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Fusarium wilt of bananas: An integrated disease management manual

MONOGRAPH
223

Fusarium wilt of bananas: An integrated disease management manual

Tony Pattison
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ACIAR

2026

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Cover: A semi-mature banana bunch
Photo: ACIAR

Foreword

Fusarium wilt has challenged banana growers since an incursion of the soil-borne fungal disease in Panama in 1890. New planting ground was seen as the solution to avoid the disease, and then new varieties. However, by 1990 a new strain of the disease was discovered in Cavendish bananas and has since spread rapidly through Southeast Asia. The disease has decimated banana industries and livelihoods. There are more than 1,000 varieties of bananas (including plantain) but Cavendish bananas are grown in most of the world's 150 banana-producing countries, and represent almost half the annual production at around 50 million tonnes globally.

The Australian Centre for International Agricultural Research (ACIAR) is mandated under the ACIAR Act (1982) to work with partners across the Indo-Pacific region and Africa to generate the knowledge and technologies that underpin improvements in agricultural productivity, sustainability and food systems resilience for smallholder farmers, fishers and foresters. We do this by funding, brokering and managing research partnerships for the benefit of partner countries and Australia.

Recognising the impact of Fusarium wilt on smallholder livelihoods, ACIAR supported research in Indonesia in the early 2000s to identify and understand the spread of the disease. During this period researchers identified the dominance of the Tropical Race 4 strain among the many forms of *Fusarium* species affecting commonly grown banana cultivars.

ACIAR has maintained its support of research and capacity development to understand Fusarium wilt. Recognising that disease management options differ between smallholder growers and larger corporate growers, recent ACIAR investment has focused on management practices to reduce on-farm impact for smallholder growers, while also aiming to minimise spread of the disease to neighbouring regions and countries.

ACIAR's research investment to develop integrated disease management systems for Fusarium wilt supports our vision of reduced poverty and improved livelihoods for smallholder farmers. Further, the integrated on-farm practices that reduce Fusarium wilt, which advocate for greater plant biodiversity and resource protection within banana-based growing systems, contribute to responsible environmental management and climate adaptation.

The information in this publication synthesises an important and large body of research investment by ACIAR. The publication will be a valuable resource for smallholder banana growers and their advisors, across all banana-producing countries, to understand and manage Fusarium wilt.

Dr Nick Austin
ACIAR Chief Executive Officer (Acting)

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The information in this manual is based on the experience of author Tony Pattison who has worked with smallholder farmers in Southeast Asia and Latin America, with a focus on soil-borne diseases in banana plantations. Tony has been researching Fusarium wilt in Australia, the Philippines, Indonesia, Laos and Malaysia for more than 20 years.

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Abbreviations

ACIAR	Australian Centre for International Agricultural Research
DNA	deoxyribonucleic acid
DPI	Department of Primary Industries (Queensland)
FHIA	Fundación Hondureña de Investigación Agrícola
Foc	*Fusarium oxysporum* f. sp. *cubense*
TR4	Tropical Race 4
VCG	vegetative compatibility groups

Photo: ACIAR

About this manual

This manual is a guide for advisers of smallholder banana growers – including farm advisers, extension workers and farm leaders – in helping banana growers manage Fusarium wilt (also referred to as Panama disease) on their farms.

The manual presents factors to consider and a decision-making process to guide growers in implementing management practices to prevent the disease from entering the farm, reduce the spread of the disease in the event of an incursion, and minimise plant losses.

The strategies and practices suggested accord with the principles of integrated disease management – location, prevention, protection, reduction, resistance and commitment. The approach is adapted to a progression of 4 disease scenarios – no threat of the disease, an imminent threat, a recent on-farm incursion of the disease, and widespread plant losses.

The manual introduces the Fusarium Wilt Integrated Risk Tool, which can be downloaded and used to assess the risk of Fusarium wilt to a grower's banana production system based on the current disease situation and the grower's practices.

The manual concludes with case studies for the different disease scenarios.

The information in this manual is based on the results and experience of research in Australia, the Philippines, Indonesia, Laos and Malaysia. The publication has broad relevance across all banana-producing countries.

Top: Fusarium wilt, also called Panama disease, is a serious soil-borne fungal disease that can rapidly kill banana plants.

Bottom: Widespread destruction of bananas on a Fusarium wilt infected farm in north Queensland

Introduction

Fusarium wilt is a serious soil-borne fungal disease that can rapidly kill banana plants. Also called Panama disease, it is responsible for widespread losses in commercial banana plantations around the world. The disease spreads easily through soil, water, tools and infected plants. It causes plant leaves to yellow, wilt and eventually die. Once the disease is in the ground, it is nearly impossible to eliminate.

In the 1950s, the disease was responsible for widespread destruction of banana plantations in Central and South America, resulting in the abandonment of the susceptible Gros Michel variety by commercial plantation growers.

Growers then adopted the Cavendish cultivar, which was resistant to the type or 'race' of *Fusarium* that had destroyed the Gros Michel industry. However, in the 1990s a new strain of Fusarium wilt – Tropical Race 4 (TR4) – was discovered to be infecting the Cavendish banana. The TR4 strain was first reported in Indonesia and Malaysia and spread rapidly within Southeast Asia, wiping out the Cavendish-based export industry in both countries.

TR4 made its way to Australia in 1997 and was first detected in the Northern Territory. Just 6 years later, the territory's burgeoning banana industry was wiped out. However, due to strict quarantine measures, Australia's major banana production hub in Queensland remained disease-free.

In 2005, the disease reached the Philippines, one of the world's largest banana-exporting nations. Knowledge gained in Indonesia formed the basis of a research program between the Philippines Government and ACIAR, and a series of projects was developed to help smallholder banana farmers fight TR4. In 2012, research led by the Queensland Department of Primary Industries started to increase knowledge of on-farm biosecurity, minimise Fusarium wilt incursions, develop long-term management strategies to slow the spread of the disease, and develop options to allow smallholder producers to return to economic production. A series of research projects has continued in Southeast Asia, and in 2022 research started in eastern Africa.

Today, a greater understanding of soil biology and how easily the disease is transferred, along with increased awareness of on-farm biosecurity, has helped reduce the spread of the disease. While there is no chemical option for controlling the disease, the identification of simple farm management techniques – such as growing disease-suppressive groundcovers under the banana canopy and planting cultivars that are more disease-resistant – has made banana plants less susceptible to incursions of the disease.

Banana basics

Botanically, bananas are regarded as giant herbs with no woody tissue. The above-ground stem, which is made of tightly packed leaf bases, is referred to as a 'pseudostem' (**Figure 1**). The true stem is underground, a swollen structure known as a rhizome, often referred to as a 'corm'. The buds, or 'eyes', on the rhizome produce suckers, which are the shoots that develop into new plants.

As a sucker grows, new leaves emerge from the plant's centre; a tightly rolled emerging leaf is called a 'cigar leaf'. Once enough leaves have developed, the plant initiates a bunch from the rhizome. This bunch grows upward through the pseudostem, emerging at the top before hanging down. Bracts (modified leaves) lift to reveal female flowers, which develop into the edible fruit. The male flowers form at the end of the bunch in what is often called a 'bell'. In commercial farming, the bell is often removed to improve fruit quality, though it is edible in some cultivars.

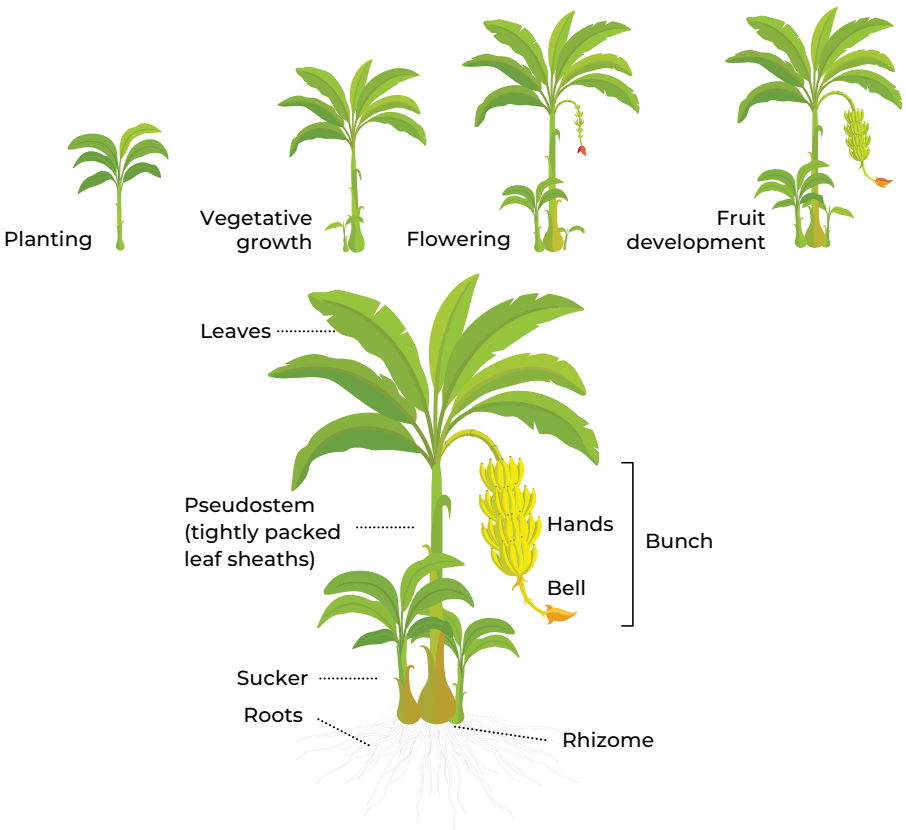


FIGURE 1 Banana growth stages and common plant structures

When the fruit reaches maturity, the bunch is harvested by cutting the fruit stalk, or 'peduncle'. Each bunch is composed of several 'hands' (rows of bananas), and each hand is made up of 'fingers' (individual bananas). Fruit may be marketed as whole bunches, hands, or clusters of 4–6 fingers. Bananas are typically harvested green to allow controlled ripening closer to market.

After harvest, the remaining leaves and top portion of the plant are removed, encouraging new sucker growth from the rhizome. In commercial production, one or two strong suckers are selected to replace the harvested plant, while others are removed to focus the plant's resources on the next crop. The standing pseudostem decomposes, returning nutrients to the suckers and supporting the next growth cycle. With careful management, a banana 'mat' – the connected clump of banana plants and suckers that share the same root system – can continue producing fruit for many years.

Photos: ACIAR

Bananas are typically harvested green to allow controlled ripening closer to market.

Fusarium basics

Fusarium is a large and diverse genus of fungi found in soils, plant debris and many natural habitats across the world. There are more than 400 recognised *Fusarium* species, and advances in DNA analysis continue to reveal even more diversity within this group. While some species are closely related and form 'species complexes', their biology, host range and impact can be very different. Many *Fusarium* species live harmlessly in the soil, or inside plants (as endophytes), while others cause serious diseases in a wide range of crops. This makes the *Fusarium* genus important both ecologically and economically.

In nature, *Fusarium* species act as natural recyclers, breaking down organic material and contributing to nutrient cycling. However, several species produce toxins (mycotoxins) that can contaminate grain and other food products, posing risks to human and animal health. From a plant health perspective, *Fusarium* species are notorious for causing wilts, root rots, crown rots and fruit rots. These diseases affect over 80 of the world's most important food and fibre crops, reducing yields and increasing production costs.

Fusarium species typically produce 3 types of spores – microconidia, macroconidia and chlamydospores – which can help the fungus to spread and survive (**Figure 2**). It is the resistant chlamydospores that can survive for long periods in soil, making management difficult once land becomes infested.

Aerial view of a banana field in the Philippines devastated by Fusarium wilt, showing a large area in the centre where bananas have died allowing grasses and weeds to dominate

Photo: ACIAR

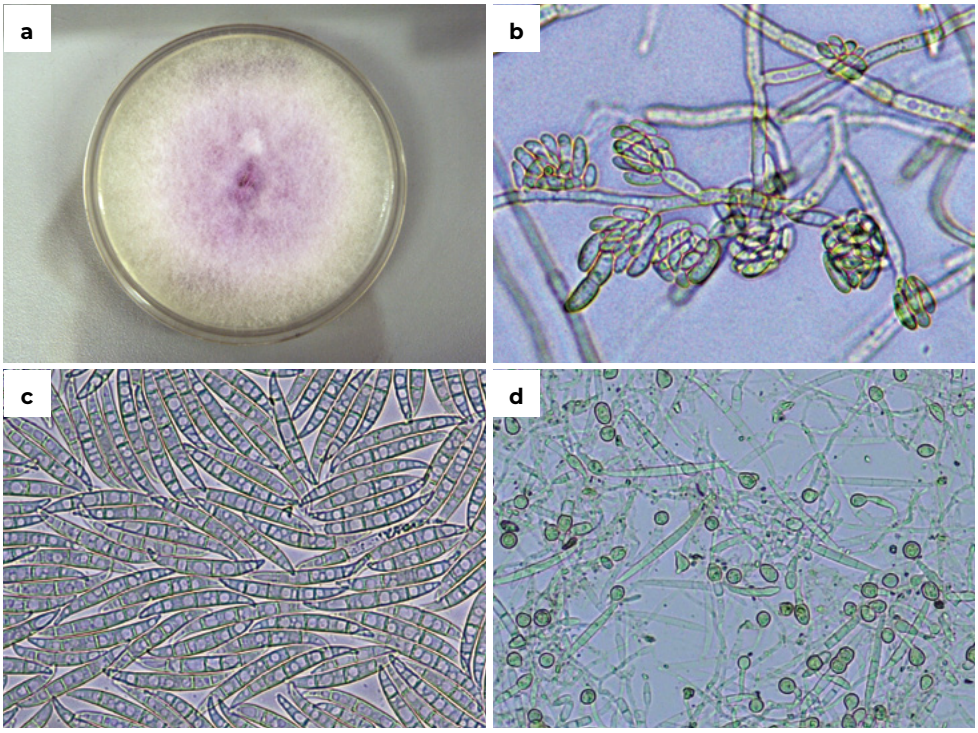


FIGURE 2 *Fusarium* species typically produce 3 types of spores – microconidia, macroconidia and chlamydospores

(a) *Fusarium* fungus showing mycelial growth on an agar plate. (b) Microconidia being produced from fruiting structures produced from the *Fusarium* mycelium. (c) *Fusarium* sickle-shaped macroconidia. (d) The production of chlamydospores.

Source: Wayne O'Neill, Queensland Department of Primary Industries

Several *Fusarium* species are associated with bananas, but the most significant is *Fusarium oxysporum* f. sp. cubense (or 'Foc'), the cause of Fusarium wilt. Foc is classified into different races based on the banana cultivars they attack, and into vegetative compatibility groups (VCGs) based on genetic compatibility between isolates. More than 20 VCGs of Foc have been identified from bananas worldwide.

The most damaging strain today is Tropical Race 4 (TR4) (also known as VCG 1213/16), which is capable of infecting Cavendish bananas, the dominant variety in global trade, and many other cultivars.

The banana market

Bananas are the most widely traded fruit around the world, with about 20 million tonnes, valued at US$15 billion, traded annually. Despite their prominence in international markets, the global banana trade represents less than 16% of total production – most bananas are consumed domestically in producing countries.

Globally, there are an estimated 300 to 1,000 banana cultivars, ranging from dessert varieties eaten fresh to cooking types such as plantains. Bananas are consumed in many forms – fresh, cooked, dried, or processed into packaged foods and beverages. The most widely traded variety is from the Cavendish subgroup, which dominates the fresh fruit export market.

Beyond the fruit, banana leaves are used in cooking and food presentation, and the stems can be processed into fibre for textiles, paper and livestock feed.

When the fruit reaches maturity, the bunch is harvested by cutting the fruit stalk, or 'peduncle'.

20m tonnes

of bananas are traded annually, valued at US$15 billion

84%

of total production is consumed domestically in producing countries

~300 to 1,000

banana cultivars globally

versatile

Bananas are consumed in many forms – fresh, cooked, dried, or processed into packaged foods and beverages

low waste

Banana leaves and stems have many uses

SECTION

1

Fusarium wilt in banana plants

SECTION

1

Fusarium wilt in banana plants

1.1 The disease and its symptoms

Fusarium wilt of banana, also called Panama disease, is a serious soil-borne fungal disease that can rapidly kill infected plants. It is caused by the pathogenic fungus *Fusarium oxysporum* f. sp. *cubense*. The Tropical Race 4 (TR4) strain of this fungus is currently causing widespread losses in commercial banana plantations around the world.

The Fusarium wilt TR4 fungus can survive in the soil and it can also survive on organic matter (as a saprophyte feeding on dead and decaying organic matter, and recycling nutrients back into the soil) and around the roots of most plants (**Figure 3**). Some plants and weeds appear to be better hosts of the fungus than others. All of this makes the fungus impossible to eradicate once the disease has been detected. The surviving fungal structures, chlamydospores, mycelium and infected plant material together form the 'disease inoculum' which is capable of reinfecting banana plants and causing the Fusarium wilt disease (**Box 1**). However, it is possible to manage the disease inoculum (the parts of the fungus that can infect banana plants), keeping the fungus in the soil at a low level so that it has minimal impact on banana production.

Box 1 Pathogen versus disease

When talking about Fusarium wilt of banana (Panama disease), it is important to distinguish between the pathogen and the disease – they are related, but not the same thing.

The **pathogen** is the cause of the problem. With Fusarium wilt, the pathogen is the fungus *Fusarium oxysporum* f. sp. *cubense* (Foc). This fungus lives in the soil and in plant tissues. It can produce different types of spores, which initiate the disease when they come in contact with the roots of a susceptible banana plant. Chlamydospores can survive for decades in the soil.

The **disease** is the result of the pathogen infecting the plant. Fusarium wilt is the set of symptoms and damage caused by the fungus inside the plant. In bananas, this includes the symptoms of leaf yellowing, leaf wilting, pseudostem splitting, and the discolouration (yellow to red to reddish black) of vascular tissue inside the pseudostem and corm.

Think of the pathogen as the culprit and the disease as the crime scene. The fungus is what spreads and infects, while Fusarium wilt is what you see and deal with in the field. Understanding this difference helps in understanding how to manage the pathogen to prevent the disease.

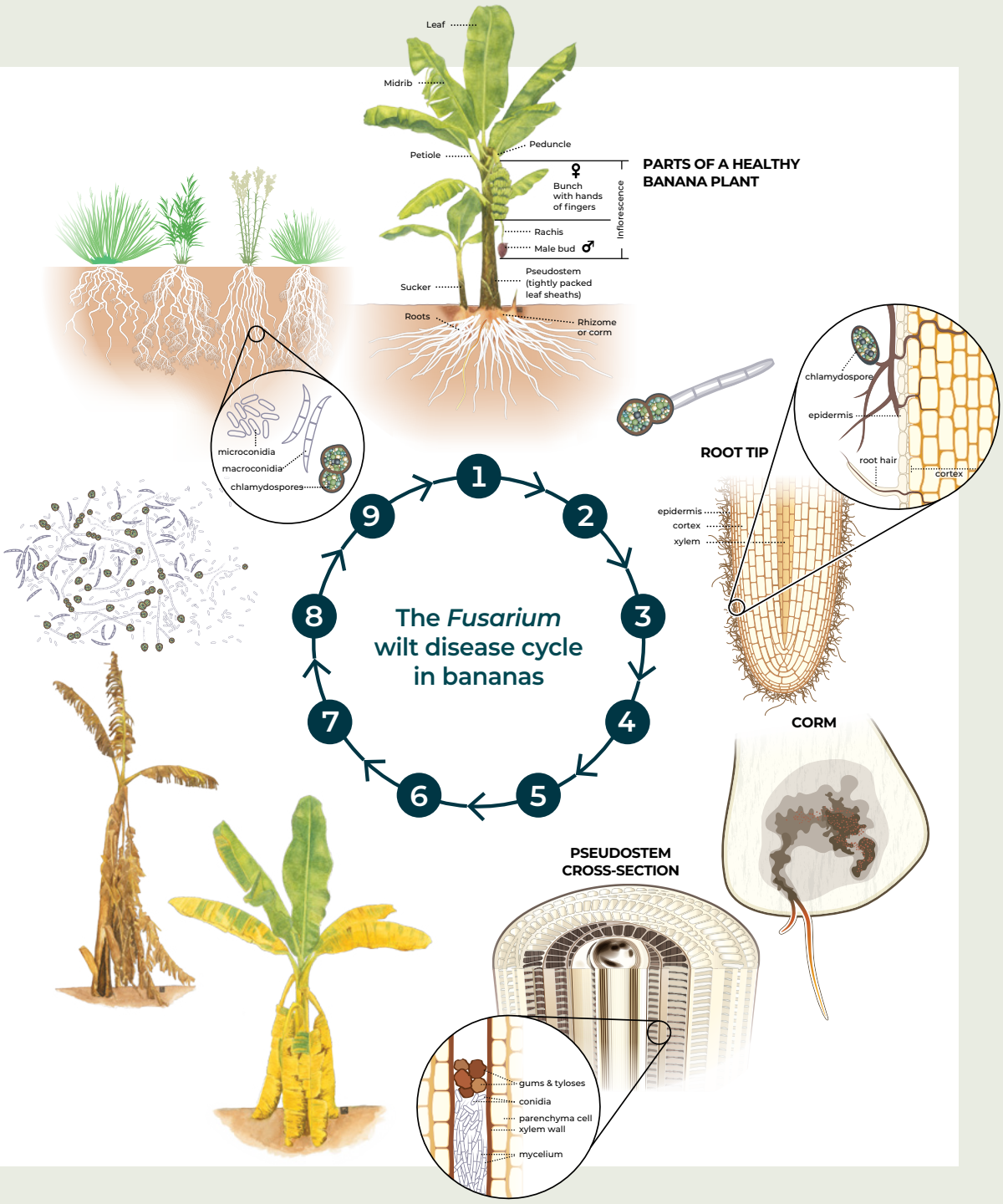
Symptoms of the disease include leaf yellowing (top) and discolouration of vascular tissue inside the pseudostem (bottom).

