDMU is a highly effective method at reducing or even eliminating *Xvm* inoculum.

Disadvantages

CDMU is very **labor intensive** and **time consuming**. Both the uprooting of the infected mat and the removal/destruction of the infected plant debris are very physically demanding. Reportedly, one person can remove at most 2 large mats in a single day.

The need to replace infected mats with **new clean planting material** adds another hurdle. Potential latent infections in suckers sourced from the farmers' own field or neighboring fields require regular monitoring.

Production losses resulting from CDMU are also high, since healthy bunch-producing plants within an infected mat also need to be removed. Additionally, the time the soil needs to remain bare after uprooting and before replanting represents a significant period when no production takes place. Moreover, it can take a long time for new planting material to actually produce bunches and for the field to be restored to pre-infection production levels, this can be up to 20 months at the mid- to high-altitude sites in the East and Central African region. This slow return on investment from disease control to healthy producing mats can potentially be too long to ensure food security and livelihood earnings for smallholder farmers, and be perceived as inadequate. Annual crops can be planted at sites where banana mats have been uprooted, and during the initial stages of new banana plant growth. This to minimize plot level yield losses.

These disadvantages add up for smallholder farmers and **low adoption levels** of the CDMU control package are generally reported.

Single Diseased Stem Removal

Single Diseased Stem Removal (SDSR) is a novel Xanthomonas wilt control package and is presented as a suitable and practical alternative to CDMU in most circumstances. SDSR is based on research findings that *Xvm* bacteria do not systematically infect all the physically interconnected stems on a mat and that low bacterial inoculum levels inside a stem might not cause symptoms. The removal of [a] single diseased stem[s] on a mat can thereby allow for the remaining healthy stems to remain on the infected mat, and produce edible bunches.

Background: Incomplete spread at mat level

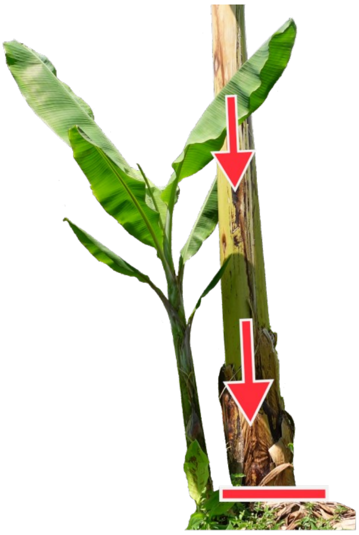

Figure 15: Incomplete spread of Xvm.

Xvm bacteria do not systematically infect all the physically interconnected suckers on a mat, (incomplete systemic spread of the *Xvm* bacteria, Fig. 15). In mats that contain an infected plant or plants, the remaining healthy-looking plants are able to produce edible bunches and new healthy-looking lateral shoots can develop. Removal of the single diseased stem on an infected mat could thereby control the disease, and the removal of the complete infected mat is thus not necessary.

Nevertheless, a random spread pattern from infected mother plants to lateral suckers has been observed. The density of bacteria inside a stem might (initially) be too low to cause symptoms (latent infection), and the asymptomatic (i.e. healthy looking) stem can continue to develop bunches. It remains possible that the disease will develop from this latent infection and symptom expression will present. At this stage, the stem should be removed using SDSR.

Under rigorous application of SDSR, a gradual decline of bacterial load (and thus latent infections) to levels that cannot initiate disease have been observed in subsequent generations. Applying SDSR rigorously for an extended period of time (see further) will eliminate the disease from the field.

Methodology

Single diseased stem removal

SDSR consists of cutting visibly diseased stems within a mat at soil level, in a timely way, at first observation of a symptom, while all symptomless suckers are allowed to remain standing (Fig. 16).

The apical meristem or actively growing part of plants in the vegetative growth stage should be destroyed to prevent sprouting.

The exposed pseudostem base should ideally be covered with some soil to reduce the availability of exposed bacterial ooze and contact with the bacteria.

Figure 16: SDSR.

Disposal of infected plant material

Removed infected stems should be heaped at the edge of the field and left to decompose. The plant debris should be kept as intact as possible when it is transported to the compost heap, to avoid ooze leakage onto the soil. At the compost heap site, the debris may be cut into smaller pieces, to speed up plant decay. If the plant debris is cut, it is highly recommended to cover the compost heap with other plant debris or a small layer of soil is recommended to avoid contact of insects or animals with the bacterial ooze.

Alternatively, the felled infected stem can be left to decompose on the spot next to the banana mat. This is generally not recommended when other crops are cultivated in between the banana mats, or when animals are free to roam in between the mats.

[Similarly to recommended plant disposal in the CDMU control package, plant debris can also be buried, although this is more labor-intensive.]

Screening

Effective SDSR application requires close monitoring of the field and continuous removal of new symptomatic plants. Latent infections, and thus the incomplete removal of the *Xvm* inoculum, can pose a risk for the re-occurrence of disease symptoms, and any new diseased stem should be removed immediately after symptom spotting.

It is recommended to apply SDSR at regular intervals during the first phase of management, with at least weekly monitoring during the first 3 to 4 months of application. The frequency of field monitoring can be reduced when most of the *Xvm* inoculum seems to be removed and potential new symptoms only present sporadically.

Through field assessments, long Xanthomonas wilt incubation periods of up to 24 months have been observed, as have the occurrences of small outbreaks at irregular intervals over a period of many months. Consistent long-term monitoring is thus essential.

Preventive measures

Similar to the CDMU control package, all preventive measures discussed in Module 2, including early removal of the male bud, tool sterilization and the use of clean planting material, remain essential components of the SDSR control package. Namely, even when infections have been detected in a field, the correct/rigorous implementation of preventive measures will prevent the remaining healthy mats in the field from becoming infected, and will prevent the spread to neighboring fields. Additionally, regular screening of banana mats is needed to detect new symptom expressions early on.

Advantages

Consistent application of SDSR has been shown to effectively reduce and even eliminate disease appearance as mats recover under the combined effects of incomplete systemic spread and latent infections.