Life cycle of *Fusarium oxysporum* f. sp. *cubense*

Fusarium oxysporum f. sp. *cubense* (Foc) is a soil-borne fungus that survives in soil and plant residues. The life cycle and infection process can be described as a 9-step sequence. Disease development begins when spores germinate and come in contact with banana roots. Infected plants return spores to the soil meaning many infection cycles can occur within an infested plantation, allowing inoculum levels to build up over time.

1. Infected plant material, infested soil or contaminated irrigation/ flood water is introduced to Fusarium-wilt-free soil.
2. Chlamydospores in the soil germinate in response to chemicals that exude from the roots.
3. Germ tube from chlamydospore makes contact with host root system and colonises the spaces between the cortical cells.
4. Fungus enters the root xylem and moves up to the rhizome and pseudostem through growth of hyphae and production of conidia.
5. Fungal mycelium, along with gums and tyloses produced by the plant as a defence response, blocks and discolours the xylem.
6. Blockage of the xylem vessels leads to water stress and wilting.
7. Vascular system is extensively colonised. Fungus invades parenchymal and cortical tissues and produces abundant chlamydospores.
8. Chlamydospores and shortlived microconidia and macroconidia are released from decaying plant material into the soil.
9. The fungus survives for many years as dormant chlamydospores, living on dead organic matter or dying plant material and around the roots of weed and grass hosts.

FIGURE 3 Life cycle of *Fusarium oxysporum* f. sp. *cubense*, the cause of Fusarium wilt
Source: Adapted from Queensland Department of Primary Industries (2017)


Leaf
Midrib
Petiole
Peduncle
Bunch with hands of fingers
Inflorescence
Rachis
Male bud
Pseudostem (tightly packed leaf sheaths)
Sucker
Roots
Rhizome or corm
PARTS OF A HEALTHY BANANA PLANT
microconidia
macroconidia
chlamydospores
chlamydospore
epidermis
root hair
cortex
ROOT TIP
epidermis
cortex
xylem
CORM
PSEUDOSTEM CROSS-SECTION
gums & tyloses
conidia
parenchyma cell
xylem wall
mycelium
The Fusarium wilt disease cycle in bananas
1
2
3
4
5
6
7
8
9

The first sign of Fusarium wilt is yellowing of the lower, older leaves. There can be many causes of leaf yellowing in bananas, such as waterlogging, nutrient deficiencies, water stress and other diseases. Careful diagnosis is required if growers suspect Fusarium wilt for the first time. The leaf yellowing and leaf collapse caused by Fusarium wilt may progress with time. As the fungus spreads through the banana plant, it clogs up the vascular system, preventing the movement of water and nutrients. The *Fusarium* fungus also releases a toxin, helping it to move through the plant. Together, the clogging of the vascular system and the presence of the toxin result in the leaf yellowing and eventual collapse of the leaves, which is the characteristic symptom of Fusarium wilt.

Another external sign is the splitting of the pseudostem, though this does not always occur. Together, the leaf yellowing and pseudostem splitting are a sure sign of Fusarium wilt infection.

Inside the plant, discolouration of the vascular tissue is the main diagnostic symptom of Fusarium wilt. This can sometimes be difficult to see during early infections. It can also be limited to a localised area of the plant in the early stages of infection. The internal symptoms start at the base of the plant and can be found higher up as the leaf yellowing becomes more severe. Dark discolouration in the banana rhizome is also evidence of internal infection.

Following a period of stress, such as hot dry weather, extreme wet weather or very cold weather, the plant's defences and the microorganisms protecting the plant are inactivated (dysbiosis) which allows the fungal pathogen, Foc, to dominate and spread through the banana plant.

The symptoms of Fusarium wilt of banana (**Figure 4**) include:

- leaf yellowing, starting with the lower leaves
- leaves collapsing near the pseudostem, forming a skirt of dead leaves around the stem of the plant
- the younger leaves remain green and upright but may become distorted
- pseudostem splitting occasionally occurs at the base of the plant, with the split typically being 2 or 3 layers deep; some banana cultivars are more prone to splitting than others
- the internal tissue of the pseudostem becomes discoloured, initially becoming yellow, then progressing to red and a black-red colour.

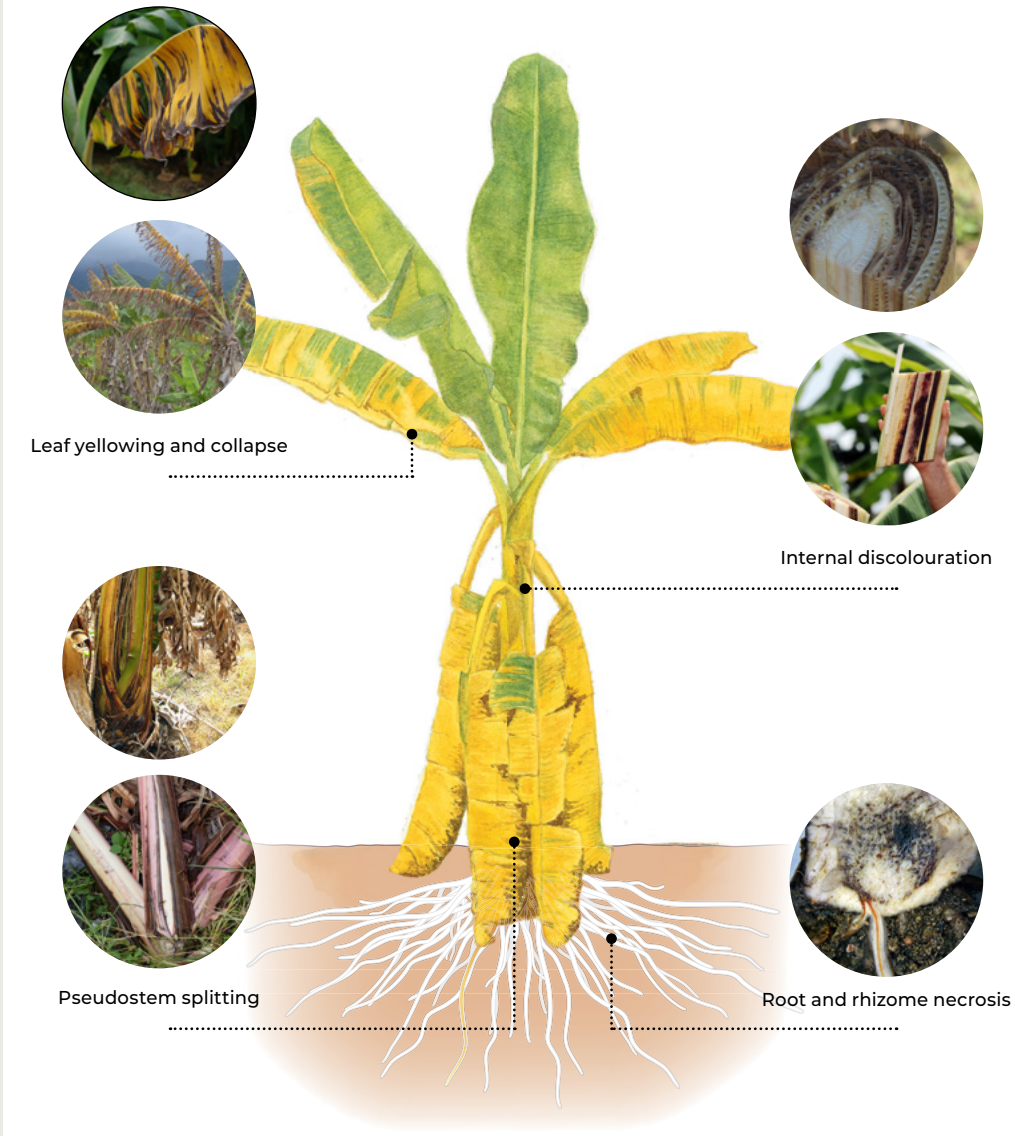


FIGURE 4 Typical external and internal symptoms of Fusarium wilt of banana
Source: Emily Pattison and Wayne O'Neill, Queensland Department of Primary Industries

1.2 On-farm disease scenarios

Fusarium wilt does not affect all banana farms equally. Banana growers face 4 different disease scenarios and the first step is to determine which scenario they currently face (**Figure 5**):

●○○○

Scenario 1: No threat

Fusarium wilt is not present on the farm and is not in the area.

●●○○

Scenario 2: Threat

Fusarium wilt is present in the area but is currently not present on the farm.

●●●○

Scenario 3: Incursion

Fusarium wilt has recently been detected on the farm but is currently isolated to a few plants and is not widespread.

●●●●

Scenario 4: Widespread plant losses

Fusarium wilt is widespread on the farm and causing significant plant losses.

The time it takes to move from one scenario to the next depends on how rapidly symptomatic plants are identified and on the management decisions the banana grower makes. How Fusarium wilt is managed will differ for each scenario as the emphasis on different disease management strategies changes. However, general disease management principles can be applied.

One thing is certain – the do-nothing approach and denial of the disease impacts will allow the disease to progress unabated.

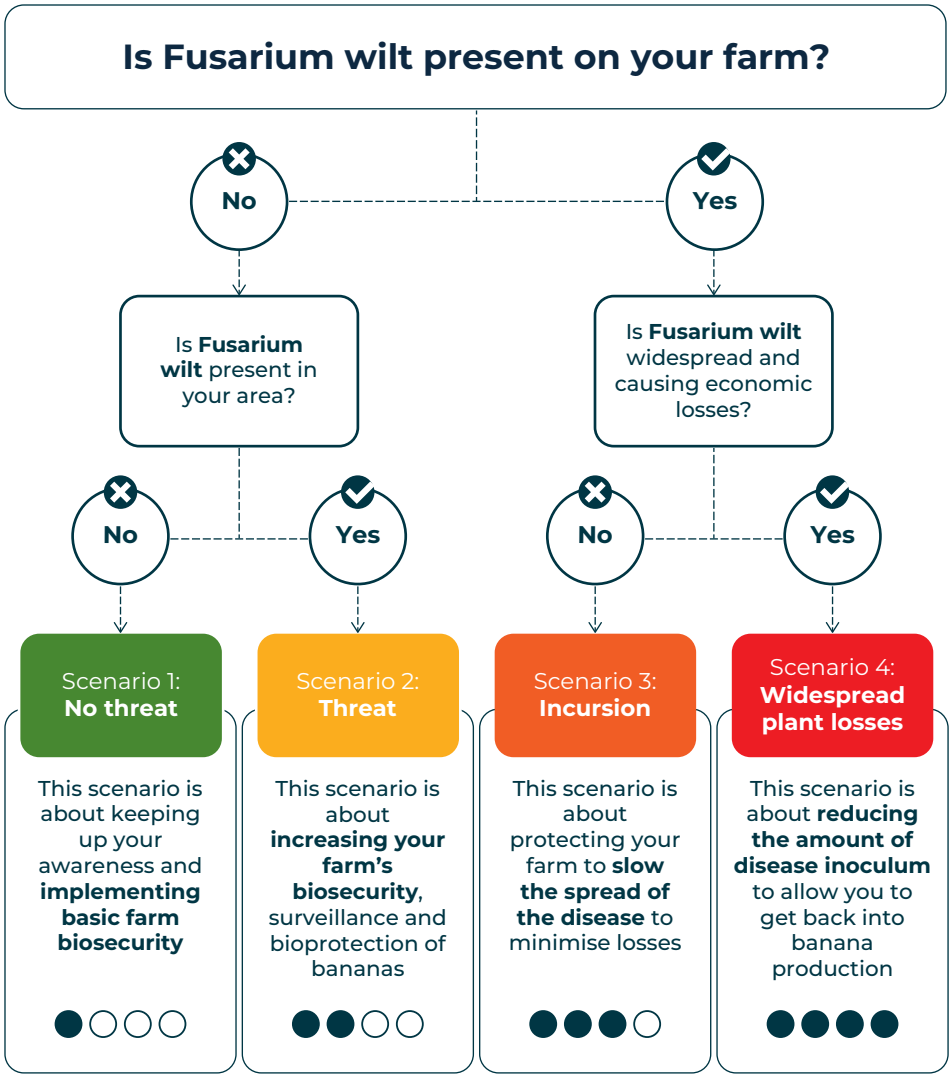


FIGURE 5 Decision tree to assess the threat scenario of Fusarium wilt on banana production

Together, leaf yellowing and internal vascular discoloration are a sure sign of Fusarium wilt infection.

1.3 Disease risks

The risks that Fusarium wilt pose to bananas can be categorised as inherent or induced.

Inherent risk refers to the level of disease threat that exists due to natural or unavoidable factors, independent of any preventive measures taken by the grower. Inherent risk arises from environmental conditions, pathogen presence and crop susceptibility, and it defines the baseline risk level that must be managed to prevent crop losses.

Many of the inherent risks of Fusarium wilt are difficult to control by banana growers in the short term. These include the location of the farm, especially its proximity to other banana farms. The inherent risks related to banana production increase as the threat caused by Fusarium wilt increases.

Recognising inherent risks is important, but when it comes to practical management it is important to address the risks that are within the banana grower's control. These are the induced risks.

Induced risk refers to the risk of disease outbreaks or increased susceptibility to disease that arises as a result of human actions, decisions or interventions within the farming system. Unlike inherent risks, which are naturally present, induced risks are often unintended consequences of agricultural practices or management choices.

Induced risks stem from the banana grower's decisions and practices. Doing nothing is a management decision that can induce the greatest risk to banana production. Decisions about the type of planting material, soil management and equipment used on the farm can all induce a risk, as they are the decisions made by the farm owner.

1.4 Outcomes from Fusarium wilt

Once Fusarium wilt is present in the area, there are 3 possible outcomes for banana farms:

- **Disease incursion** of Fusarium wilt onto the farm. The banana grower's recognition of, and response to, Fusarium wilt can affect the progression of the disease to the other possible outcomes.
- **Disease spread** of Fusarium wilt, causing crop losses. Typically, Fusarium wilt follows an exponential increase in the number of infected plants. However, inoculum management decisions and crop management decisions may slow the spread, and delay or avoid the exponential disease increase.
- **Loss of livelihood** due to crop losses and increased costs of production. Living with Fusarium wilt of banana is difficult and requires changes in farm management practices to protect livelihoods. Changing to resistant cultivars is an option for some banana growers, but not all. Replanting bananas without reducing the disease inoculum has been shown to lead to crop failure.

The outcomes for banana growers change with the changing scenarios (**Table 1**). However, the risk of crop loss is medium to high once the disease is on the farm, and the risk of livelihood loss is high when the disease is allowed to spread unabated.

Table 1 Risk of outcomes posed by Fusarium wilt as the scenario faced by the banana grower changes with increasing disease pressure

Disease scenario	Risk of disease incursion	Risk of disease spread and crop loss	Risk of livelihood loss
●○○○ **No threat**	Low	Low	Low
●●○○ **Threat**	Medium to high	Low	Low
●●●○ **Incursion**	High or certain	Medium	Low to medium
●●●● **Widespread plant losses**	High or certain	High or certain	Medium to high

1.5 Principles of integrated disease management

The 6 key principles of an integrated disease management system for Fusarium wilt are location, prevention, protection, reduction, resistance and commitment. The principles are explained more fully on pages **20** to **23**.

When a banana grower decides to take the do-nothing approach, their decision can lead to the disease outcomes being realised rapidly. Similarly, banana growers who rely on only one principle of disease control for Fusarium wilt, such as prevention, do not get the best control.

An integrated disease management approach for Fusarium wilt combines several components that help to manage the disease in different ways (**Figure 6**).

More detailed information about the management strategies and practices that growers can use to apply these principles to the management of Fusarium wilt is given in **Section 2**.

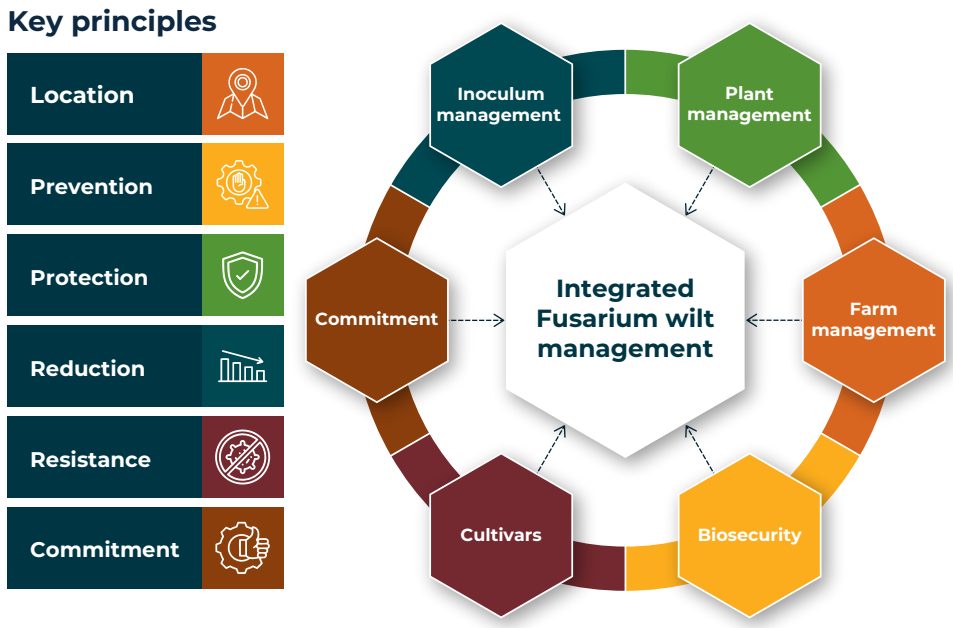


FIGURE 6 An integrated disease management system for Fusarium wilt in banana plants combines strategies and practices based on 6 key principles.

Key principle
Location

Location is about the inherent risk of Fusarium wilt based on the farm's geographical and climatic location.

Key principle
Prevention

Prevention is about minimising the risk of Fusarium wilt entering the farm.

Location will influence the risk level of a farm to Fusarium wilt in relation to:

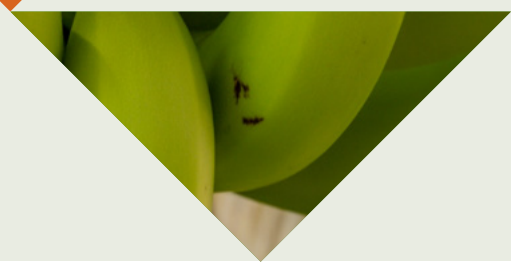
- the proximity of other banana farms
- the proximity of banana farms already infected by Fusarium wilt
- the suitability of the local climate for banana production
- the vulnerability of the farm to flooding, drought, heat and other climatic extremes.

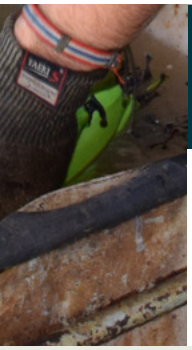
Location is an inherent risk of banana production, which is difficult to control for most banana farmers.

Prevention refers to a set of practices and measures designed to reduce the risk of plants becoming infected by Fusarium wilt by keeping the disease out of the farm.

Disease prevention is less costly than ongoing management of Fusarium wilt. The key aspects of preventing Fusarium wilt from entering a banana farm are:

- understanding the disease – how it spreads and what it looks like
- on-farm biosecurity to actively keep the disease out.





Key principle

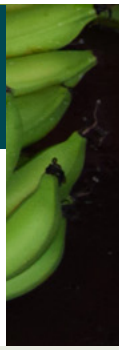
Protection

Protection is about strengthening the plants' defences to reduce their susceptibility to infection.

Key principle

Reduction

Reduction is about lowering the pathogen population to decrease the severity of the disease outbreak.



Protection refers to the set of strategies and practices aimed at safeguarding banana plants from Fusarium wilt. Plant protection can be biologically or chemically mediated. With no effective chemicals currently available to protect banana plants, protection relies on soil microorganisms providing the defence.

Protection of bananas against Fusarium wilt can be categorised as follows:

- Taking a broad view of the farm and the surrounding boundaries. Windbreaks and tree lines can reduce movement of the disease between neighbouring banana farms.
- Managing how the bananas are grown, and how crop management practices affect the soil microbial community. Taking an ecological view of disease management is important because the beneficial soil microbial community can suppress diseases through various mechanisms. For example, soil microbes produce antimicrobial compounds, compete for nutrients, induce systemic resistance, and use chemical signalling to suppress plant pathogens. Therefore, practices that enhance the soil microbial community are essential to slow the disease progression.

Reduction refers to the strategies and practices used to decrease the amount of disease inoculum in a crop, thereby lowering the likelihood of disease outbreaks, and helping to protect plants.

Reducing and managing disease inoculum is crucial to allowing the continual production of bananas in the presence of Fusarium wilt. Managing inoculum is focused on managing infected plants and preventing the spores released from infected banana pseudostems from overwhelming the soil microbial community. Strategies for reducing inoculum are used once Fusarium wilt is present and becomes widespread. Inoculum can be reduced through crop rotations and growing plants that are poor hosts to the pathogen. While Fusarium wilt of bananas is a disease of bananas only, the fungus can survive in and around the roots of a wide range of other plants, on un-decomposed soil organic matter and as chlamydospores in the soil.

Key principle

Resistance

Resistance is about selecting and growing resistant banana varieties and cultivars to naturally counteract the disease.

Resistance refers to the ability of a plant to prevent or minimise infection and damage caused by pathogens. Disease-resistant plants possess genetic traits that allow them to either fend off infection entirely or limit the extent and impact of disease. There are 2 types of resistance – general resistance for all races of the pathogen, and specific resistance for only specific disease races.

Resistance is commonly reported as the best method of managing Fusarium wilt in bananas. Several criteria must be met for new cultivars to be accepted into the banana supply chains for either export or domestic consumption:

- They must demonstrate some resistance to Fusarium wilt TR4.
- They must be agronomically as productive and suited as the banana cultivars that are being replaced.
- The fruit must be transportable and not require different transport, storage and ripening conditions to current cultivars.
- The fruit must have similar appearance, flavour and 'eatability' to current cultivars.
- They must be acceptable to consumers in terms of the way they are grown and produced.

Cavendish-type bananas (*Musa* AAA Cavendish subgroup) make up a large proportion of the bananas grown throughout Southeast Asia. For the banana export trade, a few highly productive cultivars such as Williams, Grand Nain, Valery, or variations of these cultivars, make up most of the fruit traded between countries. The narrow genetic base and clonal propagation makes banana plants particularly susceptible to disease epidemics, such as Fusarium wilt. Therefore, replacing current commercial cultivars with Fusarium-resistant cultivars is seen as a panacea to the Fusarium wilt problem for bananas. However, to date, no Fusarium-resistant banana cultivar meets all of the criteria listed.

Some cultivars are more resistant to Fusarium wilt but compromise on some of the preferred qualities. Therefore, it is a farm management and economic decision whether those compromises outweigh the risk of growing a susceptible cultivar.

Key principle

Commitment

Commitment is about engaging and supporting growers to consistently implement disease management practices.

Commitment refers to the willingness, motivation and commitment of farmers to take proactive steps in preventing and managing plant diseases in their crops.

For a banana grower, the people they work with and engage with on their farm can be their greatest allies and their weakest links in the management of Fusarium wilt.

An integrated response that involves the collective action of all interested and affected people is more likely to achieve greater benefits for the farm and the wider farming community.

However, there is no single strategy that ensures collective action in response to disease incursions. Understanding the roles of people on the banana farm, and the threats and benefits they pose, can help the grower develop a collective proactive culture where managing Fusarium wilt is everyone's responsibility.

A banana farm manager trims hands off a banana bunch in Panabo, Davao del Norte, the Philippines.

1.6 Scenario-based disease management

The management of Fusarium wilt is not static. As the disease scenario changes, so does the priority order for the principles of integrated disease management.

●○○○

Scenario 1: **No threat**

Fusarium wilt is not present on the farm and is not in the area. Reducing the likelihood of a disease incursion relies on the principles of integrated disease management being applied in the following order:

- commitment
- protection
- prevention
- resistance
- location.

See page **30**.

●●○○

Scenario 2**: Threat**

Fusarium wilt is present in the area but currently not present on the farm. Reducing the likelihood of a disease incursion relies on the principles of integrated disease management being applied in the following order:

- prevention
- commitment
- protection
- resistance
- reduction
- location.

See page **39**.

●●●○

Scenario 3: **Incursion**

Fusarium wilt has recently been detected on the farm but is currently isolated to a few plants and is not widespread. Reducing the likelihood of the disease becoming widespread relies on the principles of integrated disease management being applied in the following order:

- protection
- commitment
- reduction
- prevention
- resistance
- location.

See page **50**.

●●●●

Scenario 4: **Widespread plant losses**

Fusarium wilt is widespread on the farm and causing significant plant losses. Reducing the likelihood of livelihood loss relies on the principles of integrated disease management being applied in the following order:

- protection
- reduction
- resistance
- commitment
- prevention
- location.

See page **61**.

Dynamic disease management

As the disease risk faced by the banana grower changes, the outcomes they face, and the likelihood of particular outcomes, also change. When the disease is not present, disease management focuses on keeping the disease out. However, when there is a disease incursion, the focus should be on slowing the spread of the disease to maintain production for as long as possible. There comes a trigger point when Fusarium wilt becomes too widespread, causing economic losses and requiring a change in focus to living with the disease. This requires a reduction in the inoculum and, also, careful consideration to ensure livelihoods from banana production can be maintained.

The Excel-based Fusarium Wilt Integrated Risk Tool has been developed to assess the risk of Fusarium wilt to a grower's banana production system based on the current disease situation and grower practices. See **Section 3** (**page 79**) for more details.

Photo: ACIAR

When Fusarium wilt becomes too widespread, it can require a change in focus to living with the disease.

SECTION

2

Integrated Fusarium wilt management

SECTION

2

Integrated Fusarium wilt management

The management of Fusarium wilt on a banana farm is determined by the disease scenario faced by the grower. As the incidence of Fusarium wilt increases and the farm moves from one disease scenario to the next, the grower will need to adopt different strategies and practices to minimise the impact of the disease.

This manual recommends an ecological approach to disease management by investigating why Fusarium wilt is a problem to banana production, rather than a reactionary approach of treating the symptoms after the disease appears. This approach emphasises the development of disease suppression in cropping systems by promoting increased soil microbial interactions with banana plants, which promotes competition to *Fusarium* in the soil. However, soil microbial protection alone cannot reduce the impact of Fusarium wilt. Help is required through disease minimisation strategies.

This section provides details about using the principles of an integrated disease management system (**Figure 7**) to determine the practices to manage Fusarium wilt. For each of the 4 disease scenarios – threat, no threat, incursion and widespread plant losses (introduced on **page 14**) – the principles are presented in order of priority.

Disease suppression is important for promoting increased soil microbial interactions with banana plants, but other strategies are also needed to reduce the impact of Fusarium wilt.

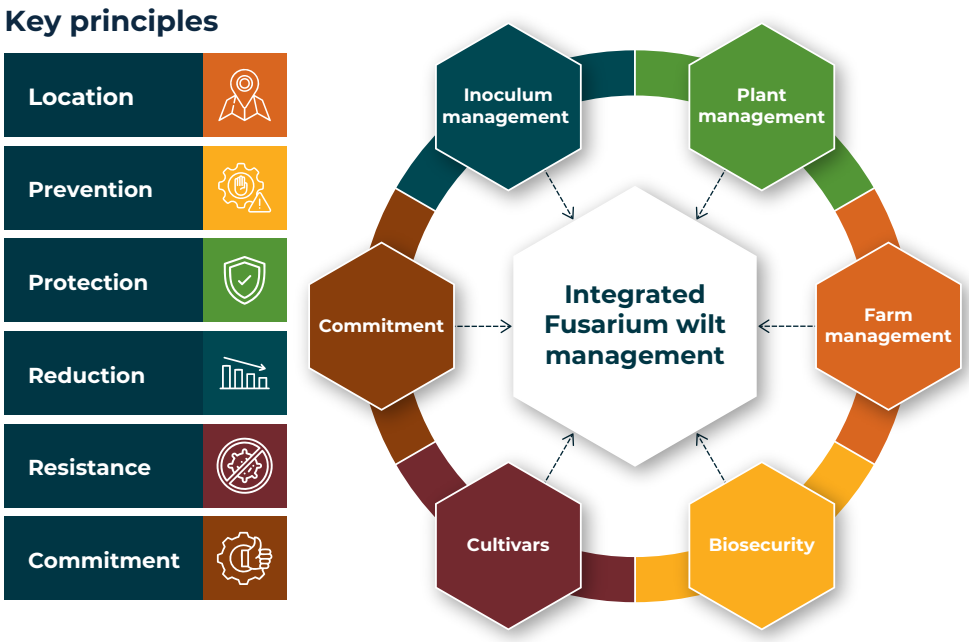


FIGURE 7 An integrated disease management system for Fusarium wilt in banana plants combines strategies and practices based on 6 key principles.

●○○○ Scenario 1: **No threat**

When Fusarium wilt is not on the farm and not in the area, management resources should be allocated to keeping the disease off the farm. Establishing a strong commitment to protect the farm from the disease is the top priority. Commitment requires an understanding of how Fusarium wilt develops and spreads, and a proactive attitude to disease management. Proactive management strategies include increasing the protection of banana plants by ensuring good soil and plant health, and increasing the soil microbial community around the banana plant. Growers should implement basic on-farm biosecurity, be aware of alternative banana varieties, and monitor the known locations of the disease to reduce risk and improve preparedness.

Priorities

Commitment p **31**

Protection p **33**

Prevention p **34**

Resistance p **36**

Location p **38**

Priority 1
Commitment

When Fusarium wilt is not present on the farm and is not in the area, people are the most likely source of an introduction of the disease. It is important that workers and farm visitors are aware of the risks posed by Fusarium wilt.

Sharing farm equipment

Sharing farm equipment and tools with neighbours, family and friends is one of the greatest risks for introducing Fusarium wilt. While sharing equipment can be a way to share expenses and keep production costs down, the practice can spread contaminated soil and plant material from farm to farm. To reduce the risk of introducing Fusarium wilt in the future, the grower should consider investing in their own equipment and tools, and explain to others why it is best not to share them.

Training staff

Farm staff, who are in the field most days, are well placed to observe early signs of disease. Teaching staff the typical symptoms of Fusarium wilt, such as leaf yellowing and abnormal growth, and having a process for reporting sick plants can help to detect the disease early. A trained and trusted regular farm employee can supervise casual staff who may be unfamiliar with Fusarium wilt symptoms.

Staff training also needs to include the importance of farm biosecurity, ensuring that it is everyone's responsibility to follow protocols to keep the disease out of the farm. A lapse in farm biosecurity, such as someone entering the farm with muddy footwear, can lead to the introduction of the disease and a loss of income for all.

Creating a culture of vigilance and prevention when the disease is not present can make it easier if the disease threat should increase.

Farmers at a field day in north Queensland place disposable covers over their boots to prevent contamination at the site. Creating a culture of disease vigilance and prevention is good practice.
Photo: Brian Casey, Australian Banana Growers' Council

Making farm staff aware of the typical symptoms of Fusarium wilt, such as leaf yellowing, can help to detect the disease early.

Allocating farm resources

There are many low-cost preventive activities that smallholder and large-scale growers can implement to reduce the risk of Fusarium wilt being introduced onto the farm. Additionally, if resources permit, farmers can consider allocating more farm resources to biosecurity, as well as investing in their own farm equipment and tools.

Engaging family and close associates

Family and close associates (neighbours, friends and workers) should be aware of the risks that Fusarium wilt pose for the farm. They should understand that the disease can be managed but should it arrive in the area or on the farm, their support is needed to minimise spread.

Reporting and sourcing information

Having a trusted source of information is important in managing Fusarium wilt. Generally, government and grower representatives can provide impartial information on management of Fusarium wilt. The grower should be familiar with who can provide impartial information and who should be notified if there is a disease incursion.

Priority 2
Protection

Healthy growing conditions and healthy plants are important for strengthening a plant's defences and reducing its susceptibility to infection.

Plant health

Plant health can be defined in many ways. In the context of Fusarium wilt, healthy plants are those with minimal pest and disease pressure from other sources, such as leaf diseases, plant-parasitic nematodes, and insects. Free from biotic stresses, healthy plants tend to be more disease tolerant. They also tend to reflect a beneficial association between soil microorganisms and the plant, which strengthens the plant's defences. When other pests and diseases of bananas are managed, banana plants remain in good health and are less likely to succumb to Fusarium wilt. This also slows down the spread of the disease across the farm.

When plants are in poor health, Fusarium wilt can be difficult to identify. Leaf yellowing of bananas is a common response to plant stress and a symptom of diseases caused by bacterial rots or other leaf diseases. Therefore, leaf yellowing caused by Fusarium wilt can easily be overlooked.

Plant vigour

Vigorously growing banana plants tend to reflect good growing conditions. Banana plants that have poor growth can be under environmental, nutritional, water or biotic stress. Stressed bananas are more likely to succumb to Fusarium wilt and allow the fungus to increase rapidly.

However, plants that experience 'luxurious' conditions may be equally susceptible to disease. Very vigorous plants grown in luxurious nutrient and environmental conditions tend to put more resources into growth rather than plant defence. Therefore, plant vigour needs to be balanced – a lack of resources can lead to stress whereas luxurious growing conditions can lead to reduced plant defence.

Growing conditions should promote plant vigour but not at the expense of developing the plant's defences.

Priority 3
Prevention

When Fusarium wilt is not a threat, an informal biosecurity plan may be sufficient to create awareness of threats to the farm and an understanding of disease prevention practices. There are several simple biosecurity measures that can be implemented, which reduce the threat of Fusarium wilt to the farm, as well as the threat of other diseases, pests and weeds.

Recognising the symptoms of poor banana growth

Learning to recognise the symptoms of Fusarium wilt (see **Section 1.1**) as well as symptoms of other causes of poor banana growth will enable appropriate plant management and disease prevention. Fusarium wilt in bananas typically begins with yellowing of the lower leaves, which can also be a symptom of other issues, such as nutrient deficiencies or water stress. Stressful environmental conditions can weaken a plants defences making them more susceptible to infection by the *Fusarium* pathogen.

Restricting farm access

Being aware of who comes onto the farm and when they are arriving allows for preparation or exclusion of high-risk visitors. The opportunity to control access to the farm means that contaminated equipment, tools and footwear can be cleaned before entering.

Vehicle washdown facility in the Philippines (above) and a vehicle bath in north Queensland, Australia (below)

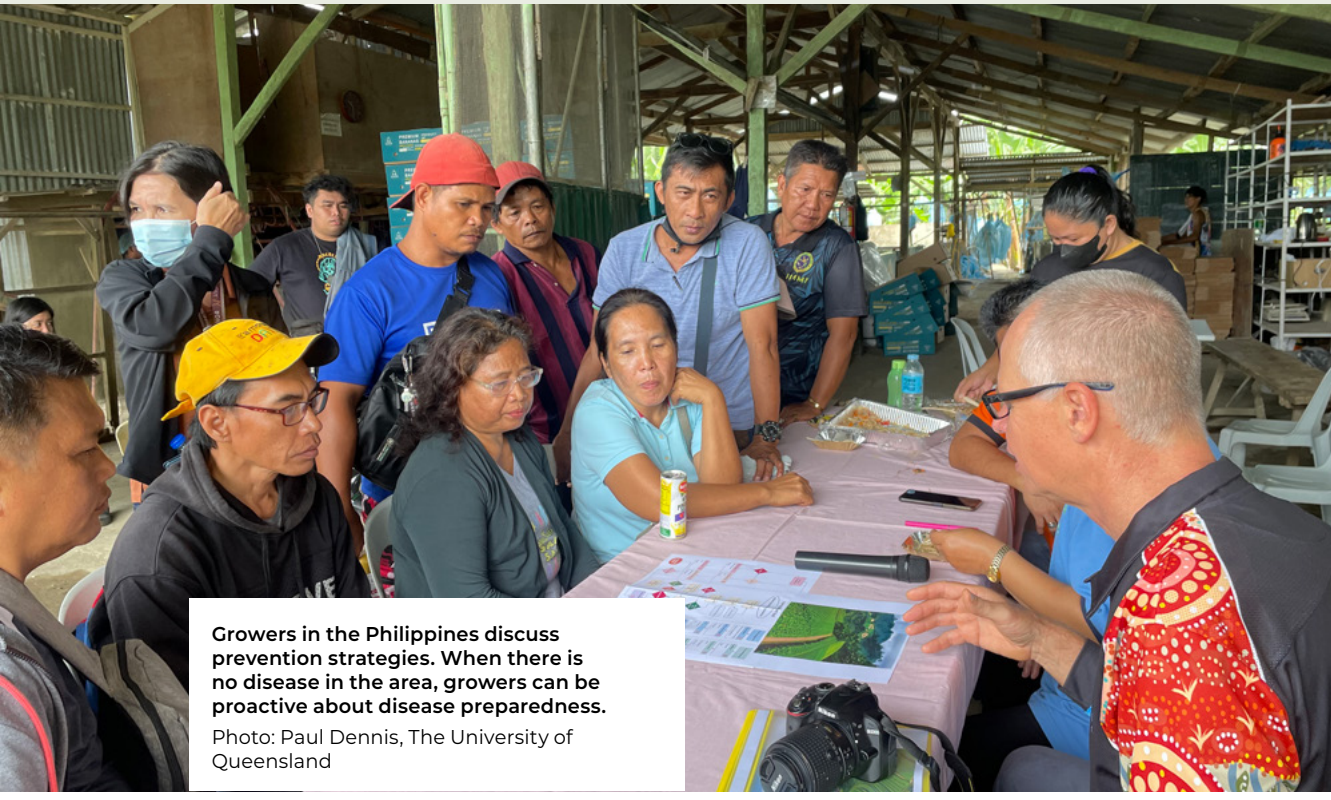
The greatest risk of introducing Fusarium wilt on to a banana farm is through contaminated footwear. If people cannot be excluded from the farm, then make sure they have clean footwear. Providing footwear for anyone entering the farm is considered best practice. Alternatively, establish footwear decontamination stations to remove soil and disinfect footwear. Always ensure the disinfectant used is suitable for the purpose.

Restricting access onto the farm may be difficult for smallholder banana growers, especially those belonging to cooperative farming groups. In some countries it is culturally offensive to prevent people from moving across farmland. If it is not possible to prevent people from entering the farm area through a central point, try to create awareness and implement measures to reduce the risks of spreading the disease.

Biosecurity zoning

Zoning the farm is a consideration for a biosecurity plan when the threat of Fusarium wilt increases. Zoning is the practice of dividing the farm into sections with different levels of access for visitors and workers.

The greatest risk of introducing Fusarium wilt on to a banana farm is through contaminated footwear. Foot baths and footwear for visitors can reduce this risk.



Growers in the Philippines discuss prevention strategies. When there is no disease in the area, growers can be proactive about disease preparedness.

Photo: Paul Dennis, The University of Queensland

Priority 4

Resistance

When Fusarium wilt is not present on the farm or in the area, highly productive cultivars that are susceptible to Fusarium wilt can be grown. However, it is important to understand the susceptibility or resistance of the chosen cultivar, and it always important to source clean, disease-free planting material.

Understanding cultivar resistance

Even though Fusarium wilt is not a threat to the farm, it is important to understand the susceptibility or resistance of the varieties being grown or new varieties being selected. Most commercial Cavendish banana cultivars that are grown for export or supermarkets are susceptible to Fusarium wilt TR4 (see **Table 2**). Understanding the resistance or susceptibility of banana cultivars is part of implementing an integrated management strategy. When getting advice on cultivar resistance, growers should check that information is from a reliable source and has been independently validated.

Using vegetative planting material

Vegetative planting material used for propagation, such as the rhizome (corm) or suckers, can harbour the Fusarium pathogen and is the most common method of spreading the disease within and between farms and over large distances. At low infection levels, infected banana plants do not always show external symptoms, such as leaf yellowing, or internal symptoms, such as rhizome discolouration.

Sourcing banana planting material from outside the farm is a big risk for introducing Fusarium wilt. Propagating new plants with on-farm vegetative material reduces the risk of bringing new diseases onto the farm, although it can spread pests and disease already present, such as nematodes. Using on-farm material is acceptable while the disease is not in the area, but to minimise risk, growers should plan to source planting material raised by tissue culture.