This method is far less labor-intensive and time-consuming than CDMU. Removing individual stems is less intensive than uprooting an entire mat, and less infected plant debris needs to be disposed of.

Yield losses are also minimized as healthy plants remain available on treated mats for the production of bunches, and no production-free period is necessary. Accordingly, no new clean planting material is needed.

SDSR can be effectively applied for a fraction of the time and cost of CDMU whilst maintaining banana bunch production, making it the more attractive control package for most farmers.

Disadvantages

The removal of disease inoculum is more gradual when using the SDSR method compared with complete removal through CDMU. Latent infections can develop into symptomatic plants even years after the SDSR control package is initially started. While this is not a problem, and continuous application of SDSR should be performed, the re-emergence of Xanthomonas wilt infections can be very demotivating for a farmer. The perception that the control package is not fully working can cause the abandonment of the practice.

Which control package should we apply: CDMU or SDSR?

Both CDMU and SDSR have been shown to be effective in reducing and eliminating the disease. The choice of either CDMU or SDSR generally depends on the farming system and level of disease occurrence.

CDMU is generally recommended for larger, well-managed and market-oriented banana production systems that are able to invest in targeted disease eradication. Rapid eradication of Xanthomonas wilt in these larger fields is often worth the period of reduced production by the removal of entire mats.

SDSR is more appropriate and recommended for less intensively managed banana cropping systems, often smallholder subsistence farms that benefit more from this cost-effective treatment. Additionally, SDSR is suitable for farms with limited access to clean planting material.

CDMU could also prove cost-effective for smallholder farming when the Xanthomonas wilt infection is still new with only few plants or mats affected, providing a window for full eradication. Here, a complementary application of CDMU and SDSR is advisable, with SDSR used as a monitoring approach after CDMU application.

Case study - Comparing the effectiveness, cost and time of CMDU and SDSR

Researchers performed a direct comparison between CDMU and SDSR across farms in four study sites in Rwanda, to get a clear picture on the differences in effectiveness, the resource needs, and the impact on production losses.

As such, in fields affected by Xanthomonas wilt, the researchers monitored the disease incidence through the course of a year, during which CDMU and SDSR were continuously applied. They recorded how much time it took on average to apply the control packages per infected banana mat or stem, how much money this cost the farmer, and how much productive stems were ultimately lost.

Disease incidence reduction

At the start of the experiment, the disease incidence of plants infected with Xanthomonas wilt ranged between 3.5 and 9.4%.

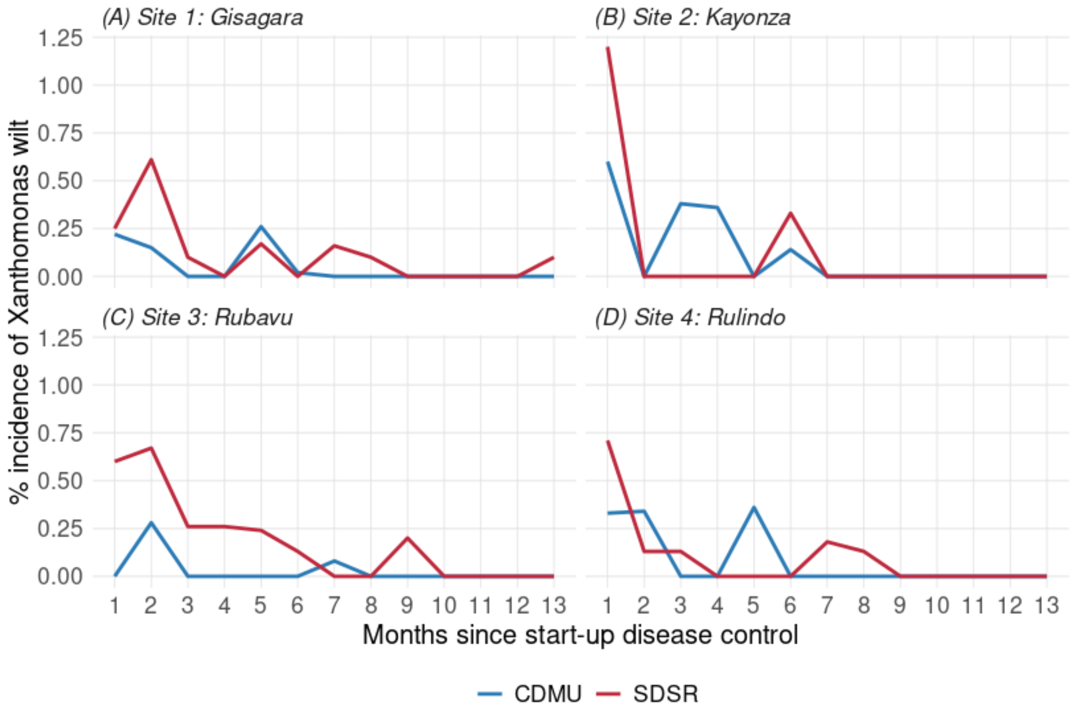

Figure 17: Progress of disease incidence for one year in banana fields managed with complete diseased mat uprooting (CDMU) or by single diseased stem removal (SDSR) in four sites. The graphs show small fluctuations (0 to 1%) in the incidence of Xanthomonas wilt one month after the start-up of control practices.

One month after initially removing infected mats or stems (Fig. 17), the disease incidence dropped from an average 6.2% to 0.3% through CDMU, and from 7.0% to 0.7% through SDSR.

After the initial decline, incidence of Xanthomonas wilt remained below 1% for both CDMU and SDSR at all sites. Continued management during the consecutive months was necessary in both cases, CDMU and SDSR, to remove newly symptomatic plants. These new symptom appearances were related to latent infections.

The average time it took until no diseased banana plants were observed was shorter in the CDMU managed fields compared to the SDSR managed fields.

- With CDMU, no new symptomatic plants were observed after 6 to 8 months.
- With SDSR, no new symptomatic plants were observed after 7 to 10 months at three of the study sites, while at one site, some newly symptomatic plants were still appearing at the end of the experiment.