Sourcing clean planting material

The preferred way of establishing a new planting is to use tissue-culture plantlets. These should be purchased from an approved, accredited nursery. Nursery accreditation means that plants are grown in clean, non-banana-based potting material and verified to be free of viral diseases. Purchased planting material should be free of soil and any other sources of contamination.

Tissue-culture plants may require additional management during establishment, particularly additional irrigation and weed control, compared with replanted vegetative material.

Pisang Raja are a prized banana variety, with different cultivars having different resistance to Fusarium wilt TR4.

Table 2 Resistance and susceptibility to Fusarium wilt TR4 of some common banana cultivars tested in field situations with natural and artificial inoculum

	Banana cultivar resistance to Fusarium wilt TR4		
Banana subgroup	**Susceptible**	**Intermediate**	**Resistant**
Cavendish (AAA)	· Williams · Grand Nain · Baxi	· GCTCV218 · GCTCV119 · ZJ03 · ZJ06	· GCTCV215 · GCTCV247 · ZJ04
Plantain, False Horn (AAB)			· Most cultivars
Plantain, French (AAB)	· Uganda plantain		· Most cultivars
Iholena (AAB)	· Luba · Tigua · Uzakan · Wisu	· Maritú · Rukumamb	· Kofi
Maoli Popoulu (AAB)	· Pacific plantain		· Poingo
Mysore (AAB)		· Pisang Ceylan	· Thap Maeo
Ney Mannan (ABB)			· Blue Java
Pisang Awak (ABB)	· Dwarf Ducasse · Guangfen		· Khom Namwa
Pisang Raja (AAB)	· Pisang Raja Bulu	· Pisang Raja #2 · Pisang Raja	· YN2 · Pisang Raja
Silk (AAB)	· Most cultivars		
Hybrids		· FHIA-03 (AABB)	· Most FHIA hybrids

Source: Modified from Munhoz et al. (2024)

Priority 5
Location

Location may present an inherent risk for an incursion of Fusarium wilt. Depending on landscape and environmental features, the farm's location may present threats that are difficult for the grower to manage.

Farm location

When there is no disease on a farm or in the area, the risk of an incursion is low. Fusarium wilt is far more likely to spread between neighbouring banana farms. Isolated farms, such as those in upper parts of valleys or farms surrounded by other land uses, are less likely to have banana disease problems.

Blocks and farms that have public access areas, such as roads and walkways, may be subject to a higher risk of disease incursion, as farm biosecurity practices cannot be imposed on public areas.

Flooding risk

Flooding and inundation of water into banana fields can carry soil and the pathogen. Therefore, low-lying areas close to waterways tend to be at higher risk of Fusarium wilt incursion. The risk is even higher when there are banana farms upstream. Understanding the flooding risk of banana fields can help growers identify the risk pathways for the disease entering the farm.

Irrigation from rivers or dams

Irrigation water can pose a risk of incursion and spread of Fusarium wilt. Bananas need water, particularly where rainfall is seasonal. It is important to understand where the growers' irrigation water is coming from and if there is a potential for contamination. On-farm water storages, where water is captured and recycled, can be a source of spreading Fusarium wilt.

Where bananas are flood-irrigated from canals and channels, there is a very high risk that the irrigation water can bring Fusarium wilt onto the farm and spread it between plants.

●●○○ Scenario 2: **Threat**

When Fusarium wilt is present in the area but currently not on the farm, prevention is the top priority for an integrated disease management program. This requires a strong commitment from everyone involved in the farm to consistently follow biosecurity practices. Effective protection involves improving soil health and understanding how farm management decisions can influence the spread of the disease. Banana growers should stay informed about disease-resistant banana cultivars, know how to manage infected plants, and be aware of potential disease pathways onto their farm so that they can reduce risk and improve resilience.

Priorities

Priority 1
Prevention

When Fusarium wilt is in the area around the farm, prevention is the top priority for disease management. Growers should be building their understanding of the disease and implementing disease prevention practices – all of which contribute to a farm biosecurity plan.

Creating a farm biosecurity plan

A farm biosecurity plan sets out the practical steps a grower will take to prevent weeds, pests and diseases entering the farm. It documents the practices and assigns responsibilities to all people associated with the farm. When Fusarium wilt is detected in the area it is time for growers to put a biosecurity plan in place, if they do not have one already.

Some useful links to information about creating a farm biosecurity plan are listed in **Section 5**, pages **108–109**.

Recognising the symptoms of poor banana growth

Being able to recognise and distinguish between the symptoms of Fusarium wilt (see **Section 1.1**) and other diseases and conditions affecting plant growth is critical when Fusarium wilt has been found in the area of the farm. Fusarium wilt in bananas typically begins with yellowing of the lower leaves, which can also be a symptom of other issues, such as nutrient deficiencies or water stress.

As Fusarium wilt progresses, the fungus blocks the plant's vascular system and releases toxins, eventually leading to leaf collapse. Stem splitting may also occur, and internal symptoms include dark discolouration of vascular tissue, especially in the rhizome.

When the disease is in the area, the decontamination of footwear and tools is critical. Providing footwear for anyone entering the farm is considered best practice.
Photo: ACIAR

If banana plants are already impacted by stressful environmental conditions, their defences will be weakened, allowing the Fusarium pathogen to spread more easily.

Restricting farm access

Restricting access to the farm can minimise the likelihood of contaminated soil or plant material being introduced. Ideally, people should enter the farm through a central point, with clean footwear, tools and machinery. Being aware of who comes onto the farm and when they arrive allows high-risk visitors, especially those with dirty footwear and equipment, to be excluded.

The greatest risk of introducing Fusarium wilt on to a banana farm is through contaminated footwear. If people cannot be excluded from the farm, then make sure they have clean footwear. Providing footwear for anyone entering the farm is considered best practice. Alternatively, establish footwear decontamination stations to remove soil and disinfect footwear. Always ensure the disinfectant used is suitable for the purpose.

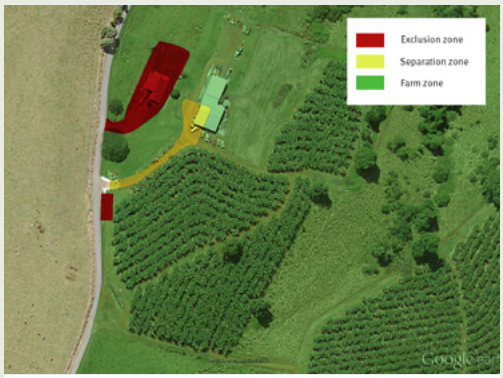
As the threat of Fusarium wilt increases, growers may need to consider additional barriers to prevent people and animals entering the farm. Additional fencing and deterrents help to keep out unwanted visitors from potentially infested farms.

Restricting access onto the farm can be difficult for smallholder banana growers, especially those belonging to cooperative farming groups. In some countries it is culturally offensive to prevent people from moving across farmland. If it is not possible to prevent people from entering the farm area, try to create awareness and implement measures to reduce the risk of spreading the disease.

Farm zoning

Zoning is the exercise of dividing the farm into sections with different levels of access for visitors and workers. A minimum of 2 zones should be established – the farming zone where bananas are grown and a public zone where visitors and suppliers can access buildings. Only people essential for banana production can enter the farming zone. Anyone can visit the public zone. A physical barrier can help separate the zones. This does not have to be expensive – it may be as simple as some twine.

A 3-zone system should be used for larger farms. The third zone represents the separation zone and usually encompasses the pack shed. This provides an extra level of protection to the banana plants as people need to decontaminate as they move between zones.



An example of farm zones on a banana farm in Queensland. Farms should have a minimum of 2 zones, and larger farms could have 3 zones, to keep visitors to the property away from the banana-growing areas.

Source: Queensland Department of Primary Industries

Priority 2
Commitment

When Fusarium wilt is in the area, the people associated with the farm become more important to help keep the disease out and support the grower to maintain a Fusarium-wilt-free banana farm.

Ending the sharing of farm equipment

The sharing of farm equipment with neighbours, family and friends should cease when Fusarium wilt has been detected in the area. While sharing equipment can be a way to share expenses and keep production costs down, the practice increases the likelihood of introducing Fusarium wilt to a farm.

Now is the time to invest in equipment and tools that stay on the farm and explain to others why it is best not to share high-risk tools. It may also be necessary to improvise on how farm tasks are performed rather than borrowing equipment from other farms.

Packhouse workers in Ecuador. It's important to create a disease-awareness culture where disease prevention is a responsibility shared by everyone to protect their livelihoods.

Training staff and building a disease-awareness culture

The training of farm staff and making them aware of the risks of Fusarium wilt becomes more important when Fusarium wilt has been detected in the area. As farm staff and contractors are in the field every day, there should be a reporting structure for any sick or suspicious plants they may observe. Update people working on the farm about the symptoms of Fusarium wilt and remind them of the need to ensure farm biosecurity protocols are maintained at all times. For successful management of Fusarium wilt, it becomes important to create a disease-awareness culture where prevention of the disease is a shared responsibility by everyone to maintain livelihoods. In Queensland, Australia, the banana industry, through the Australian Banana Growers' Council, provides a dedicated grower support team to help with on-farm surveillance of Fusarium wilt.

Allocating farm resources

Additional resources should be used to keep the disease out of the farm now that the risk of an incursion has increased. This may include investment in biosecurity and prevention activities, such as the purchasing of 'farm only' footwear, chemicals for footbaths, and decontamination stations. Consider allocating resources to improving the resilience of the banana crop. By increasing the microbial diversity and activity in the soil through soil management (such as vegetated groundcovers), it is possible to slow the spread of Fusarium wilt should the disease enter the farm.

Working with family and close associates

The grower's social network, including family and friends, should be made more aware of the increased risk of Fusarium wilt, how it can be managed and what could happen if it is unmanaged. Family can help develop plans for dealing with Fusarium wilt and should be aware that the progression of the disease can still be slowed, but the grower may require additional support should it enter the farm.

Reporting and sourcing information

Having a trusted source of information is important in managing Fusarium wilt. Generally, government and grower representatives can provide impartial information on management of Fusarium wilt. Information sources should be able to provide information about disease identification, alternative cultivars, and how to deal with an incursion should it happen. It is also very important to be familiar with regulations and reporting requirements, should the disease be found on the farm. Fusarium wilt of banana is a notifiable disease in many locations and support may be provided to help manage the disease.

Information related to the spread of Fusarium wilt of banana being gathered from affected farms across Laos

Photo: ACIAR

Priority 3
Protection

When Fusarium wilt is in the area, the threat of an incursion increases. Soil management can help reduce the likelihood of the pathogen becoming established and slow the spread of Fusarium wilt across the farm.

Improving soil health and soil biological diversity

Increasing the microbial activity in the soil can help to protect plants and slow the spread of Fusarium wilt. Soils under longer-term banana cultivation tend to have reduced soil microbial biomass compared to less intensive land uses. The diversity of soil fungi tends to be particularly reduced under bananas, allowing *Fusarium* species to dominate the fungal community.

By increasing the diversity of plants growing around bananas and interacting with banana root systems, either through vegetated groundcovers or intercropping, it is possible to increase the bioprotection of banana plants through increased beneficial soil microbial interactions.

Importantly, improving soil microbial interactions to protect plants takes time and should be started before the disease arrives on the farm.

Managing soil pH

The pH of the soil is very important for allowing soil microorganisms to function optimally. Under acid soil conditions, less than pH 6.5, the diversity and abundance of bacteria and fungi declines. As the abundance and diversity decline, the ability of the soil microbial community to suppress Fusarium wilt also diminishes. Maintaining a close-to-neutral pH (pH 7.0) helps to maintain a functioning soil microbial community to protect banana plants and slow the spread of Fusarium wilt. Soil pH management alone is not enough to stop Fusarium wilt from infecting plants but provides a basis to build biological protection of banana plants.

Vegetated groundcovers can contribute to the bioprotection of banana plants through increased beneficial soil microbial interactions in the root zone.

Under high nitrogen conditions, banana plants can become more susceptible to disease, as their defence chemicals are diluted in favour of growth.

Managing nitrogen

Nitrogen is one of the most limiting nutrients in agricultural soils, and highly sought after by plants and soil organisms. Therefore, the application of nitrogen can have profound effects on plant growth and soil microbial communities.

Under high soil nitrogen conditions, banana plants respond by putting more resources into growth and less into plant defences. This makes the plants more susceptible to a range of diseases, as the defence chemicals become diluted within the plant.

High application rates of inorganic nitrogen fertilisers (nitrates and ammonias) favour fast-growing organisms. This reduces the diversity of soil microorganisms as the slow-growing organisms are 'swamped' by the fast-growing organisms. Because fast-growing organisms have evolved for rapid reproduction, they have few mechanisms to suppress other organisms. Slower growing soil organisms tend to have 'competitive' mechanisms that keep other soil organisms in check when soil resources are limited. Therefore, conditions that favour the fast-growing organisms and reduce slower growing organisms can favour soil-borne diseases, such as Fusarium wilt.

Priority 4

Resistance

When Fusarium wilt is in the area, it is critical to understand the susceptibility or resistance of cultivars being grown and selected for future plantings. For future plantings, it is important to source clean, disease-free planting material.

Understanding cultivar resistance

When Fusarium wilt is not present on the farm but is in the area, it is important that the grower understands the susceptibility or resistance of varieties and cultivars to help assess risk (see **Table 2**, **page 37**). This will help them understand the risk of Fusarium wilt affecting current plants, as well as inform decisions for future plantings. Most commercial Cavendish banana cultivars grown for exports or supermarkets are susceptible to Fusarium wilt TR4. However, there are global efforts to breed replacement cultivars that are resistant to Fusarium wilt.

Growers should be familiar with the varieties and cultivars available and understand how other options compare to the cultivars currently being grown – agronomic qualities as well as market acceptance are important. Cavendish banana cultivars with increased resistance to Fusarium wilt have enabled continued banana production in the presence of the disease but the success of their resistance may be at the cost of some agronomic characteristics.

Understanding the resistance or susceptibility of banana cultivars is part of implementing an integrated management strategy.

Using vegetative planting material

Vegetative planting material used for propagation, such as the rhizome (corm) or suckers, can harbour the *Fusarium* pathogen and is the most common method of spreading the disease within and between farms and over large distances. At low infection levels, infected banana plants do not always show external symptoms, such as leaf yellowing, or internal symptoms, such as rhizome discolouration.

Banana planting material should not be sourced from outside the farm when there is Fusarium wilt in the area. Propagating new plants with on-farm vegetative material reduces the risk of bringing new diseases onto the farm, although it can spread pests and disease already present, such as nematodes. Using on-farm material can still present a risk if the disease is in the area. Growers should aim to source planting material raised by tissue culture.

Sourcing clean planting material

The preferred way of establishing a new planting is to use tissue-culture plantlets. These should be purchased from an approved, accredited nursery. Nursery accreditation means that plants are grown in clean, non-banana-based potting material and verified to be free of viral diseases. Purchased planting material should be free of soil and any other sources of contamination.

Tissue-culture plants may require additional management during establishment, particularly additional irrigation and weed control, compared with replanted vegetative material.

Priority 5
Reduction

When Fusarium wilt is not on the farm but is in the area, steps can be taken to prepare for reducing inoculum, should an incursion occur.

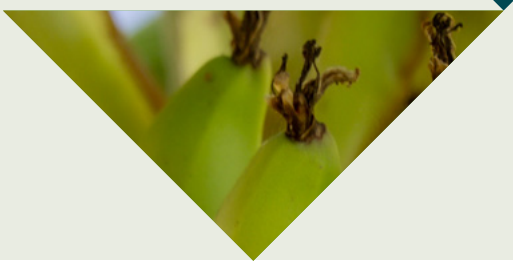
Knowing the regulations and responsibilities

The reporting and management of Fusarium wilt-infected banana plants may differ for different countries and regions, and even for different races of the disease. Should a Fusarium wilt TR4 incursion occur, growers should be aware of their responsibilities and obligations.

In some countries or regions, Fusarium wilt TR4 is a notifiable disease. This means that authorities should be notified if there is a sick or suspect plant on a farm. In other countries and regions, Fusarium wilt TR4 is considered endemic, meaning there are no obligations to report infected plants. However, all individual growers and businesses have a general biosecurity obligation, which means growers must take reasonable steps to prevent the introduction, spread, and establishment of pests, diseases and invasive species. Therefore, it remains very important to take all reasonable steps to prevent the disease from spreading to other farms.

Developing a plan

Growers should plan how to isolate an infected plant should a disease incursion happen (**Box 2**, **page 48**). Being prepared makes the task of isolating infected plants less daunting. Knowing the requirements and having materials ready helps with disease inoculum management. The earlier that infected pseudostems are removed and destroyed, the greater the chance of keeping Fusarium wilt under control and slowing the spread on the farm.



Box 2 Managing Fusarium wilt-infected bananas in Queensland, Australia

Queensland has strict rules for managing plants infected with Fusarium wilt TR4, which include destroying infected plants and creating destruction zones. The aim is to manage disease inoculum and thereby contain the disease to a few farms in the Tully River valley.

The code of practice for the management and control of Fusarium wilt TR4 on infested property in Queensland offers examples of practices that can be used to contain infected plants. The current code of practice states:

- Within 3 business days of receiving the positive result, the [destruction] zone must:
  - extend 5 metres in both directions along the row from the infected plant
  - be bordered by a temporary barrier to deter unauthorised access
  - have signage indicating no unauthorised access.
- Within 15 days of confirmation, if the plant is wilted or cut:
  - cut pseudostems at 10 cm above the growing point
  - chop material into 60–80 cm pieces and bag with 1 kg of urea
  - gouge out the corm and apply:
    - » glyphosate (5 mL)
    - » imidacloprid (18 mL)
    - » bifenthrin (500–750 mL)
    - » urea (200 g on the corm + 1 kg/m^2 around the stool).
- If the plant is still standing:
  - inject glyphosate and imidacloprid at specified rates depending on plant height
  - spray bifenthrin on the stool and surrounding soil
  - mark fruit if present to prevent sale or consumption.
- All other banana plants in the destruction zone must be destroyed using the same method within 15 days of the initial plant destruction. Between 10 and 15 days after destruction:
  - chop remaining plant material
  - gouge and treat corms with urea
  - apply urea at 1 kg/m^2 across the entire zone
  - cover the zone with high-grade plastic sheeting and secure it.
- Within 5 weeks, the destruction zone must be:
  - permanently fenced to restrict access by people, vehicles and machinery
  - fitted with signage to deter entry
  - surrounded by a 0.5 m wide band sprayed with bifenthrin, repeated again 5–6 months later.
- The destruction zone must be:
  - kept free of banana regrowth, which must be chemically treated; fencing and signage [must be] maintained to ensure continued access restriction.

Priority 6
Location

As the threat of Fusarium wilt increases, the farm's location in relation to infested farms can determine the likelihood of a disease incursion. While the management of the disease on other people's farms is beyond a grower's control, there are some measures that they can take to slow an incursion onto their farm and to reduce the impact of the disease should it arrive. In the longer term, growers should be aware of some of the strategies that may reduce the inherent disease risk.

Diversifying land use

In areas at risk of a Fusarium wilt incursion, it may be possible to increase the diversity of land use that separates the farm from neighbouring farms. This may include the use of vegetated buffer zones or diversified cropping.

Where the farm is in a geographically isolated area, it may also be possible to reduce the number of non-essential visitors to the farm.

Diverting overland water

Where water flows from one farm to another there may be an opportunity to divert the flow of water from the neighbouring farms into an external drainage system. This may require additional drainage infrastructure or the creation of levies. All earth works should be considered in line with environmental regulations. Preventing water from entering the farm via neighbouring farms can reduce the risk of a Fusarium wilt incursion.

Preventing water from entering the farm via neighbouring farms can reduce the risk of a Fusarium wilt incursion.

Vegetated groundcover and grass cover can also help to slow water movement, trap sediment and provide some protection against pathogen incursion by overland flow.

Considering irrigation water alternatives

Banana plants need water to be productive. Underground water sources may be an alternative to rivers and dams. In some cases, there may also be an opportunity to treat the water; though this can be very expensive it may be an option for larger farms.

●●●○ Scenario 3: **Incursion**

When Fusarium wilt has been detected on the farm but is currently isolated to a few plants, the top priority for management is to protect the farm by minimising conditions and opportunities for disease to spread. Soil health is the top priority. This includes enhancing soil microbial activity and diversity to slow disease spread. Success also depends on the commitment of everyone involved in the farm to adopt proactive changes in management practices and maintain strong biosecurity. Prevention and inoculum management remain critical to limiting further spread. At this stage, it is important to be aware of alternative banana cultivars with potential resistance to Fusarium wilt and to understand how climate conditions may influence the expression of symptoms.

Priorities

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Priority 1
Protection

Following the first incursion of Fusarium wilt onto the farm the focus is on slowing the spread of the disease and keeping the number of infected plants to a minimum. Enhancing microbial protection of the plants becomes critical to slow the spread of the disease.

Selecting groundcovers

Groundcovers help to prevent the movement of soil particles that may be carrying the pathogen. The increase in vegetation cover also helps to conserve soil moisture and buffer soils from temperature extremes. Diverse vegetation cover on the soil promotes biological diversity below the soil surface, increasing the likelihood that beneficial microorganisms can interact with banana roots.

Groundcovers help to prevent the movement of soil particles that may be carrying the pathogen.

The additional diversity of plants helps soil organisms by supplying carbon through their roots and protecting the soil from extreme climatic changes.

It is important to select groundcover plant species that provide effective resources for soil microorganisms. Short-lived annual plants (such as *Eleusine indica*) provide little benefit to a stable, diverse soil microbial community. However, low-growing perennial species (such as *Arachis pintoi* and *Paspalum conjugatum*) are better suited to banana systems. Intercropping with vegetables such as chillies can provide additional income for smallholder growers.

Promoting soil health

Soil health and biological diversity can be promoted by adding carbon amendments and organic matter to the soil. Higher levels of organic matter tend to support a greater abundance and diversity of soil organisms. Building soil organic matter can take time and is dependent on the soil type and the amount and type of inputs used. Some organic amendments, such as eucalyptus mulch and medicinal type plants, may contain compounds that are toxic to the *Fusarium* pathogen.

Soil amendments are different to biofertilisers. Amendments have higher carbon:nitrogen ratios and are often applied in high quantities at, or before, planting to boost soil organic matter.

Biofertilisers and nutrient sources
Biofertilisers are effective in promoting microbial diversity, depending on the source of the fertiliser and the environmental conditions. Biofertilisers add nutrients and influence soil microbial communities through complex pathways, including the addition of complex carbon compounds. These compounds decompose in the soil, supporting soil microbial community diversity and abundance. Unlike typical mineral fertilisers used by banana growers, biofertilisers add a range of elements beyond nitrogen, phosphorus and potassium, they buffer soil pH changes and they enhance nutrient recycling. Overall, they contribute to building healthier soil ecosystems. However, the selection of biofertilisers requires care. For example, biofertilisers made from untreated banana waste should be avoided as they could introduce the *Fusarium* pathogen to the banana plantation.

Soil pH
Soil pH influences the function of microrganisms in the soil. Under acid soil conditions, less than pH 6.5, the diversity, abundance and function of bacteria and fungi declines. As abundance and diversity decline, the ability of the soil microbial community to suppress Fusarium wilt diminishes. Maintaining a close-to-neutral pH (pH 7.0) helps maintain a functioning soil microbial community to protect banana plants and slow the spread of Fusarium wilt.

Managing nitrogen

Nitrogen is one of the most limiting nutrients in agricultural soils and has profound effects on plant growth and soil microbial communities.

High nitrogen levels can reduce soil biological diversity and reduce plant defences, allowing Fusarium wilt to dominate the microbial community and spread.

Under high soil nitrogen conditions, banana plants respond by putting more resources into growth and less into plant defences. This makes the plants more susceptible to a range of diseases, as the defence chemicals become diluted within the plant.

High application rates of inorganic nitrogen fertilisers (nitrates and ammonias) favour fast-growing organisms. This reduces the diversity of soil microorganisms as the slow-growing organisms are 'swamped' by the fast-growing organisms. Because fast-growing organisms have evolved for rapid reproduction, they have few mechanisms to suppress other organisms. Slower growing soil organisms tend to have 'competitive' mechanisms that keep other soil organisms in check when soil resources are limited. Therefore, conditions that favour the fast-growing organisms and reduce slower growing organisms can favour soil-borne diseases, such as Fusarium wilt.

Priority 2
Commitment

Once Fusarium wilt has been detected, it is important to minimise the spread of the disease around the farm. It is also important to identify infected plants early and destroy them to prevent disease inoculum building up and infecting other plants and parts of the farm. The people associated with the farm become allies in disease management, spotting any 'sick' or unusual-looking plants and reporting them immediately.

Surveilling the disease

Regular farm surveillance is important to detect any new infections. Field staff should be aware of the symptoms of Fusarium wilt and know how to mark any suspect plants for inspection. Staff may require frequent updating on disease symptoms. Periods of climatic stress – such as hot weather, drought, waterlogging or cold – can increase the expression of symptoms of Fusarium wilt. Therefore, staff should be vigilant for signs of new infections after such periods.

The spread of Fusarium wilt in symptomatic plants does not always follow a regular pattern. The number of infected plants rises slowly and then increases exponentially if unmanaged. Therefore, the aim of regular surveillance, together with inoculum management and plant protection strategies, is to keep the incidence of Fusarium wilt as low as possible for as long as possible.

In Queensland, Australia, a dedicated grower support team helps with on-farm surveillance of Fusarium wilt through the Australian Banana Growers' Council.

Staff should also be aware of any movement restrictions around the farm, now that the disease has been detected. If possible, when performing farming operations field staff should visit the areas where infected plants are found last. This will reduce the potential movement of contaminated soil and plant material. Farm staff should be aware of restricted areas and not enter any destruction zones without proper authority.

Everyone associated with the farm needs to be vigilant for any breaches in farm protocols that could increase the spread of the disease around the farm. Keeping the incidence of Fusarium wilt as low as possible should become a shared responsibility.

Reporting sick plants

A reporting structure should be in place so that farm workers and staff know who to report any sick or suspect plants to. This could be field supervisors or the farm owner. Farm staff, which may include workers and contractors, should be made aware of their responsibilities in the field, and that the management of Fusarium wilt is taken seriously.

Farm staff should also know who to report breaches of protocol to, as everyone on the farm has a shared responsibility to reduce the spread of the disease.

Allocating resources

Once Fusarium wilt has been detected, resources should be allocated to stopping the spread. This may include buying materials to destroy infected plants and establishing destruction zones. More tools may also be required for work in contaminated areas, so that the same tools are not being used in both diseased and disease-free areas of the farm.

Slowing the spread of the disease may also require additional resources to enhance soil microbial activity. The grower may need to apply lime to amend soil pH, and/or change fertiliser and groundcover practices.

Engaging family and close associates

The grower needs to inform family, workers and friends that Fusarium wilt has been detected on the farm. Family can help develop plans for dealing with Fusarium wilt and should be made aware that the disease can still be slowed, but additional support may be needed while managing the disease.

Reporting and sourcing information

Following the detection of Fusarium wilt on the farm, the grower should notify the appropriate people and comply with any regulations for disease management. It is very important that the grower understands the regulations and reporting requirements.

Staff movement around the farm should be restricted when the disease has been detected.

To slow the spread of the disease, growers may need to apply lime to amend soil pH, and/or change their fertiliser and groundcover practices.

They should also keep in contact with trusted information sources and remain up to date with the latest information about disease identification, alternative cultivars, and how to slow the spread of the disease. Fusarium wilt of banana is a notifiable disease in many locations and support may be available to help growers manage the disease.

Priority 3
Reduction

Once Fusarium wilt has been detected, it is crucial to act quickly to prevent build-up of disease inoculum in the soil and to prevent movement of soil and plant material from the infested area (see **Box 2**, **page 48**). It is important to disturb the soil as little as possible to avoid spreading the disease, which may require tools and equipment to remain within the infested area. Depending on local regulations, infected plants may need to be destroyed once the disease has been confirmed present.

Managing infected plants entails isolating them, destroying them and creating a 'no-go' area around the infested areas.

Isolating infected plants

As soon as Fusarium wilt symptoms are suspected in a plant – such as leaf yellowing, leaf stem collapse and pseudostem splitting – the plant should be marked and isolated to prevent people from moving plant material and soil from the area around the plant. As Fusarium wilt is easily moved in plant material and soil, care should be taken to ensure workers and other farm staff do not accidently move infected material. Marking suspect plants, with highly visible tape, for example, can help to deter people from interfering with the infected plant.

Early detection is the key to managing disease inoculum, so people on the farm should be trained to recognise and report any suspicious plants, and to isolate these plants to reduce the likelihood of disease spread.

Suspect plants should be clearly marked to deter people from interfering with them and inadvertently spreading the disease.

During the initial stages of infection, it is important to find new infections early and eliminate them. This keeps the disease inoculum as low as possible, protecting the rest of the farm. Early detection also relies on people being vigilant when in the field. Drones and satellite imagery can usually pick up infections later, and are useful for determining the disease spread.

Destroying infected plants

Regulations may determine when plants may be destroyed (see **Box 2**, **page 48**). If local regulations require official samples, the infected plants should not be destroyed until after the samples have been supplied. Experience has shown that destroying infected plants to hide the presence of the disease can lead to Fusarium wilt becoming rapidly widespread, resulting in the loss of farm livelihoods. So follow local regulations and protocols to protect both the farm and the banana industry.

Once the grower receives the approval to destroy infected plants, or if the disease is considered endemic in the region and reporting is no longer required, it is important that no infected plants remain in the field. The infected banana pseudostems must be removed to prevent them from desiccating and returning spores to the soil.

Infected pseudostems are an enormous source of disease inoculum that can reinfect banana plants. As infected banana plants dry out, the *Fusarium* fungus moves out of the vascular tissue and colonises all of the banana pseudostem tissue. The fungus also develops huge quantities of chlamydospores in the air spaces of the banana pseudostem. This makes the decaying banana pseudostem the main source for increasing disease inoculum in the soil.

Chlamydospores are a tough, long-lasting spore that allow the fungus to survive and reinfect other plants. They can last in the soil for many years, and the presence of banana roots can activate them to start new infections.

There are several ways of treating infected pseudostems to remove them from the banana plantation, but treatment needs to comply with local rules and regulations.

A common method is to cut the pseudostem up, place it into tough plastic bags, and treat the cut material with urea before sealing the bag. The urea provides nitrogen which helps to decompose the banana material, and generates ammonia which can be toxic to the *Fusarium* fungi. In Queensland, Australia, this material is kept within the destruction zone and allowed to decompose in the bag, which reduces the risk of disease spread.

Destruction of infected plants in the Philippines using rice hull burning

Destruction zone using urea covered with black plastic in north Queensland

In areas where Fusarium wilt destruction is not regulated, the urea treatment can be applied using large plastic containers instead of plastic bags. The containers can be easily moved around the farm without touching the soil.

Burning of infected banana material has been used in some regions, but some infected material can often remain and infected plants can regrow. Therefore, results from burning can be more erratic, leaving viable infected material in the soil.

Aerial view of a destruction zone in a banana plantation in Queensland, Australia, following an incursion of Fusarium wilt (left) and multiple destruction zones as the disease becomes more widespread (right). Map Data © Google 2026

Creating a 'no-go' destruction zone

Access to the areas around the destroyed infected plants should be restricted, particularly with a new incursion of the disease onto a farm. Experience from first incursions on newly infected farms shows that isolating large areas of land around the infected plants and destroying all of the bananas within that area can slow the spread of the disease. This can help to keep bananas in the rest of the farm free from infection.

The size of the 'no-go' zone may also be dictated by local regulations. If not, it is good practice to remove the neighbouring plants to avoid root-to-root contact. Fusarium wilt infects banana plants through the root system, firstly forming a net around the roots before moving into the root and into the water-conducting tissue (xylem vessels), through the rhizome (corm) and up the pseudostem where it blocks the movement of water and nutrients (see **Section 1**, **page 8**).

It is only then, when the water-conducting tissues are blocked, that the external symptoms appear. Therefore, in the initial infections, when only a few plants are infected, presume that the plants next to the symptomatic plant are also infected and need to be destroyed.

Some areas may also benefit from having a 'buffer zone' around the 'no-go' zone, where entry is restricted to key personnel.

Priority 4

Prevention

Following the first incursion of Fusarium wilt onto the farm, the disease management focus changes to preventing it from moving further around the farm and onto other farms.

Creating an incursion plan

A Fusarium wilt incursion plan describes how to deal with the first incursion of the disease. That is, how to isolate and destroy the infected plants early to keep the disease inoculum as low as possible.

Following the biosecurity plan

The emphasis of the farm biosecurity plan now is to prevent the movement of Fusarium wilt off the farm. This ensures that no soil or plant material is moving off the farm and potentially contaminating other banana farms in the area. The barriers, decontamination areas and protocols now work both ways – containing the disease within the farm and preventing new infections from outside the farm.

Restricting movement of plant material and soil on the farm

Following the first incursion, it becomes important to reduce the movement of plant and soil material around the farm. If possible, areas that have become infested and show symptoms of Fusarium wilt should be visited last during farm operations. Fusarium wilt is easily spread in contaminated plant material and soil. However, infected plants do not always express external symptoms, meaning that contaminated soil and plant material can unknowingly be moved around the farm.

Decontaminating footwear and tools

Having protocols in place to remove plant material and soil from footwear and equipment as people move around the farm can help to reduce the spread of the disease. This is easier to do if the farm has been split into management zones.

Allocating management zones

As well as having biosecurity zones – such as public areas, a separation zone and farming zones – it may be possible to divide the farm into infected, high-risk and protected zones:

- Infected zones are the areas around the infected plants.
- High-risk zones might be areas downhill from an infested area, where water flows from one area to another, or flood-prone areas of the farm.
- Protected zones are those that do not have the disease and can be isolated from the rest of the farm. Some form of decontamination when entering a protected area may help to keep Fusarium wilt out and slow the spread of the disease.

Priority 5
Resistance

Once Fusarium wilt has been detected, it is important to minimise the spread of the disease around the farm. Using vegetative planting material to establish new plantings greatly risks spreading the disease within the farm.

Sourcing clean planting material

Vegetative planting material – sourced from within or outside the farm – should not be used when Fusarium wilt has been detected on the farm. An infected plant may not be showing symptoms but its rhizome (corm) or suckers may carry the pathogen. Visual inspection is not a guarantee that the plant is disease-free.

The preferred way to establish a new planting is to use tissue-culture plantlets, purchased from an approved, accredited nursery. Nursery accreditation means that plants are grown in clean, non-banana-based potting material and verified to be free of viral diseases.

Tissue-culture plantlets are the preferred way of establishing new plantings.
Photo: ACIAR

Purchased planting material should be free of soil and any other sources of contamination. Tissue-culture plants may require additional management during establishment, particularly additional irrigation and weed control, compared with replanted vegetative material.

Knowing which cultivars to plant

When Fusarium wilt is on the farm it is important that the grower understands the susceptibility or resistance of different varieties and cultivars (see **Table 2**, **page 37**). This will help them understand the potential impact of Fusarium wilt on existing plantings, as well as inform decisions for future plantings. Most commercial Cavendish banana cultivars grown for exports or supermarkets are susceptible to Fusarium wilt TR4. However, there are global efforts to breed replacement cultivars that are resistant to Fusarium wilt.

Growers should be familiar with the varieties and cultivars available and understand their agronomic qualities as well as market acceptance. Cavendish banana cultivars with increased resistance to Fusarium wilt have enabled continued banana production in the presence of the disease but the success of their resistance may be at the cost of some agronomic characteristics.

A grower could consider a trial planting of new cultivars to evaluate them in their own environment and suitability for available markets. Understanding the resistance or susceptibility of banana cultivars is part of implementing an integrated disease management strategy. When getting advice on cultivar resistance, growers should check that information is from a reliable source and has been independently validated.

Priority 6

Location

Once Fusarium wilt has been detected on the farm, it is important to prevent the disease from moving to neighbouring farms via soil and water movement. Equally important is to alleviate inherent stress factors that occur due to the location of the farm. Banana plants are more susceptible to disease under stress conditions. While avoiding environmental and climatic stresses is largely out of the control of the farmer, some steps can be taken to reduce inherent disease risk.

Alleviating plant stress

Climatic, environmental and management conditions that increase the stress on banana plants also favour the development of Fusarium wilt symptoms. Periods of stress can cause 'dysbiosis', where the soil organisms become unbalanced, which can favour disease-causing organisms. Managing environmental stress on banana plants is difficult. It may be possible to alleviate water stress through irrigation, but irrigating from contaminated rivers and dams can increase the spread of Fusarium wilt.

Predictions for climate change impacts on banana production indicate that some areas will become more favourable for banana production than others. Conversely, periods of plant stress are also likely to increase, making plants more susceptible to diseases such as Fusarium wilt. Therefore, soil management to build resilience – for example, using vegetated groundcover – can reduce soil evaporation and exposure to high soil temperatures, alleviating stress and helping soil organisms recover from unfavourable weather.

Considering planting density

Planting density can influence the amount of competition and root-to-root contact between banana plants. High plant density tends to promote inter-plant competition which increases the likelihood of plant stress. However, in arid conditions high density plantings are known to help shade plants and conserve water. Therefore, environmental conditions need to be considered for the configuration of banana plants.

In high-density planting situations, it is easier for Fusarium wilt to move from plant to plant through root contact. There is also likely to be more disease inoculum present given the greater amount of banana plant residue being returned to the soil.

Minimising the movement of inoculum

Farm operations such as harvesting and de-suckering risk moving infected plant material and soil around the farm. By leaving high-risk disease areas to last while performing farm operations, a grower may end up moving less inoculum around the farm.

Scenario 4: **Widespread plant losses**

When Fusarium wilt becomes widespread, protecting plants and maintaining healthy soil remain top priorities, along with reducing the amount of disease inoculum. Growers should also consider whether resistant banana cultivars are suitable for the farm environment, and stay committed to adapting farming practices that improve soil health to limit disease spread, using the best available information. They should avoid reintroducing the pathogen into areas where disease inoculum has already been reduced. And aim to re-establish banana crops during periods of lower climatic stress, to reduce the risk of symptom expression and disease impact.

Priorities

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Priority 1
Protection

When Fusarium wilt becomes widespread, disease management focuses on living with the disease while protecting growers' livelihoods. Protecting the plants remains crucial to allow them to re-establish. The emphasis is on reducing the dominance of the *Fusarium* fungus in the soil microbial community and allowing other organisms to compete. This 'adjusting' of the soil microbial community takes time. Soil protection practices should be used in conjunction with crop rotation to 'reset' the soil system.

Timing the replanting

Replanting bananas immediately after (or into) a banana crop that is infected with Fusarium wilt – with no break – leads to very high infection rates and plant death in the newly planted crop. Ideally, there should be a break of at least 2 years, with a crop other than bananas grown during the fallow. The *Fusarium* fungus can survive around the roots of other plants and colonise un-decomposed organic matter in the soil. Some weeds can also host *Fusarium*, allowing it to survive (see **Section 5**, pages **108–109**). A lengthy fallow period with non-banana crops can reduce the *Fusarium* in the soil and allow other microorganisms to establish and recolonise the soil, but a fallow period alone will not eliminate the pathogen.

Managing soil pH

Managing soil pH is important for allowing soil microorganisms to function optimally. Under acid soil conditions (less than pH 6.5), the diversity, abundance and functioning of bacteria and fungi decline. The ideal time to adjust soil pH – through the application of carbonate amendments such as lime or dolomite – is before replanting bananas. The amount of amendment required will depend on the initial pH, soil type and the type and quality of the amendment used. Maintaining a close-to-neutral pH (pH 7.0) helps to maintain a functioning soil microbial community to protect banana plants from Fusarium wilt. Soil pH management alone is not enough to stop Fusarium wilt from infecting plants but provides a basis to build biological protection of banana plants.

Adding carbon and nitrogen to the soil

Adding high carbon:nitrogen ratio amendments can help to increase soil organic matter. Soils with more organic matter tend to support more abundant and diverse soil organisms.

Amendments with a high carbon content can lead to immobilisation of nitrogen. Immobilisation occurs when nitrogen in the soil is tied up by soil microorganisms as they decompose the organic matter. Amendments with high organic carbon content can stimulate soil fungal diversity, which is likely to be depleted in banana soils. Soil fungi provide additional competition to *Fusarium* species in the soil.

During the fallow break before bananas are replanted is the ideal time to apply high carbon organic amendments, as they will begin to decompose before the bananas are replanted.

During the fallow break is the ideal time to apply high carbon organic amendments, as they will begin to decompose before the bananas are replanted.

After replanting is the ideal time to grow other crops, such as vegetables, in among the banana plants.