Production losses

The removal of complete diseased mats in CDMU managed fields results in a higher loss, as productive asymptomatic stems on a diseased mat are also removed. On the other hand, applying SDSR, only the symptomatic stems are removed and productive asymptomatic stems on these mats remain. As such, the overall productive stem loss was higher using CDMU, with an average of 35% of productive stems in the fields lost, compared to SDSR, with an average 15% of stems lost (Fig. 18).

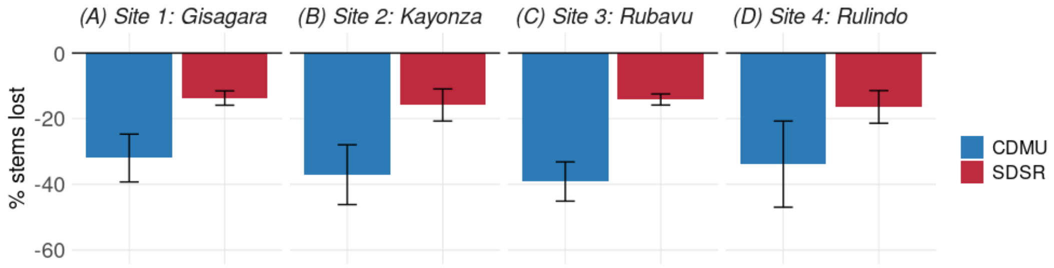

Figure 18: Percentage of plants lost due to Xanthomonas wilt during the first 6 months of the study.

Time

Applying CDMU took considerably longer than applying SDSR (Fig. 19):

• Cutting a single infected stem is much faster than uprooting an entire infected banana mat.

• The disposal of the plant debris (cutting up and disposal of the debris on a compost heap) takes longer for an entire mat, related to the larger amount of debris.

• Replanting is only needed when applying CDMU.

• In total, removing an entire infected mat, destroying the debris and replanting new healthy suckers took on average 36.5 minutes, while only 4.2 minutes were needed to cut and destroy a single infected stem.

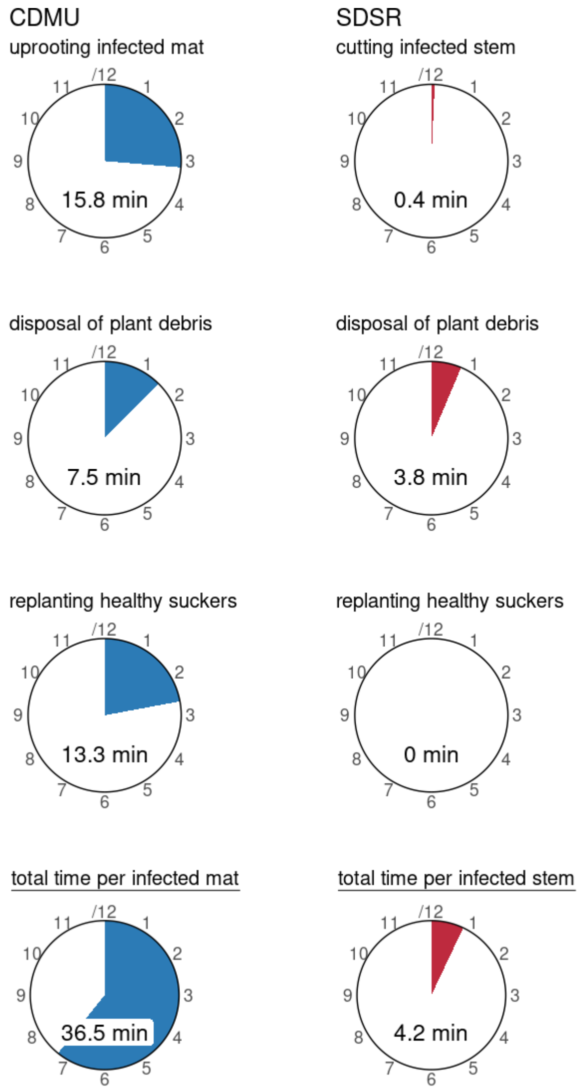

Figure 19: Average time the farmer needed for the main steps of CDMU and SDSR.

Cost

The total cost for the farmer was higher when applying CDMU compared to SDSR (Fig. 20):

• Labour cost is directly related to the amount of time it takes to apply the control.
In total, labour cost for removing an entire infected mat, disposal of the debris and replanting new healthy suckers was 218.8 Rwandese francs (Frw), compared to 25.4 Frw to cut and destroy a single infected stem.

• Acquiring new healthy planting material is a substantial cost for the farmer.

• The additional cost of 400 Frw for new planting material, brings the total cost of CDMU up to 618.8 Frw per banana mat, compared to 25.4 Frw per stem with SDSR.

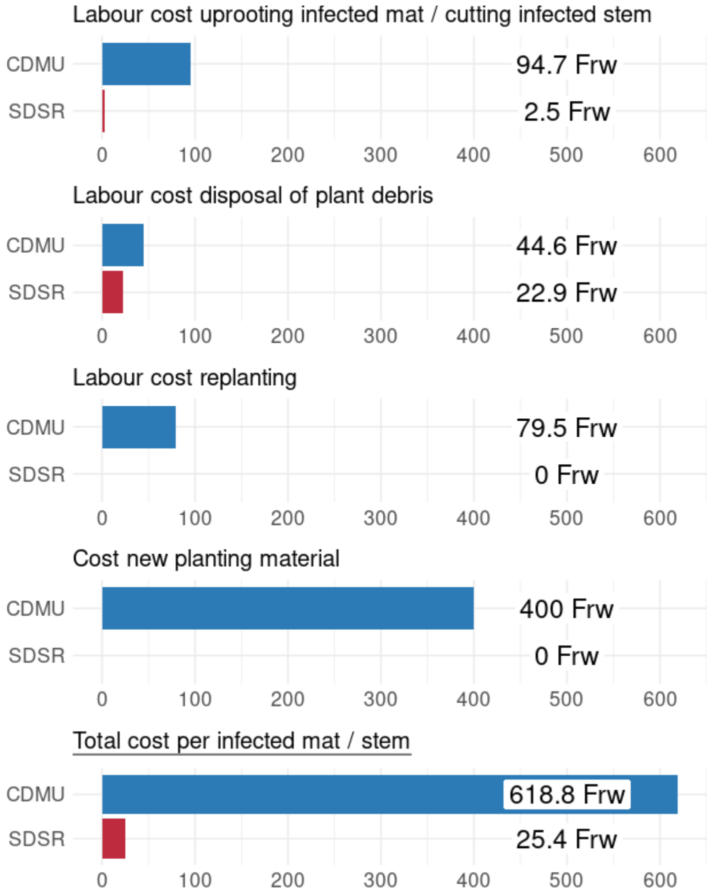

Figure 20: The cost for the farmer of the main steps of CDMU and SDSR.