Planting groundcover

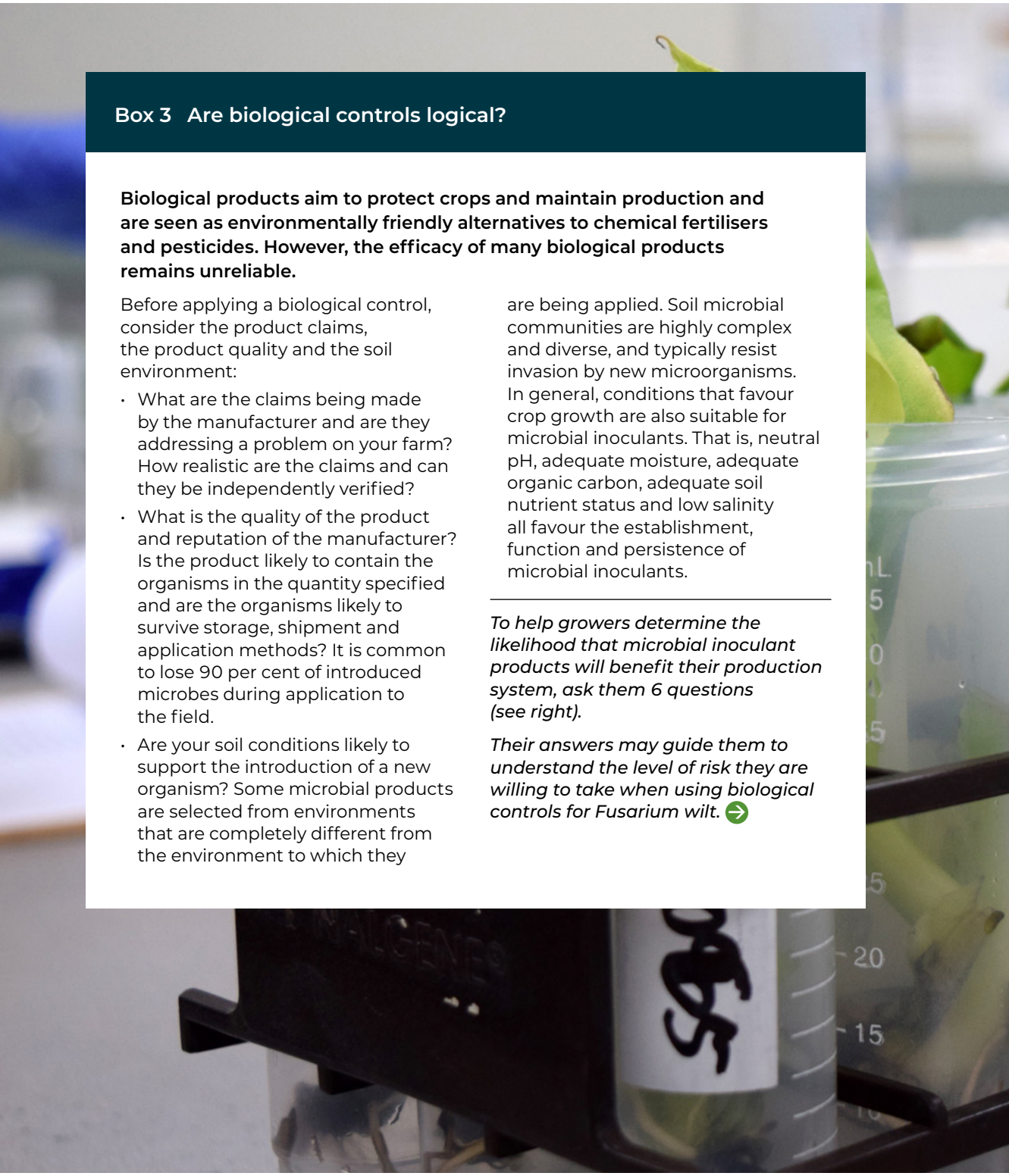
After replanting bananas, vegetated groundcover should be re-established. Groundcover helps to protect against the movement of soil particles, conserve soil moisture, buffer soils from temperature extremes, and increase the diversity of soil organisms interacting with the banana plants. Care needs to be taken when re-establishing groundcover around banana plants. If groundcovers are established when the banana plants are too young, they can compete with the banana plants. However, once the banana plants are established, they can compete and shade out some of the groundcover competition. It may take time for low-growing perennial groundcover species (such as *Arachis pintoi* and *Paspalum conjugatum*) to become established and outcompete annual weeds.

For intercropping situations, after replanting is the ideal time to grow other crops in among the banana plants. Vegetables such as chillies can provide additional income for smallholder growers and also increase the interactions of soil microbial communities with banana plants.

Using biological controls

Biological controls can be contentious. There are many claims about them and about their effectiveness with Fusarium wilt of banana. And in many situations a benefit from their application has been observed.

The development of new techniques and the increasing understanding of soil microbial interactions with plants and other soil organisms augurs well for improvements in microbial inoculants. One of the big challenges to the widespread use of biological controls is the inconsistency in response that is often experienced. Understanding the environmental constraints and the requirements of the microbial inoculant may partly address this challenge.
See **Box 3**, **page 64** for more details.



Box 3 Are biological controls logical?

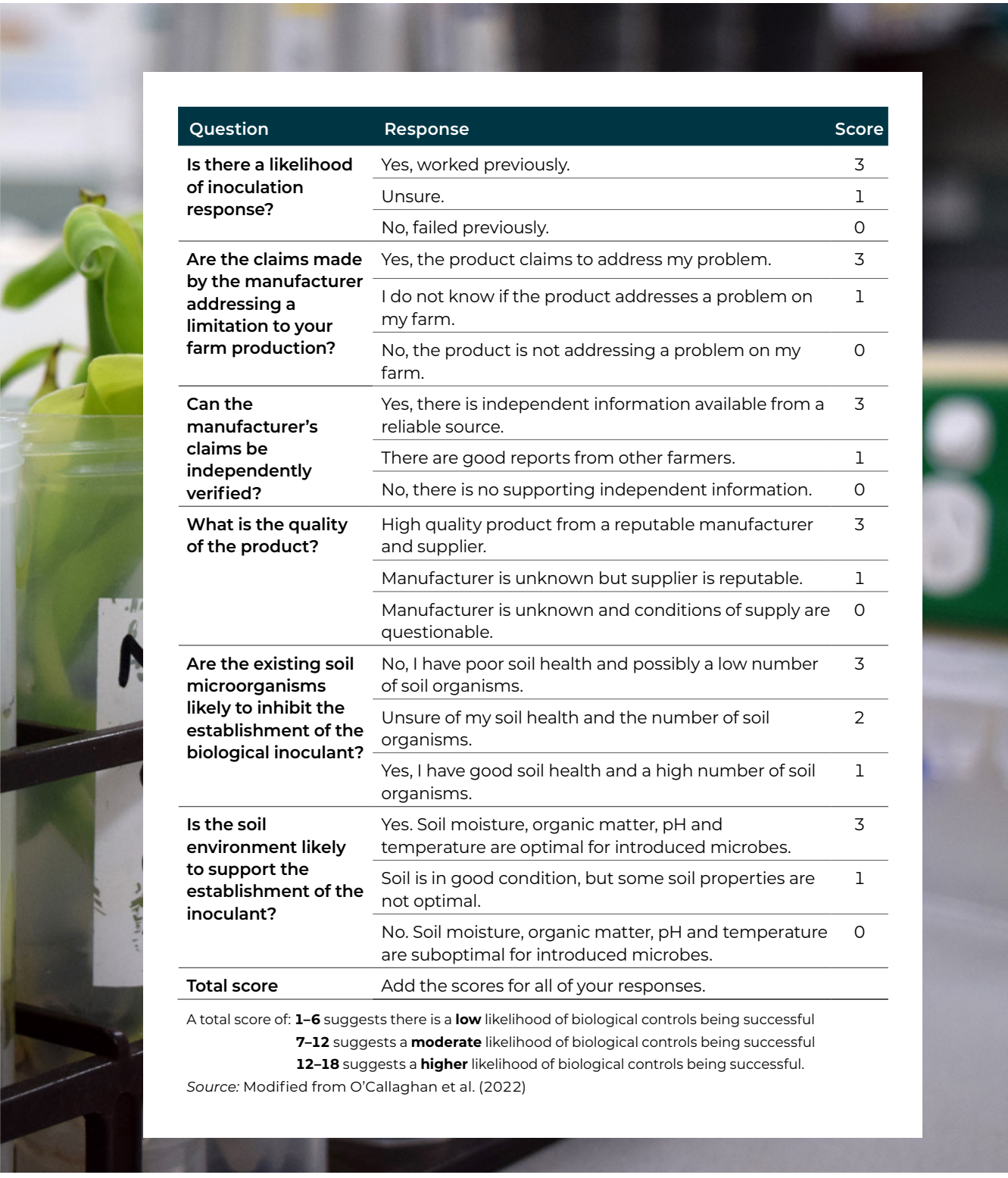
Biological products aim to protect crops and maintain production and are seen as environmentally friendly alternatives to chemical fertilisers and pesticides. However, the efficacy of many biological products remains unreliable.

Before applying a biological control, consider the product claims, the product quality and the soil environment:

- What are the claims being made by the manufacturer and are they addressing a problem on your farm? How realistic are the claims and can they be independently verified?
- What is the quality of the product and reputation of the manufacturer? Is the product likely to contain the organisms in the quantity specified and are the organisms likely to survive storage, shipment and application methods? It is common to lose 90 per cent of introduced microbes during application to the field.
- Are your soil conditions likely to support the introduction of a new organism? Some microbial products are selected from environments that are completely different from the environment to which they are being applied. Soil microbial communities are highly complex and diverse, and typically resist invasion by new microorganisms. In general, conditions that favour crop growth are also suitable for microbial inoculants. That is, neutral pH, adequate moisture, adequate organic carbon, adequate soil nutrient status and low salinity all favour the establishment, function and persistence of microbial inoculants.

To help growers determine the likelihood that microbial inoculant products will benefit their production system, ask them 6 questions (see right).

Their answers may guide them to understand the level of risk they are willing to take when using biological controls for Fusarium wilt.



Question	Response	Score
Is there a likelihood of inoculation response?	Yes, worked previously.	3
	Unsure.	1
	No, failed previously.	0
Are the claims made by the manufacturer addressing a limitation to your farm production?	Yes, the product claims to address my problem.	3
	I do not know if the product addresses a problem on my farm.	1
	No, the product is not addressing a problem on my farm.	0
Can the manufacturer's claims be independently verified?	Yes, there is independent information available from a reliable source.	3
	There are good reports from other farmers.	1
	No, there is no supporting independent information.	0
What is the quality of the product?	High quality product from a reputable manufacturer and supplier.	3
	Manufacturer is unknown but supplier is reputable.	1
	Manufacturer is unknown and conditions of supply are questionable.	0
Are the existing soil microorganisms likely to inhibit the establishment of the biological inoculant?	No, I have poor soil health and possibly a low number of soil organisms.	3
	Unsure of my soil health and the number of soil organisms.	2
	Yes, I have good soil health and a high number of soil organisms.	1
Is the soil environment likely to support the establishment of the inoculant?	Yes. Soil moisture, organic matter, pH and temperature are optimal for introduced microbes.	3
	Soil is in good condition, but some soil properties are not optimal.	1
	No. Soil moisture, organic matter, pH and temperature are suboptimal for introduced microbes.	0
Total score	Add the scores for all of your responses.	

A total score of: **1–6** suggests there is a **low** likelihood of biological controls being successful
7–12 suggests a **moderate** likelihood of biological controls being successful
12–18 suggests a **higher** likelihood of biological controls being successful.

Source: Modified from O'Callaghan et al. (2022)

Aim to re-establish banana crops during periods of lower climatic stress when the plants' defences and the microorganisms protecting the plants are activated and more likely to prevent the fungal pathogen from spreading through the banana plants.

Managing nitrogen

When managing an infested area or replanting a new area, nitrogen fertiliser is essential but must be managed carefully.

Nitrogen is one of the most limiting nutrients in agricultural soils and has profound effects on plant growth and soil microbial communities. Under high soil nitrogen conditions, banana plants put more resources into growth and less into plant defences. This makes the plants more susceptible to a range of diseases, as the defence chemicals become diluted within the plant.

High application rates of inorganic nitrogen fertilisers (nitrates and ammonias) favour fast-growing organisms. This reduces the diversity of soil microorganisms as the slow-growing organisms are 'swamped' by the fast-growing organisms. Because fast-growing organisms have evolved for rapid reproduction, they have few mechanisms to suppress other organisms. Slower growing soil organisms tend to have 'competitive' mechanisms that keep other soil organisms in check when soil resources are limited. Therefore, conditions that favour the fast-growing organisms and reduce slower growing organisms can favour soil-borne diseases, such as Fusarium wilt.

Managing soil health

Organic biofertilisers are effective in promoting microbial diversity, depending on the source of the fertiliser and the environmental conditions. Beyond merely adding nutrients, biofertilisers influence soil microbial communities through complex pathways, including the addition of complex carbon compounds. Their decomposition in the soil supports soil microbial community diversity and abundance. Unlike the typical mineral fertilisers used by banana growers, biofertilisers add a range of elements beyond nitrogen, phosphorus and potassium, they buffer soil pH changes and they enhance nutrient recycling. Overall, they contribute to building healthier soil ecosystems. However, the selection of biofertilisers requires care. For example, biofertilisers made from untreated banana waste should be avoided as they could introduce the Fusarium pathogen to the banana plantation.

Priority 2
Reduction

Once Fusarium wilt becomes widespread, inoculum management is an important component for managing the disease. However, there are now 2 elements to this. The first is managing the infection to keep the number of infected plants low and prevent inoculum returning to the soil from the infected pseudostems – 'inoculum management' (see **Box 2**, **page 48**). The second is 'resetting' the banana system to reduce the inoculum in the soil before replanting bananas – 'inoculum reduction'.

Inoculum management

To keep the number of infected plants low and prevent inoculum returning to the soil from the infected banana pseudostems, suspected diseased plants need to be isolated and infected plants need to be destroyed. Early detection and eradication remain the key to managing disease inoculum.

Isolating suspect plants
The process of isolating banana plants when the disease is widespread is similar to that used after the first incursion of Fusarium wilt. As soon as plants appear with suspect Fusarium wilt symptoms, such as leaf yellowing, leaf stem collapse and pseudostem splitting, the plant should be marked and isolated to prevent people from moving plant material and soil from the area around the plant.

Destroying infected plants
Destroying the infected banana pseudostems remains a key component of preventing inoculum from returning to the soil. Infected pseudostems are an enormous source of disease inoculum that can reinfect banana plants. Destroying them prevents spores returning to the soil. Once the disease is considered 'widespread', growers should presume that the entire crop is infected. It is still important to destroy the symptomatic plants but the destruction zones encompassing neighbouring plants can be made smaller.

Destruction zone, north Queensland

Rice hulls being burned to destroy infected plants in the Philippines

The infected banana pseudostems can be destroyed by:

- cutting the infected banana pseudostem close to ground level and then into smaller pieces
- placing the material into tough plastic bags or large plastic containers and treating it with urea
- keeping the bags or containers in areas where they will pose minimal risk of disease spread.

The use of herbicides alone is not enough to reduce Fusarium wilt inoculum. On the contrary, allowing the infected pseudostems to remain in the field after treating them with herbicide can increase disease inoculum because the *Fusarium* fungus can grow on dead banana material, increasing the risk of greater disease inoculum build-up and of infecting other banana plants.

Use of bamboo sticks dipped in glyphosate to kill infected banana plants in the Philippines

Inoculum reduction

Destroying the banana crop and preparing the land for replanting is an important component of inoculum reduction. However, these operations all increase the risk of spreading the pathogen. Important disease management factors need to be considered.

Mechanical plant removal

Mechanical plant removal typically requires heavy machinery that pulls out infected plants and builds a pile for destruction. This operation disturbs and moves large volumes of soil, which can result in infected plant material and soil being moved around the farm and off the farm. Such an operation should be planned very carefully and all equipment used cleaned thoroughly before leaving the infested area.

Chemical plant removal

Chemical plant removal typically uses a herbicide such as glyphosate to kill the banana plants. Glyphosate not only destroys the banana plants but can also prevent further plant and sucker regrowth. Preventing banana regrowth is an important part of Fusarium wilt inoculum management. However, killing banana plants with herbicides can also provide the pathogen with additional resources to survive in the soil. The *Fusarium* fungus is a very good saprophyte, which means it can survive, grow and reproduce on dead organic material, such as un-decomposed banana residue. Therefore, care needs to be taken when destroying banana plants to ensure all banana material – leaves, suckers, pseudostems and rhizomes – is completely decomposed before replanting bananas. Any organic banana material that is not destroyed greatly increases the potential Fusarium inoculum in the soil and the speed of reinfection.

A minimum of 2 years without bananas and growing a crop that is a poor host to the *Fusarium* fungus has been a successful approach to reducing inoculum to a point where bananas can be grown again economically.

Timing the fallow period

Fusarium cannot be eradicated from an area once it has become established, but, by allowing sufficient time for the inoculum to decline, it is possible to keep the disease levels low enough to allow economic banana production and minimise plant losses. Replanting bananas immediately following destruction of an infected crop will lead to high rates of infection in the initial crop cycle, reduced crop life and increased risk of livelihood loss. Observations from farms that have successfully managed Fusarium wilt indicate that a minimum of 2 years without bananas and, instead, growing crops that are poor hosts to the *Fusarium* fungus is required.

Sufficient time should be allowed for the banana material to decompose completely, reducing the fungus's chance of survival. However, the longer the period without bananas the more effective the fallow period will be. Fusarium can survive in the soil as resistant chlamydospores for as long as several decades. It can also survive in and around the roots of nearly all plants, though plant roots also encourage microbial competitors which help keep the inoculum low.

Rotation of bananas with a mix of sorghum and sunn hemp in north Queensland

New banana plants interplanted in a maturing corn crop in the Philippines

Planting a rotation crop

Planting a rotation crop is a common method to reduce plant diseases. A species that is not a pathogen host can reduce the amount of disease inoculum before replanting a susceptible crop. However, in the case of Fusarium wilt of banana, no crops have been found to be completely resistant to the fungus, though some crops are better non-hosts than others. The suitability of rotation crops for bananas depends on the farming system.

Many smallholder banana growers need cash crops to sustain their income during the period when they are not growing bananas. Corn is a cash crop commonly grown in rotation with bananas. It is considered a moderate host, but growing 3 successive corn crops has been shown to reduce disease inoculum, allowing bananas to then be replanted. Pineapples, eggplants, chillies and tomatoes have been grown in rotation with bananas and led to a reduction in disease. Paddy rice is another cropping system which has been used successfully in rotation with bananas to help reduce Fusarium wilt in subsequent banana crops.

For larger farms, green manures are more suited as a rotation crop with bananas. They add organic matter to the soil and can help improve soil health. Signal grass (*Urochloa decumbens*) can also be a good rotation crop as it is a poor host of the *Fusarium* fungus.

Crop rotations can also boost microbial diversity, which allows soil organisms with different competition strategies to interact and compete with the *Fusarium* fungus. Growing a diversity of crops for more than 2 years can reduce inoculum and, when combined with other integrated disease management strategies, allows susceptible banana cultivars to be successfully replanted with minimal plant losses.

Priority 3
Resistance

Once Fusarium wilt becomes widespread and growing bananas is no longer economical, it is necessary to reduce the inoculum in the soil and restart with a new planting. Using resistant banana cultivars can reduce the likelihood of rapid disease spread once bananas are replanted. However, the decision to plant currently available resistant cultivars depends on the specific farm situation and the markets supplied.

Understanding cultivar resistance

Most commercial Cavendish banana cultivars grown for exports or supermarkets are susceptible to Fusarium wilt TR4. Growers should be familiar with the pros and cons of the various resistant cultivars and whether they are suitable for the farm, environment and market (**Table 2**, **page 37**). Some banana markets are very particular about the size, shape and appearance of fruit, and may apply discounts if bananas do not meet these criteria.

Sourcing clean planting material

A new planting should be established with tissue-culture plantlets (not vegetative plant material). Plantlets should be purchased from an approved, accredited nursery. Nursery accreditation means that plants are grown in clean, non-banana-based potting material and verified to be free of viral diseases. Purchased planting material should be free of soil and any other sources of contamination. Tissue-culture plants may require additional management during establishment, particularly additional irrigation and weed control, compared with replanted vegetative material.

Before replanting bananas, growers should allow enough time for the disease inoculum to reduce, and prepare the land, which may include providing additional irrigation. A rotation crop that is a poor host to the Fusarium wilt pathogen should be grown for at least 2 years (see **page 70**). When planting, growers should minimise soil disturbance and the movement of contaminated soil around the farm. This may require additional machinery and cleaning of machinery, tools and footwear.

Expanding the area planted to resistant cultivars

Growers may able to expand the area planted to bananas on their farms with resistant varieties or cultivars. As the threat from Fusarium wilt increases, growers should be fully aware of alternative cultivars. It may also be possible to re-plant disinfested farm areas with resistant cultivars to overcome the increase in disease severity on the rest of the farm.

Tissue-culture bananas from an approved accredited nursery are the most reliable source of planting material.

Cultivar assessment trial for resistance to Fusarium wilt

Interplanting cultivars

Growing a mix of banana cultivars with a mix of resistance to Fusarium wilt keeps disease incidence low. However, this approach is more suitable for smallholder growers who supply local markets, where different banana varieties are common. The idea is to grow some high value susceptible cultivars in among lower value resistant cultivars. The hope is that the resistant cultivars keep the disease inoculum low enough that the susceptible cultivars are buffered from one another and from the disease in the soil. Interplanting resistant and susceptible cultivars may not be suitable for larger scale export plantations, particularly those that are mechanically managed, as they are in Australia.