Moreover, this cost calculation does not account for production losses discussed above.

Conclusion

- Both CDMU and SDSR are effective at reducing the incidence of Xanthomonas wilt
- SDSR is the easier and cheaper control option, and a higher percentage of production is maintained.
- Fields managed with CDMU can have a faster overall recovery.

[This case study was published in '*Blomme et al. (2021). Comparing effectiveness, cost- and time-efficiency of control options for Xanthomonas wilt of banana under Rwandan agro-ecological conditions. European Journal of Plant Pathology 160, 487-501. DOI 10.1007/s10658-021-02258-z*']

Module 4: What can go wrong with Xanthomonas wilt disease management?

Consistent and correct application of preventive practices combined with the control packages CDMU and SDSR when needed will result in effective disease containment, reduced disease incidence and severity, and the recovery of field production levels. Multiple successes have been achieved at local, regional and even national levels.

Effective management of Xanthomonas wilt is however not always achieved. Research has identified several pitfalls for the implementation of disease management, generally associated with the incomplete or incorrect application of the recommended packages.

In this module we have a closer look at the most common pitfalls, and recommend ways of dealing with them.

Perceived partial effectiveness of disease management

When implementing the SDSR control package, the sporadic re-appearance of diseased plants due to latent infections can be perceived as a failure of the applied measures and can be very discouraging for farmers. Because of this perceived re-emergence of the disease, farmers sometimes give up and stop applying prevention and control practices, and the disease can take hold again.

However, the number of affected plants will quickly reduce with rigorous SDSR application, and longer-term application of SDSR through removal of newly appearing symptomatic stems (related to latent infections) will lead to successful management and possibly eradication.

Farmers therefore need to be informed of the dynamics of the disease with SDSR application in advance to prevent any discouragement.

Preventive measures, especially when applied in healthy fields, do not have a clear effect that can be noticed by the farmer, because nothing happens (which is the point, the disease does not enter/occur). Over time, some preventive practices might be applied less rigorously or dropped by the farmer because they are perceived as time-consuming and labor-intensive, or because they are assumed as ‘no longer needed’. This can of course reduce the overall effectiveness of disease management.

Case study – Monitoring the appearance of symptomatic stems on SDSR-managed farms

At three field sites in South Kivu, eastern DR Congo, SDSR was implemented on 30 farms affected with Xanthomonas wilt (90 farms in total were studied), and the incidence of symptomatic plants was monitored weekly for one year.

The farms in the Cikoma area were heavily affected by Xanthomonas wilt, with on average 45.5% of the banana mats showing symptoms. In Kagundu, an average of 32.6% of the banana mats was affected across the farms. In Bukunda, the impact of Xanthomonas wilt was lower, with only 1.4% of banana mats showing symptoms.

By implementing SDSR and cutting all visibly affected stems, the disease incidence dropped drastically within the first week (Fig. 21).

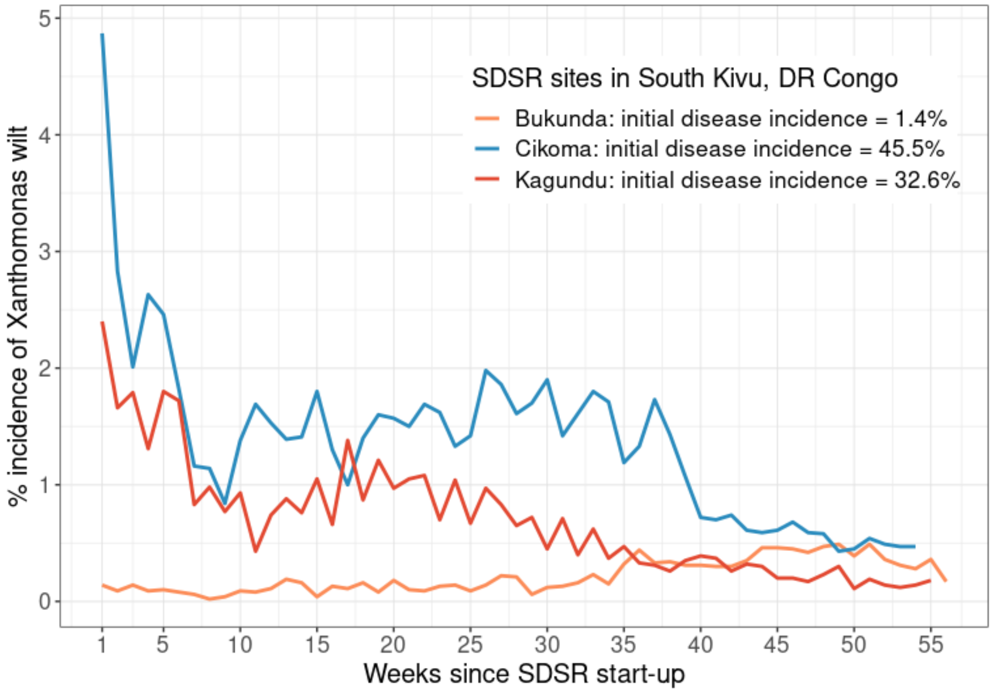

Figure 21: Progress of disease incidence for one year following the removal of single diseased stems at three sites. The graphs show fluctuations in disease incidence one week after the start-up of SDSR.

In **Cikoma**, where the farms were most heavily affected, the disease incidence fluctuated between 1-2% in the following 9 months (40 weeks) of SDSR implementation. This means that 1-2% of banana mats on the farms still developed new symptoms weekly, and the newly infected stems needed to be cut down. After 9 months, the appearance of newly symptomatic plants reduced and only 0.5% of banana mats presented new symptoms.

In **Kagundu**, only 0.5-1.5% of banana mats developed new symptoms on a weekly basis in the first 8 months (35 weeks) of SDSR implementation, while this dropped to 0.2-0.4% after this period.

In **Bukunda**, the least affected farms, very few newly symptomatic plants were recorded weekly (only ~0.1%). A small flare-up can be seen after 8 months, when 0.5% of banana mats developed symptoms. Nevertheless, by correctly applying SDSR, these numbers dropped again in subsequent weeks.

Conclusion: In SDSR-managed fields, diseased plants can sporadically re-appear for a longer period of time, although in very low numbers. The study also identified an overall decline in bacterial load in subsequent generations of latently infected mats. As such, by regularly monitoring and applying SDSR, less and less visibly infected plants will appear over time, and new symptom appearances will eventually halt. In general, small numbers of re-appearances can be expected during the first 2 years.

[This case study was published in '*Blomme et al. (2017). A control package revolving around the removal of single diseased banana stems is effective for the restoration of Xanthomonas wilt infected fields. European Journal of Plant Pathology 149, 385-400. DOI 10.1007/s10658-017-1189-6*']

Extension services have to inform farmers on the long-term effort and expected time-frame

Farmers need to be well informed that SDSR might have to be applied over prolonged periods, perhaps over 2 years or more, but that the number of affected plants will quickly reduce after the onset of rigorous SDSR application. It is critical to clarify that weekly re-appearances of a small number of symptomatic plants are a normal aspect of disease management through SDSR, and that these numbers will reduce over time.

Extension services need to emphasize that Xanthomonas wilt management is a long-term project. If possible, extension services should revisit communities in order to assure farmers that their applied disease management is effective, or to help adjust if needed.

Farmer training also needs to include the following message: SDSR prevents the complete uprooting of mats and prevents the need to replant with healthy planting material. SDSR also prevents a sharp and prolonged drop in plot yield as most stems in a mat keep standing and produce harvestable/edible bunches.

Achieving collective action

All banana farmers in a community should apply **preventive practices**. If, for example, only half of the farmers apply preventive measures, the other half of the fields are at risk of introducing Xanthomonas wilt into the community. Once established, transmission of Xanthomonas wilt within the community is more difficult to prevent.

Accordingly, and ideally, all farmers with infected fields in a community should incorporate **control practices** (SDSR or CDMU). If a farmer is unwilling to apply control and dispose of infected plants, the disease will remain in the community for longer, and the risk of transmission to healthy fields increases. Similarly, when applying SDSR, all farmers need to be motivated to apply the practice for an extended period, to account for the prolonged presence of the inoculum.

Achieving collective action can be difficult in smallholder farming communities (Fig. 22) due to the varying importance of bananas for farmers' livelihood. If the production of bananas is not the main interest of the farmer, he or she will be less likely to invest consistent effort into disease management.

Extension support is generally provided at the community level. Leaders should be informed of the difficulties in achieving collective action, and should present options personalized to the needs of various farmers in the community. For example, some members of the community who are well trained could be appointed to monitor multiple smallholder farms. This could alleviate the responsibility of less invested farmers.

Figure 22: Community-level disease control actions.

Difficult access to information and training

Extension services do not reach all smallholder banana farmers, and the level of knowledge-sharing can vary depending on the mode of communication.

In-person activities by extension services are generally most effective, including

- awareness campaigns,
- farmer field schools and
- community actions

Broadcasting information via TV and radio can reach a wide audience, but has the limitation of being one-way (i.e. the farmer cannot ask questions).

Both single-visit extension services and broadcasting can leave the farmer with questions, and follow-up information is difficult to access.

In recent years, **participatory approaches** have been developed to initiate a two-way stream of information. For example:

- Community Knowledge Worker: Local leaders are trained as Community Knowledge Workers and act as a communication node between local farmers and external experts. Using mobile phone applications, they could provide farmers with direct access to agricultural information through an agriculture call center, and simultaneously collect data and surveys on local Xanthomonas wilt infestations and management issues for researchers.
- Smartphone application Tumaini: farmers are able to access current information on disease management while at the same time contributing through data collection. While showing great potential, smallholder farmers still have limited access to smartphones, and the effective implementation of digital extension tools can take time.

Practical constraints

Ease-of-use of the recommended practices

In recent years, recommended prevention and control packages have been updated to improve the ease-of-use for the farmer. This topic has been discussed throughout modules 2 and 3. For example, initially recommended tool sterilization by fire, while effective, can more easily be performed by washing the blade with water and soap. Similarly, SDSR has greatly improved the ease-of-use of infected plant disposal compared to CDMU.

Ongoing research on Xanthomonas wilt disease management takes into account the needs of the farmers, and will continue to update packages where needed.

Limited availability of resources

Disease management practices are often difficult to implement due to

- high labor demand,
- time consumption, and
- cost of full packages

Farmers have been known to take shortcuts with Xanthomonas wilt management. Both the time-consuming activity of long-term field monitoring, and the perceived reduction in need to apply Xanthomonas wilt management measures after initial incidence numbers have dropped, leads to farmers abandoning the careful application of management practices.

The main way forward is to keep motivating farmers through extension efforts, and highlight the most practical, and cost-and-time effective practices. Similarly to the ease-of-use, ongoing research on Xanthomonas wilt disease management considers the needs of the farmers, and will continue to update packages where needed.

Difficulties combining disease control practices with general farm activity

Management of Xanthomonas wilt can interfere with the timing of other farm management practices.

In farms where the banana plants are intercropped with annual crops, regular cutting of diseased plants (SDSR) during annual cropping seasons can damage these intercrops. Household needs will generally determine which practices are prioritized. While plant disposal might have to be delayed, consistent application of preventive measures might reduce the overall risk.