Taking tissue-culture plants to the field in the Philippines

Harvesting bananas in Ecuador

Priority 4

Commitment

When Fusarium wilt is widespread on the farm and some areas are no longer economically productive, it is necessary to reduce inoculum in the soil and restart with new plantings. All people associated with the farm should understand the devastation that can be caused by Fusarium wilt and its impact on current practices. At this stage, inoculum reduction is a priority for farm management, to maintain the livelihoods of growers, workers and families.

Surveilling the disease

With widespread Fusarium wilt on the farm, surveillance is important to determine the best management strategy for dealing with infected plants. Knowing the extent of infected plants helps the grower decide when it is no longer economically viable to grow bananas in certain parts of the farm. The most affected areas can be taken out of production to allow crop rotations and inoculum reduction practices to begin.

Staff should be aware of any movement restrictions on the farm and should not enter any destruction zones without proper authority. If possible, staff and workers should visit infested areas last when performing farming operations. This will reduce the potential movement of contaminated soil and plant material.

Reporting sick plants

A reporting structure should be in place so that workers and farm staff know who to report any sick or suspected infected plants to. This may be field supervisors or the grower. Farm staff, which may include workers and contractors, should be aware of their responsibilities in the field and that the management of Fusarium wilt is being taken seriously.

Farm staff should also know who to report breaches of protocol to, as everyone on the farm has a shared responsibility to reduce the spread of Fusarium wilt.

Allocating resources

With Fusarium wilt widespread, resources are required to destroy existing bananas, fallow the land, grow rotation crops and replant bananas with clean planting material, possibly a different cultivar. This may lead to a period of reduced income while the land is out of banana production. On the other hand, it may also allow diversification of income by growing other crops.

Resources should be allocated to the re-establishment of bananas and correcting any soil constraints such as drainage, low soil pH or low soil organic matter. The period before replanting should be seen as an opportunity to overcome soil constraints to enhance soil biological activity, thereby helping to protect new banana plantings from infection.

Engaging family and close associates

The grower needs to ensure that family, workers and friends understand that Fusarium wilt is widespread on the farm. Family can help develop plans for managing the disease and should be made aware that the impact of the disease can be reduced, but additional support may be needed while managing the disease. Be aware of misinformation about cures for Fusarium wilt – there is no way to eradicate the disease. However, it can still be managed through the integrated principles to keep the inoculum low. Talking to other growers who have experience in reducing disease inoculum and managing the disease may be helpful.

Reporting and information sources

Once Fusarium wilt is widespread on the farm, growers should be aware of any restrictions on using the land for other crops. For example, it may be prohibited to grow crops that soil can adhere to, such as root and tuber crops, which can be a high risk of spreading the disease. It is important growers remain familiar with any regulations and reporting requirements.

Banana growers should keep in touch with their trusted information sources to ensure they are kept up to date with the latest information on disease management. Trusted sources should have information about the best rotation crops, alternative cultivars, and where to source clean planting material.

Everyone on the farm has a shared responsibility to reduce the spread of Fusarium wilt.

Keep up to date with the latest information on disease management.

Even when the disease becomes widespread, decontamination is still important to reduce the spread of the disease.
Photo: ACIAR

Priority 5
Prevention

When Fusarium wilt is widespread on the farm, management focuses on reducing inoculum and living with the disease. However, prevention is still important to reduce the likelihood of contaminating areas where the disease inoculum has been reduced.

Removing and destroying infected plants

Use the protocols for dealing with infected plants to keep the disease inoculum as low as possible. This should include removing and destroying infected banana pseudostems to prevent inoculum build-up in the soil.

Keeping to the biosecurity plan

The emphasis of the biosecurity plan is to now prevent the movement of Fusarium wilt off the farm. This means that no soil or plant material is moving off the farm and potentially contaminating other banana farms in the area. The barriers, decontamination areas and protocols now work both ways, containing disease within the farm and preventing re-introduction of the disease.

Restricting farm movement

Even when the disease becomes widespread it is still important to reduce the movement of plant material and soil around the farm. Identifying the areas where disease is widespread can help growers plan where to start to 'reset' the banana production system.

Starting with smaller, isolated areas

When replanting bananas, it is important not to reintroduce the disease to young, susceptible plants. Replant smaller, isolated areas that can be separated from the rest of the farm and manage operations in these vulnerable areas before tackling more heavily infected parts of the farm.

Decontaminating

Having protocols in place to remove plant and soil from footwear and equipment as growers and workers move around the farm can help reduce the spread of the disease. This is easier if the farm has been split into management zones. Decontamination of tools, equipment and footwear is important in newly planted areas.

Vehicle decontamination helps ensure that no soil or plant material is moving off the farm and potentially contaminating other banana farms in the area.

Priority 6

Location

Location remains an important consideration for disease management when Fusarium wilt is widespread on the farm. Climatic and environmental stress will aid the spread of the symptoms and can dictate what management practices can be used to reduce the disease inoculum in the soil. When planning to replant bananas, consider the plantation design. Small changes in the plantation layout may reduce the impact of climatic and environmental stress, which can help to reduce reinfection and plant losses.

Reducing plant stress

Climatic, environmental and management conditions can increase the stress on banana plants. Stressed banana plants are often quick to show Fusarium wilt symptoms. When replanting bananas, consider supplementary irrigation, with additional shade to reduce periods of stress. This may require redesigning farm areas to develop a more resilient farm environment.

Manipulating planting density

When replanting bananas, consider if the density of banana plants can be manipulated to reduce inter-plant competition. This may include increasing the space between plants within rows or increasing the space between rows. Increasing row spacing can allow more light into the inter-row area which can benefit vegetated groundcovers.

Creating vegetated buffer zones

Creating vegetated buffer zones around bananas – at the farm boundary and within the farm – can reduce soil movement while adding to plant diversity. Windbreaks not only reduce wind damage on bananas but can provide more shade, help soil water recharge, and provide refuges for beneficial organisms. Growers should take care to select species that do not compete with banana plants or create hazards for farm workers. Trimmings from the boundary vegetation can be added to the soil to increase organic matter.

No practice will eliminate *Fusarium* from the soil. But increasing microbial competition through crop rotations can help protect the soil microbial community from becoming overwhelmed by the *Fusarium* fungus.

SECTION

3

The Fusarium Wilt Integrated Risk Tool

SECTION

3

The Fusarium Wilt Integrated Risk Tool

The Fusarium Wilt Integrated Risk Tool is a practical, Excel-based decision-support tool for assessing risk and managing Fusarium wilt in banana farming.

The tool is designed to help banana growers proactively manage Fusarium wilt, safeguard their crops, and reduce risks to their livelihoods. It helps them evaluate their situation based on which of the 4 disease scenarios they face – no threat, threat, incursion, widespread plant losses – and offers suggestions for managing and mitigating risks.

The suggestions are offered as general guidance and, while following them can reduce the chance of Fusarium wilt, there is no guaranteed way to prevent it entirely and no way to eradicate the *Fusarium* fungus once it is present in the soil.

What the tool provides

A worksheet prompts the grower for specific information about their farm, crop and farming practices. Based on the information entered, the tool provides:

- risk ratings for likely disease outcomes, disease incursion, disease spread and livelihood loss
- the proportion of risk that is controllable and the proportion that is out of the control of most banana growers
- a Fusarium wilt risk score for the scenario (0–100) and a risk rating (low, medium, high or very high)
- an overall comment based on the risk score
- scores for individual management categories (low, medium or high)
- comments on individual management categories
- scores for each individual question.

Workers at a banana plantation in Laos clean freshly picked bananas before packaging them for export.
Photo: ACIAR

Best practices for using the tool

To get the best out of the tool:

- give honest and accurate answers for meaningful recommendations
- reassess regularly, as farm conditions or external factors change
- implement the recommendations – the suggested strategies aim to minimise losses and protect farming livelihoods.

Download the tool

The tool is available for download at:
research.aciar.gov.au/banana-fusarium

Download now

Additional support

For further assistance, email
Tony.Pattison@dpi.qld.gov.au

SECTION

4

Case studies

SECTION

4

Case studies

This section presents 7 case studies, across the 4 disease scenarios – no threat, threat, incursion and widespread plant losses. They describe the experiences of both smallholder banana growers and larger commercial farms, highlighting the management of the threat or impact of Fusarium wilt. The case studies are accompanied by diagrams produced by the Fusarium Wilt Integrated Risk Tool.

A farm visitor passes between zones within a banana packhouse.

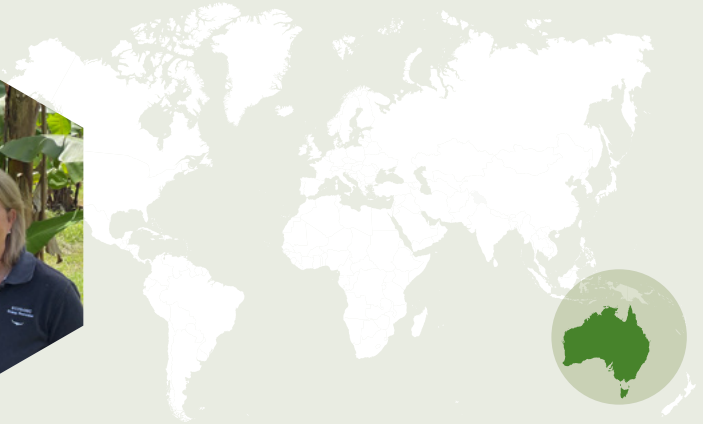
Case studies

case study

●○○○ Scenario 1: **No threat**

Frank and Dianne Sciacca

Innisfail, Queensland, Australia



Frank and Dianne Sciacca run a 45-hectare banana farm near Innisfail in north Queensland. Their farm lies in the heart of a banana production area, surrounded by other banana farms. The smaller size and the location of the farm has meant they have had to look at banana production differently.

An assessment of the farm's vulnerability to Fusarium wilt determined that the disease was not in the immediate area. However, Frank and Dianne were acutely aware of the movement of trucks and materials (such as packing pallets) between farms in the area. And being near a major road, they were careful about who and what came onto their farm.

For these reasons, they use farm biosecurity practices to keep the disease out, including barriers to stop trucks, vehicle washdowns and footbaths. Public roadways surround 3 boundaries of their farm and the fourth has an abandoned tramway. This gives them some physical separation from other farms, but their location still poses a risk. Additionally, in very heavy rainfall events the farm occasionally has flooding issues.

As well as their farm biosecurity practices, Frank and Dianne have focused on improving soil biological relationships. As part of their certified Ecoganic® farming system, they have greatly reduced their use of nitrogen fertiliser and have maintained vegetated groundcover to restore the ecology across their farm. The amount of groundcover vegetation changes with the time of year and the crop cycles. They are very particular about keeping their soil in good health and every year they have it tested for biological properties.

The farm workforce relies heavily on casual labour, and trusted farm supervisors help to keep new staff aware of the importance of managing Fusarium wilt. Frank and Dianne are also part of a farming group that regularly meets to discuss aspects of banana farming, sharing their knowledge. The risk of Fusarium wilt is a key part of these discussions.

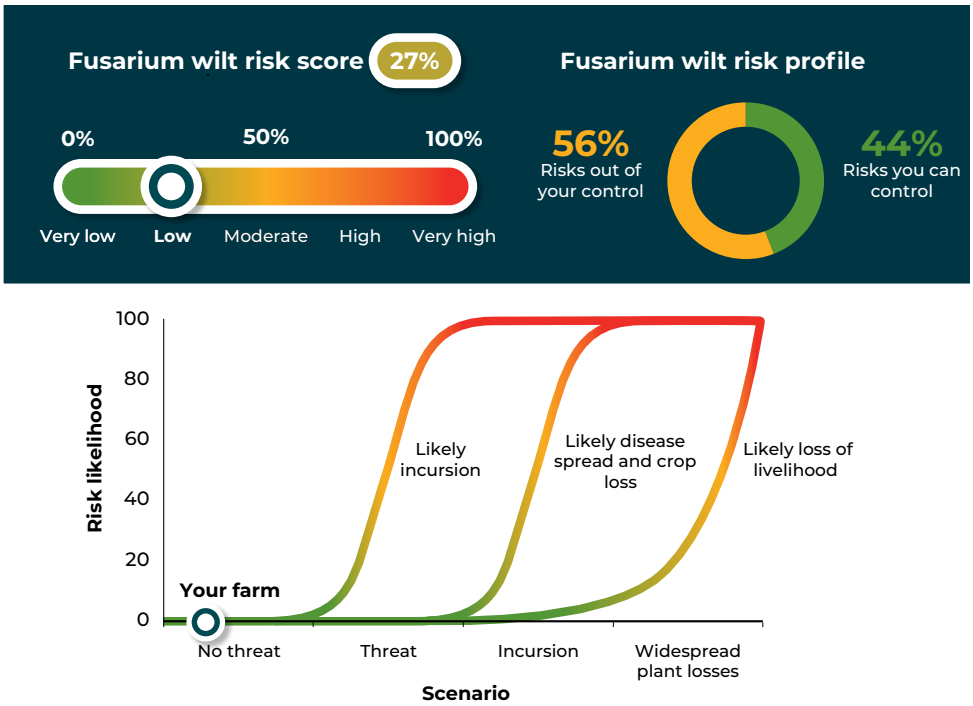


FIGURE 8 Overall Fusarium wilt risk score and risk profile for the Sciacca farm

The overall Fusarium wilt risk score (top) was regarded as low for the Sciacca farm, as was the likelihood of an incursion of Fusarium wilt (bottom) with 44% of the disease risk controllable through management.

Source: Fusarium Wilt Risk Management Tool

While the risk of Fusarium wilt to their banana operations is considered low, they are very aware of the impact the disease could have. They stay abreast of new information about the disease, and share this information with their key staff and their farming group.

More information about Frank and Dianne's farming system can be found at **www.eco-banana.com.au**

Signage, flagging and washdown facilities ensure that trucks entering the packing shed are clean and free from contamination.

Principle	Integrated disease management risk			
	Low	Medium	High	Comments
Prevention	●○○	○○○	○○○	You are using current best practice
Location	●●●	●●●	●○○	You have a high inherent risk of Fusarium wilt entering your farm
Protection	●●●	●●○	○○○	Your crop practices could be improved
Resistance	●●●	●○○	○○○	Use only clean planting material
Commitment	●○○	○○○	○○○	You are using current best practice

FIGURE 9 Risk ratings by principle for the Sciacca farm

Prevention and commitment scored low in terms of risk for the Sciacca farm, with current best practice being implemented. Protection and resistance were regarded as moderate risks for the farming systems due to the use of susceptible cultivars. The location of the farm was regarded as high risk due to the proximity of neighbouring farms and occasional flooding.

Source: Fusarium Wilt Risk Management Tool

The Sciaccas maintain vegetated groundcover around their banana plants.

Vegetation along the farm boundary helps to separate the farm from other banana farms and restrict entry into the farm.

●●○○ Scenario 2: **Threat**

Sri Nuryanti

Gunungkidul, Yogyakarta, Indonesia

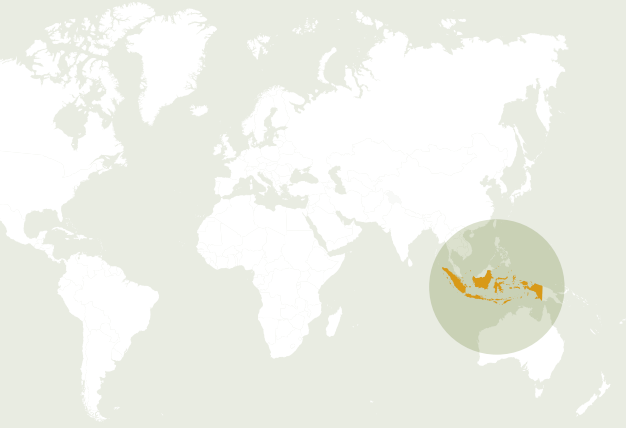


Photo: Supplied

Sri Nuryanti grows rice, long beans, chillis, spinach and bananas on her small mixed farm in the Gunungkidul region of Yogyakarta, Indonesia. Bananas are an important source of income for her household, and she grows them in the centre of the 800-square-metre farm. As is the case for many smallholder banana growers, Fusarium wilt TR4 is a threat. To lower the risks, she grows several banana varieties and cultivars, including Ambon, Kepok Kuning and Raja Putri. Each variety serves a different purpose. For example, Kepok Kuning, which is known to be resistant to Fusarium wilt TR4, is processed into fried chips for packaging and sale, whereas the other varieties are eaten fresh.

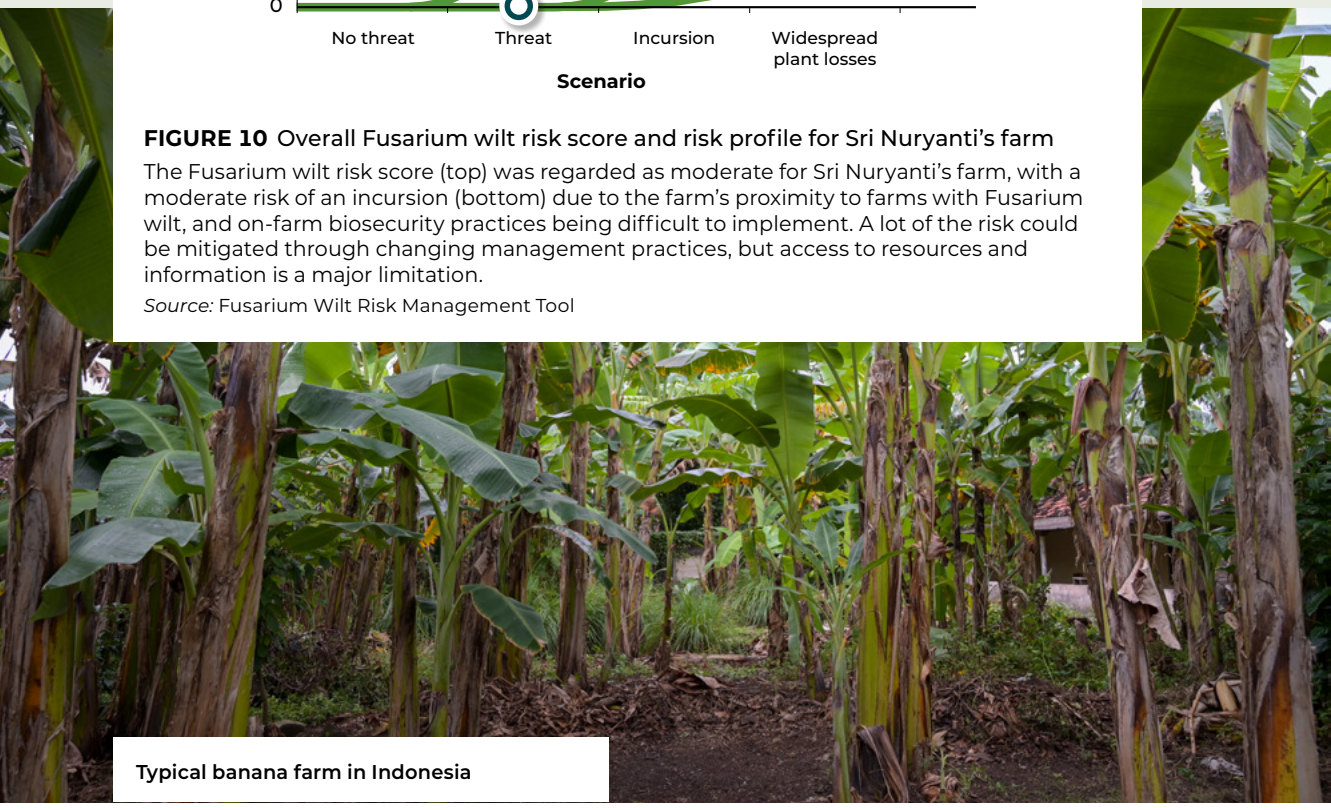
Though Sri Nuryanti sees Fusarium wilt TR4 as a threat to her farm, she believes the disease is not currently affecting her bananas. The Fusarium Wilt Integrated Risk Tool indicated that she had a moderate likelihood of disease incursion, and highlighted the various management options that could reduce the impact of the disease. However, as with many smallholder banana growers in Indonesia, on-farm biosecurity is not an option for Sri Nuryanti because for cultural reasons it is hard for her to restrict access through her farm. This results in a high-risk rating for the prevention management principle.

The farm is located near other banana farms infected with Fusarium wilt TR4, which increases the inherent risk of an incursion. However, through the use of diverse cropping – the beans, chillis and spinach are grown in the same plot as bananas – and the use of soil amendments, Sri Nuryanti can increase the biological protection of her banana plants. Having a diverse plant community above the soil supports a diverse soil microbial community below the soil.