References

This manual is based on the book chapter:

Blomme, G., Kearsley, E., Ocimati, W. (2023). Xanthomonas wilt of banana. In: Drenth, A. and Kema, G.H.J. (ed.), Achieving sustainable cultivation of bananas, Volume 3: Diseases and pests. Burleigh Dodds Science Publishing, Cambridge, UK, ISBN: 978 1 78676 981 7, https://dx.doi.org/10.19103/AS.2022.0108.10

Relevant references to all discussed topics can be found therein.

Glossary of technical terms

Term	Explanation
Abscission	The shedding of leaves or other plant parts as the result of physical weakness in a specialized layer of cells (the abscission layer) that develops at the base of the structure.
Abscission site	The location of abscission of a leaf or plant part on the standing plant. Initially, a wound will be visible, which will develop into a scar.
Abiotic	Non-living. Abiotic stresses can include inappropriate cultural practices or adverse environmental conditions such as nutrient deficiencies, drought and pesticide phytotoxicity. (Contrasts with biotic).
Alternative host	A plant other than the main host that a pathogen or pest can colonize. Alternative hosts are not required for completion of the developmental cycle of the pathogen or pest.
Antibiotic	A chemical compound produced by one microorganism that inhibits growth or kills other living organisms
Antimicrobial	Destroying or inhibiting the growth of microorganisms, specifically pathogenic microorganisms
Apical meristem	Meristem is a collection of cells at a growing point of a plant that are capable of cell division. Apical meristem is meristem at the apex (tip) of a root or shoot that is responsible for increase in length.
Asymptomatic	Containing the pathogen, but not showing visible symptoms.
Bacterial load	Synonym with inoculum density; a measure of the number of propagules of a pathogenic organism per unit area or volume. The amount of bacteria/ooze in a banana plant or mat.
Bacterium (plural: bacteria)	A single-celled, microscopic organism that lacks a nucleus. Some bacteria cause animal or plant diseases.
Biotic	Relating to life, such as disease caused by living organisms (contrasts with abiotic).
Blade (leaf blade)	The flat, photosynthetic part of the leaf.
Botanical	Derived from plants or plant parts.
Bract	A reduced leaf associated with a flower or inflorescence; modified leaf from the axil of which a flower arises.
Bract scars	The scar left on the rachis after the abscission of the bract.
Bud (male bud)	A bud is a small protrusion on the stem of a vascular plant that will later develop into a flower, leaf, or shoot. The male bud on a banana plant contains clusters of male flowers, and bracts, found at the end of the rachis.
Bunch (banana bunch)	The bunch is the descriptive term that includes all the fruits.
Causal agent	An organism or agent that incites and governs disease or injury.

Term	Explanation
Certification / certified seed or planting stock	Seeds, tubers or young plants certified by a recognized authority to be free of specified pathogen or pests, or to contain less than a minimum number of specified pathogens or other pests.
Cisgenic crop modification	A method of genetic engineering. Cisgenic crops have genetic material that has been transferred from the same species.
Clean planting material	In reference to 'banana planting material', planting material refers to the type of material used to establish a banana field or replace a banana plant. The main types of conventional planting material are suckers and corm pieces. Tissue-culture plantlets are used almost exclusively in commercial production systems. Clean planting material referes to any healthy planting material.
Collective action	Action taken together by a group of people whose goal is to enhance their condition and achieve a common objective by a group of people
Colony	The growth of a microorganism in mass, especially as a pure culture.
Complete diseased mat uprooting (CDMU)	A disease management package to control Xanthomonas wilt. It consists of uprooting entire banana mats (the rhizome and attached stems) showing symptoms of Xanthomonas wilt. The package also recommends preventive measures.
Community Knowledge Workers	Community Knowledge Workers are local leaders who actively disseminate and collect information in their communities. The CKWs were nominated from a variety of organizations working with farmer communities and trained in data collection and information delivery techniques using mobile phone applications, such as conducting digital surveys, delivering weather, market and agriculture information obtained through SMS, and providing farmers with direct access to agricultural information through an agriculture call centre.
Containment (disease containment)	The act of controlling or limiting the transmission of a disease.
Contaminated (contaminated tools)	Containing undesired or infective microorganisms.
Control practices	Disease management practices that intend to reduce disease incidence and ultimately eradicate the disease.
Corm	The rhizome is commonly referred to as a corm, but the botanically correct term is rhizome. See 'rhizome'.
CRISPR-Cas9	"Clustered regularly interspaced short palindromic repeat (CRISPR)" is a new gene-editing technology to create targeted genetic disruption in one gene or multiple genes (by multiplexed CRISPR). Cas9 (or CRISPR-associated protein 9) is an enzyme, and together with CRISPR sequences form the basis of a technology known as CRISPR-Cas9 that can be used to edit genes within organisms.
Cross section	Cutting through an object (in this case the banana stem or pseudostem), at a right angle to an axis.
Cultivar	A cultivated plant that people have selected for desired traits and when propagated retains those traits. Sometimes used synonymously with variety.
De-budding of the male inflorescence	Removing the male bud – using a forked wooden stick - as soon as the last hand on the fruit cluster has formed

Term	Explanation
Debris (plant debris)	Detached, dead plant fragments.
Diagnosis	Determination and identification of a disease.
Diagnostic	Pertaining to a distinguishing characteristic important for the identification of a disease or other condition.
Disease	An unhealthy condition (e.g., that is caused by a pathogenic bacteria, fungus, or virus) that impairs the function or performance of an organism. In the case of crops, disease impairs a plant's economic value.
Disease-escaping cultivars	Pertaining solely to infections of Xanthomonas wilt of banana, disease-escaping cultivars refers to banana cultivars that are less prone to *Xvm* bacteria transmission and infection via insects, because they do not form important infection sites on their inflorescence (normally related to bract and flower abscission sites). These cultivars have persistent flowers and bracts, or do not form open wounds when a bract or flower falls off. These cultivars can still be infected via other transmission pathways, including contaminated tools. The term 'disease-escaping' should not be confused with 'disease resistance'.
Disinfect	To eliminate a pathogen from infected plant tissues (see sterilization).
Dry season	A seasonal period of low rainfall.
Dormant stage	A condition of suspended growth and reduced metabolism of an organism, generally induced by internal factors or environmental conditions as a mechanism of survival.
Early warning system	A system or procedure designed to warn of a potential or an impending problem, in this case the risk of disease transmission or spread.
Empirical	Relying on or derived from observation or experiment.
Enset (*Ensete ventricosum*)	A herbaceous, perennial, monocarpic plant, belonging to the banana family Musaceae. Enset resembles the banana plant, although it is not cultivated for its fruits, but for its underground corm and pseudostem base which are mainly processed into starchy food products.
Epidemiology	The study of factors influencing the initiation, development, and spread of infectious disease; the study of disease in populations.
Eradication	The management of plant disease by eliminating the pathogen after it is established or by eliminating the plants that carry the pathogen.
Expression (symptom expression)	Visual presence of disease symptoms.
Extension service	The entire set of organizations that facilitate and support people engaged in agricultural activities to solve problems and to obtain information, skills, and technologies to improve their livelihoods and well-being.
Farmer Field Schools	Farmer Field Schools are traditionally an adult education approach that assists farmers to learn in an informal setting within their own environment. It is a participatory method of learning, technology development, and dissemination based on adult learning principles such as experiential learning in which technologies are demonstrated and tested on their farms.
Fungal disease	Disease cause by a fungus. A fungus is a eukaryotic organism that is usually filamentous (forming a mycelium) and heterotrophic, has cell walls composed of chitin, and reproduces by sexual and/or asexual spores.

Term	Explanation
Fusarium wilt of banana	A lethal fungal disease of banana caused by the soil-borne fungus *Fusarium oxysporum* f. sp. c*ubense.*
Gene	A unit within an organism controlling heritable characteristics; genes are organized on chromosomes.
Genetic engineering	The transfer of specific genes between organisms using enzymes and laboratory techniques rather than biological hybridization.
Genetically modified crop	A crop whose genetic makeup has been altered using genetic engineering techniques.
Genome	The complete genetic information of an organism or virus.
Genotype	The genetic constitution of an individual or group; class or group of individuals sharing a specific genetic makeup.
Herbicide	A pesticide for undesirable vegetation (weeds).
Host (host plant)	A plant that provides sustenance for a pathogen or pest.
Host range	The range of plants on which an organism, particularly a pathogen or pest, feeds.
Incidence (disease incidence)	The number of plants affected by a disease within a population.
Incomplete systemic spread	Systemic means 'capable of moving throughout a plant or other organism, usually via the vascular system'. The *Xvm* bacteria however is only capable of easily moving thoughout a single stem in a banana mat (the stem on which the initial infection occured), and cannot easily move via the rhizome to other suckers within the same banana mat. The spread throughout the mat is therefore referred to as 'incomplete'.
Incubation period	The time between penetration of a host by a pathogen and the first appearance of disease symptoms; the time during which microorganisms inoculated onto a medium are allowed to grow
Infection	The entry into a host and establishment of a pathogen.
Infection site	A site in or on a host plant where infection can occur.
Inflorescence	A flower or flower cluster.
Inoculation	To place inoculum in an infection site; to insert a pathogen into healthy tissue.
Inoculum	A pathogen or its parts, capable of causing infection when transferred to a favorable location.
Inoculum density	A measure of the number of propagules of a pathogenic organism per unit area or volume. The amount of bacteria/ooze in a banana plant or mat.
Insect	A member of the class Hexapoda (phylum Arthropoda) possessing three sets of limbs attached to a central body segment.
Intercrop	To grow two or more crops simultaneously on the same area of land.

Term	Explanation
Latent	Present but not manifested or visible, e.g., a symptomless infection by a pathogen.
Latent infection	An infection unaccompanied by visible symptoms.
Lateral shoot	See ‘sucker’.
Leaf sheath	The basal part of the banana leaf that forms the pseudostem.
Lifespan	The length of time for which an organism lives.
Macro-propagation derived plantlets	New plantlets grown on prepared corms or corm pieces which are burried in a substrate (as opposed to tissue-culture propogation using in vitro techniques). Harvested macro-propagation derived plantlets are first planted in plastic polybags and hardened [under a shade construction] before field planting.
Mat (banana mat)	Mat is the banana-specific horticultural term for the clump formed by the rhizome, the fruit-bearing stem (or stems as more than one stem can be fruiting at the same time) and the suckers.
Mechanistic (mechanistic models)	Based on the fundamental laws of natural sciences, including physical and biochemical principles.
Meristem	Plant tissue characterized by frequent cell division, producing cells that become differentiated into specialized tissues.
Microbiological diagnostic method	Culture-based detection methods, reliant on isolating, culturing and identifying the pathogen.
Mitigation	To prepare for and lessen the effect of a threat, in this case a disease.
Molecular diagnostic method	A collection of techniques used to analyze biological markers in the genome and proteome, and how their cells express their genes as proteins.
Monitoring	Carefully gathering and recording information on the abundance, development, and growth of organisms (typically pests or crops) or other factors (e.g., crop damage), often utilizing very specific procedures and commonly on a regular basis over a period of time.
Morphology	The branch of biology that deals with the form and structure of organisms without consideration of function.
Mother gardens	Field with healthy banana or plantain mats, from which lateral shoots/suckers are regularly harvested.
Mucoid	Mucus-like.
Nectar	A sugar-rich liquid that many plants secrete from specialized structures, often inside flowers, where it serves to attract pollinators such as certain insects and birds.
National Plant Protection Organizations (NPPOs)	Official service established by a government to discharge the functions specified by the International Plant Protection Convention (IPPC).
Ooze (bacterial ooze)	Exudate containing bacterial colonies.

Term	Explanation
Pathogen	A disease-causing organism.
Peduncle	In botany, the peduncle is the stalk that supports the inflorescence. Yet, in the Descriptors for bananas, the peduncle refers only to the stalk between the leaf crown and the first hand of fruit, whereas the stalk that actually supports the female and male flowers is called rachis
Perennial	Something that occurs year after year; a plant that survives for several to many years (contrasts with annual, biennial).
Persistent (persistent bracts and flowers)	Existing or remaining in the same state for a long time; enduring. Bracts and flowers that will not easily shed.
Pest	Any organism that damages plants or plant products.
Petiole	The stalk connecting the leaf blade to the leaf sheath [or pseudostem].
Preventive practices	Disease management practices that intend to slow, hinder, or prevent the transmission and new incursion of the disease.
Pseudostem (banana pseudostem)	Part of the banana plant that looks like a trunk. It is formed by the tightly packed overlapping leaf sheaths. The pseudostem continues to grow in height as the leaves emerge one after the other and reaches its maximum height when the "real" stem, which has been developping inside the pseudostem, emerges [as the inflorescence] at the top of the plant.
Pulp (fruit pulp)	The soft, succulent part of a fruit.
pv.	Abbreviation for pathovar; a subdivision of a plant pathogenic bacterial species defined by host range; pathovar for bacteria is equivalent to forma specialis for fungi.
Rachis	The elongated main axis of an inflorescence. In the descriptor for bananas, the rachis corresponds to the male peduncle supporting the male flowers in the male bud.
Resistant / resistance	The inherent capacity of a host plant to prevent or reduce the development of a disease.
Risk assessment	With respect to disease transmission: The overall process of identifying all the risks that could lead to disease establishment and spread.
Rhizome	Synonym to banana corm. Underground stem that produces lateral shoots or suckers.
Ruminant	Any of the hoofed mammals (including cattle, deer, and sheep) that chew cud.
Serological diagnostic method	Identification and diagnosis of disease based on findings of serum markers, anti-bodies or antibody-like substances specific to that disease.
Severity (disease severity)	Proportion of diseased plant tissue relative to the total amount of tissue.
Single diseased stem removal (SDSR)	A disease management package to control Xanthomonas wilt. It consists of cutting at soil level any banana stem showing symptoms of Xanthomonas wilt. The package also recommends preventive measures.
Smallholder	A small farm operating under a small-scale agriculture model.

Term	Explanation
Smartphone application	A software application developed specifically for use on small, wireless computing devices, such as smartphones and tablets.
Spatial scale	A specific application of the term scale for describing the size of a space (hence spatial), or the extent of it at which a phenomenon (in this case disease presence) or process (e.g. disease transmission) occurs.
Species	Any one kind of life subordinate to a genus but above a race; a group of closely related individuals of the same ancestry, resembling one another in certain inherited characteristics of structure and behavior and relative stability in nature; the individuals of a species ordinarily interbreed freely and maintain themselves and their characteristics in nature.
sp.	The abbreviation for a single species.
spp.	Abbreviation for multiple species.
Spread	See transmission.
Stem (banana stem)	The 'true' stem (as opposed to the pseudostem) develops inside the pseudostem at the end of the vegetative growth stage, and provides support to the last emerging leaves and the infloresence. The stem is subdivided in three parts: the underground rhizome or corm, the aerial stem, and the peduncle.
Sterilization	The total destruction of living organisms by various means, including heat, chemicals, or irradiation.
Solar radiation	A general term for the electromagnetic radiation emitted by the sun.
Subsidence (disease subsidence)	Diminishing disease presence.
Subsistence (smallholder subsistence farms)	Farming that provides for the basic needs of the farmer without surpluses for marketing.
subsp.	Abbreviation for subspecies. A subpopulation of a species, defined on the basis of more than one character (morphologic for many organisms) that distinguishes the members of the subpopulation from other members of that species.
Sucker	A lateral shoot that develops from the rhizome [or corm] and usually emerges close to the parent plant.
Susceptible / susceptibility	Prone to develop disease symptoms when infected by a particular pathogen (contrasts with resistant).
Symptom	An outward expression or change in appearance indicating that an organism is unhealthy. In plants, symptoms include chlorosis, necrosis, and wilting.
Symptomless	See asymptomatic.
Systemic	Capable of moving throughout a plant or other organism, usually via the vascular system.
Tissue-culture derived plantlets	An in vitro method of propagating healthy cells from plant tissues. The basic procedure consists in isolating the apical meristem and inducing it to form shoots.
Tolerant / tolerance	The ability of a plant host to sustain the effects of a disease without dying or suffering serious injury or crop loss

Term	Explanation
Transgenic crop modification	A method of genetic engineering. Transgenic crops have genetic material that has been transferred from another species.
Transmission (disease transmission)	The movement of a pathogen to a new host plant.
Transmission pathway	The way a pathogen is moved to a new host plant.
Vascular tissue	The tissue in vascular plants that circulates fluid and nutrients. There are two kinds of vascular tissue: xylem, which conducts water and nutrients up from the roots, and phloem, which distributes photosynthesis products from the leaves to other parts of the plant.
Vascular pathogen	A pathogen colonizing plant xylem that disrupts the normal uptake of water and minerals, resulting in wilting and yellowing of foliage.
Vector (insect vector)	An organism that transports and transmits a pathogen to a host.
Vegetative growth	The growth of leaves, roots, and stems. Does not include the growth of reproductive structures (e.g., flowers and fruits).
Vessel	A water-conducting structure of xylem tissue with openings in end walls.
Wilt	The drooping of leaves and stems from lack of water (i.e., inadequate water supply or excessive transpiration); a vascular disease that interrupts normal water uptake.
Xanthomonas vasicola pv. *musacearum*	The bacteria that causes Banana Xanthomonas wilt.
Xvm	Abbreviation for *Xanthomonas vasicola* pv. *musacearum.*
Xylem	The vascular tissue that transports nutrients and water from the roots upward through the plant.

The full online course is available at **www.crophealth.org**

List of training videos:

Module 1: Impact
Module 1: Causal agent
Module 1: Symptoms
Module 1: Spread
Module 2: Male bud removal
Module 2: Tool sterilization
Module 2: Clean planting material
Module 3: Disease detection
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Module 3: Single Diseased Stem Removal
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Module 4: Practical constraints

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