FIGURE 10 Overall Fusarium wilt risk score and risk profile for Sri Nuryanti's farm

The Fusarium wilt risk score (top) was regarded as moderate for Sri Nuryanti's farm, with a moderate risk of an incursion (bottom) due to the farm's proximity to farms with Fusarium wilt, and on-farm biosecurity practices being difficult to implement. A lot of the risk could be mitigated through changing management practices, but access to resources and information is a major limitation.

Source: Fusarium Wilt Risk Management Tool



Typical banana farm in Indonesia

Principle	Integrated disease management risk			
	Low	Medium	High	Comments
Prevention	●●●	●●●	●○○	You have little in place to prevent Fusarium wilt
Location	●●●	●●○	○○○	You have a medium inherent risk of Fusarium wilt entering your farm
Protection	●●●	●●●	○○○	To further reduce risk, consider boosting soil biodiversity to slow disease progression
Reduction	●●○	○○○	○○○	You are using current best practice
Resistance	●○○	○○○	○○○	You are using current best practice
Commitment	●●●	●●●	●○○	Your staff and social contacts could be increasing disease risk

FIGURE 11 Risk ratings by principle for Sri Nuryanti's farm

Resistance and reduction all scored low for Sri Nuryanti's farm due to her growing a mix of susceptible and resistant cultivars and her plan for dealing with Fusarium-wilt-infected plants. Location and protection were regarded as moderate risk for the farming system with her having limited resources for inputs to enhance soil microbial activity. Prevention and commitment practices were seen as high risk, with limited information and training available on Fusarium wilt management and on-farm biosecurity being unfeasible in the community.

Source: Fusarium Wilt Risk Management Tool

The mixture of banana cultivars grown greatly reduces the impact of the disease on Sri Nuryanti's Ambon and Raja Putri plants, which are both susceptible to the disease. She also has a clear plan for dealing with Fusarium-wilt-infected banana plants to help reduce the build-up of inoculum on her farm.

Sri Nuryanti is acutely aware that Fusarium wilt can affect her banana production. She stays informed about the disease through training courses and information from local knowledge sources. She also seeks to improve her knowledge and understanding of maintaining healthy banana plants by participating in local farmer group meetings.

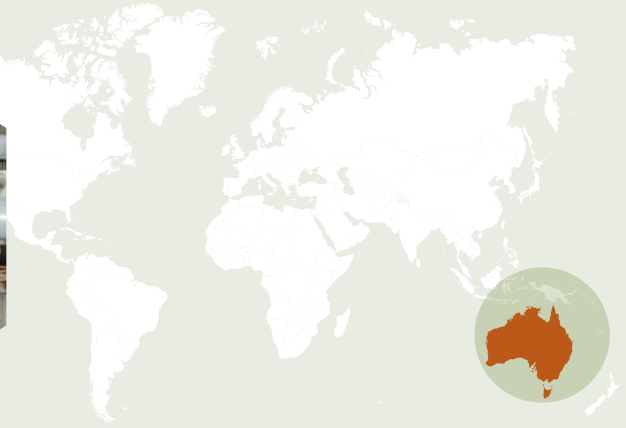
To lower her risk, Sri Nuriyanti grows several banana varieties and cultivars, including Ambon, Kepok Kuning and Raja Putri.

case study

●●○○ Scenario 2: **Threat**

Adrian and Jenny Crema

Tully, Queensland, Australia



For Adrian and Jenny Crema, the threat of Fusarium wilt TR4 entering their 85-hectare farm is always in the back of their mind. Though they currently do not have Fusarium wilt on their farm, it has been detected in neighbouring farms upstream. Their farm is located at the end of a road, but it borders other banana farms and is subject to occasional flooding during periods of intense rainfall. This means there is a large inherent risk that theirs could be the next farm in north Queensland to have a disease incursion.

To manage the risk, they rely on an integrated system of biosecurity to prevent people bringing in the disease, and they look after their soil health to protect their banana plants.

Adrian's farming philosophy is centred around having healthy soils: 'Manage for soil health and productivity will follow'. This approach has allowed him to maintain long-lived, productive plantings, with his oldest blocks being 21 years old and the youngest being 3 years old. Adrian does not see himself replanting the older blocks as they are still as productive as the younger blocks. This reduces the risk of introducing or moving Fusarium wilt in planting material.

The secret to the farm's soil health lies in:

- using vegetated groundcovers
- optimising nutrient inputs, including replacing phosphorus fertiliser with a phosphorous solubilising product
- placing the crop residues between plants to reduce weed growth
- keeping up with crop maintenance
- maintaining good drainage through an annual block maintenance program.
- keeping a neutral soil pH also helps to promote the health of the soils.

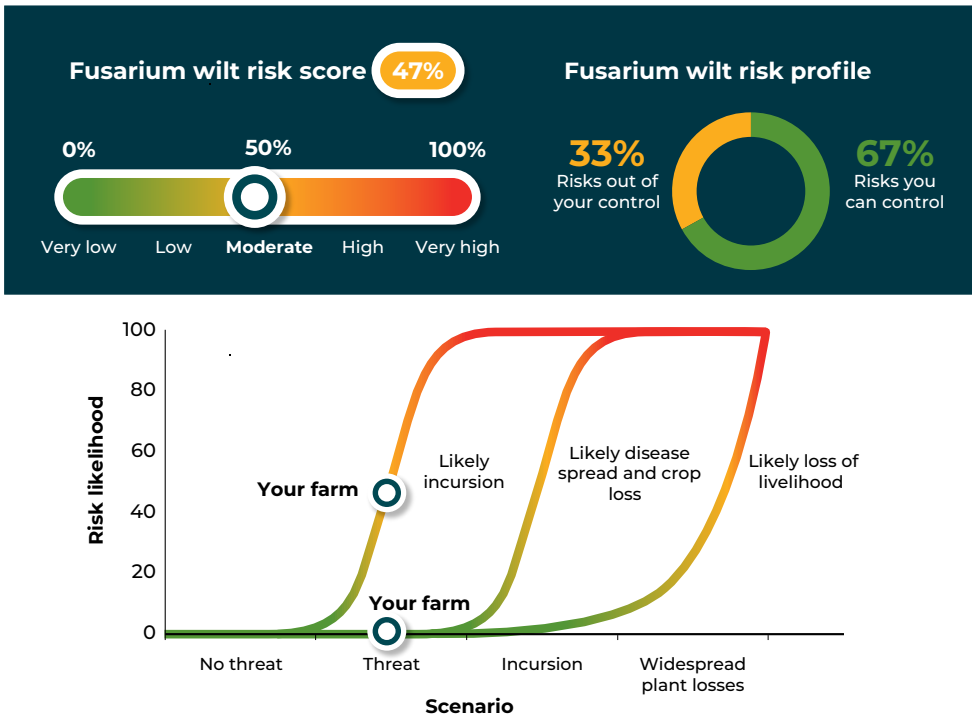
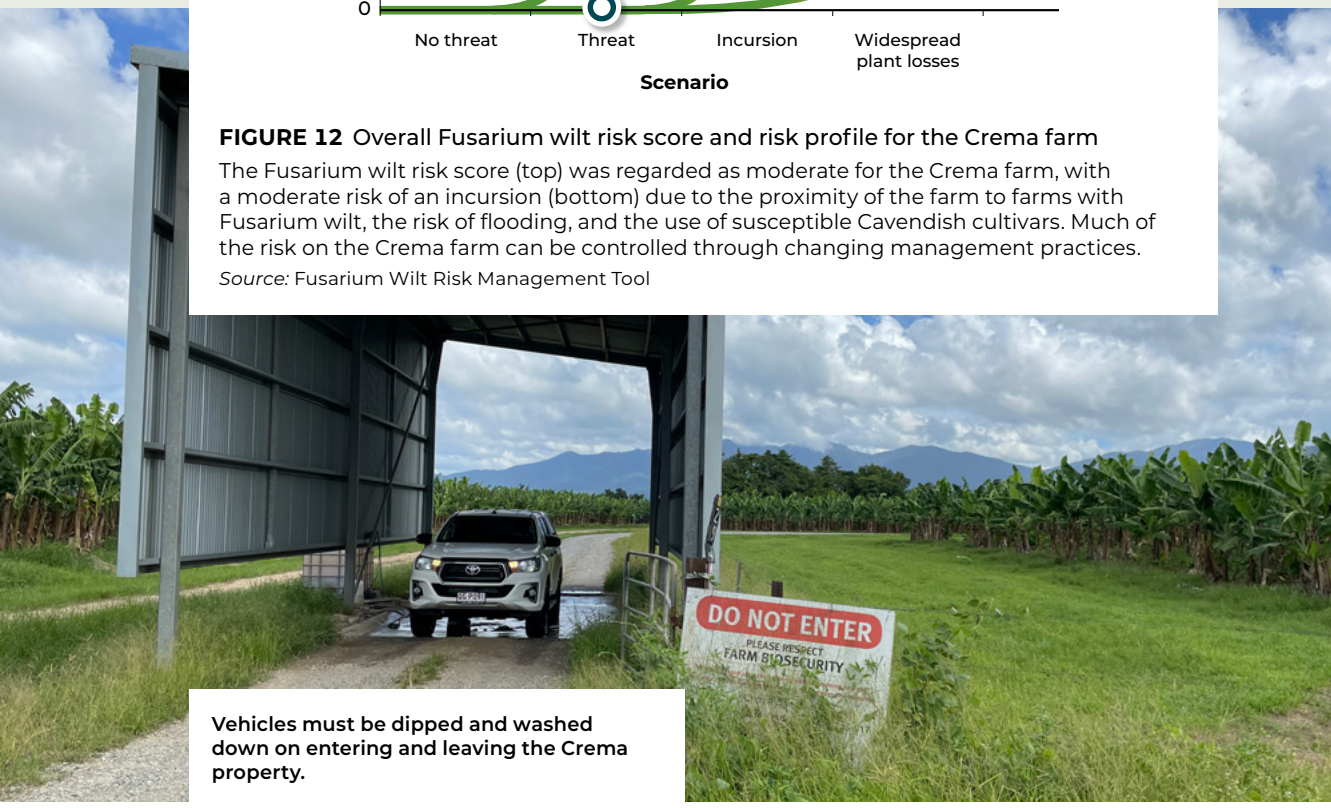


FIGURE 12 Overall Fusarium wilt risk score and risk profile for the Crema farm

The Fusarium wilt risk score (top) was regarded as moderate for the Crema farm, with a moderate risk of an incursion (bottom) due to the proximity of the farm to farms with Fusarium wilt, the risk of flooding, and the use of susceptible Cavendish cultivars. Much of the risk on the Crema farm can be controlled through changing management practices.

Source: Fusarium Wilt Risk Management Tool



Vehicles must be dipped and washed down on entering and leaving the Crema property.

Principle	Integrated disease management risk			
	Low	Medium	High	Comments
Prevention	●●●	○○○	○○○	Your disease prevention practices could be improved
Location	●●●	●●●	●●●	You have a high inherent risk of Fusarium wilt entering your farm
Protection	●●●	○○○	○○○	You are using current best practice
Reduction	●●●	●●●	○○○	Consider how you will manage an incursion
Resistance	●●●	●●●	●●○	Consider changing to tissue culture
Commitment	●○○	○○○	○○○	You are using current best practice

FIGURE 13 Risk ratings by principle for the Crema farm

Commitment and protection scored low in terms of risk to the Crema farm, with current best practice being implemented. Prevention and inoculum reduction were regarded as moderate risks for the farming systems because no procedures were in place for managing infected plants. Resistance and location were regarded as high risk due to the use of susceptible cultivars and the proximity of the farm to an infected property.

Source: Fusarium Wilt Risk Management Tool

The farm has the essential on-farm biosecurity, such as a vehicle bath and footbaths, with a separate gravel entry and visitor parking area. Adrian has a basic plan for biosecurity but his highest priority for Fusarium wilt management is keeping people on his farm informed of the risks, and ensuring his trusted employees look after casual field staff.

Adrian and Jenny's farm has a moderate risk of Fusarium wilt incursions due to the location of the farm and occasional flooding. They currently grow susceptible Cavendish cultivars and use vegetative material from the farm when they occasionally replant, which increases their risk of Fusarium wilt. They are considered to be using best practices to keep the people associated with the farm informed of the risks. Adrian does not see Fusarium wilt as a 'game-ender' to banana farming as long as he can build and maintain soil health.

Vegetated groundcover surrounds productive banana plants.

●●●○ Scenario 3: **Incursion**

Supriyadi

Gunungkidul, Yogyakarta, Indonesia

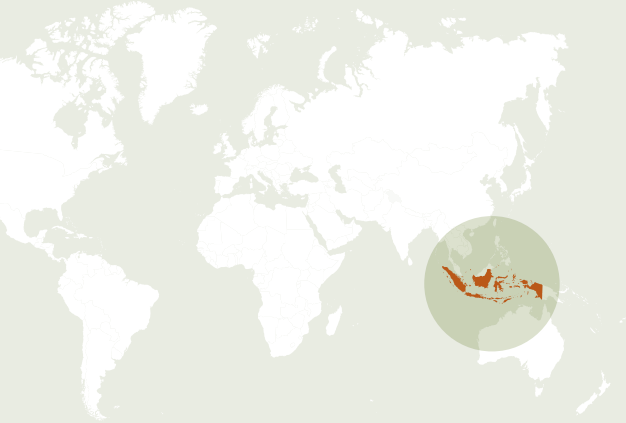


Photo: Supplied

Supriyadi has a 300-square-metre mixed farm in the Gunungkidul region of Yogyakarta in Indonesia. Half of his farm is used for rice production and the other half is used to produce corn, but bananas are also an important crop – money from the sale of his bananas helps fill the gap in household income between harvests of his rice and corn. Like most smallholder farmers in the area, Supriyadi grows a mix of banana cultivars – Pisang Susu, Tanduk and Raja Putri.

Working through the Fusarium Wilt Integrated Risk Tool allowed Supriyadi to assess the risk of Fusarium wilt to his bananas. Fusarium wilt is endemic to bananas in the region and has already been detected on his farm. This means there is a high risk that the disease will spread and cause widespread losses, reducing his income between his rice and corn harvests.

Supriyadi has divided his farm into different zones, which helps him to establish some basic prevention strategies to slow the spread around his farm. Unfortunately, he does not have access to clean planting material, and must rely on reusing vegetative material from his own farm, which is often infected with the *Fusarium* fungus.

Supriyadi tries to maintain healthy plants by keeping the soil pH close to neutral and carefully applying fertiliser. This builds a diverse soil microbial community, giving him a moderate protection risk against the spread of Fusarium wilt. He monitors his crop for disease symptoms, carefully noting the appearance of plants with disease symptoms, and isolating any infected plants from healthy plants. By removing the infected banana pseudostems, Supriyadi is reducing the risk of the disease spreading across his farm.

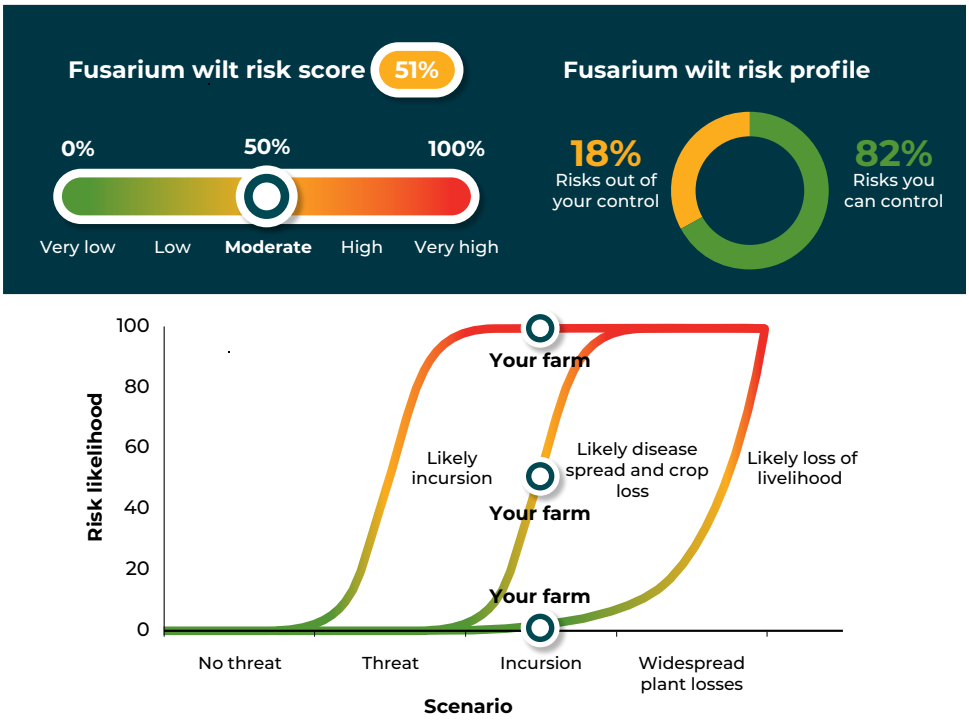


FIGURE 14 Overall Fusarium wilt risk score and risk profile for Supriyadi's farm

The Fusarium wilt risk score for Supriyadi (top) was regarded as moderate. As an incursion had already occurred, the risk of an incursion was 100%, but the risk of spread and the risk to loss of livelihood were both regarded as moderate. Most of the risks (82%) were regarded as within the control of the farm in the short term.

Source: Fusarium Wilt Risk Management Tool

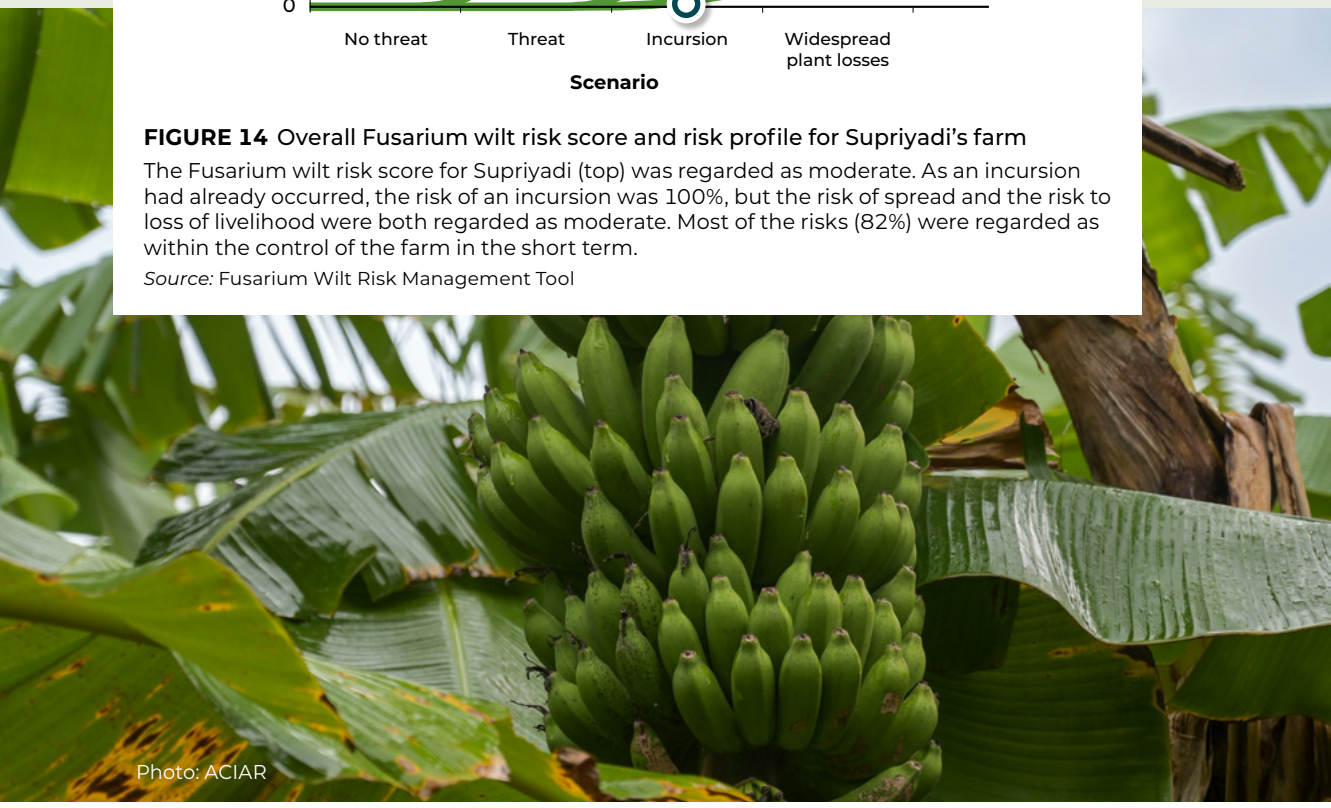


Photo: ACIAR

Principle	Integrated disease management risk			
	Low	Medium	High	Comments
Prevention	●●●	●○○	○○○	Your disease prevention practices could be improved
Location	●●●	●●●	●○○	You have a high inherent risk of Fusarium wilt entering your farm
Protection	●●●	●●●	○○○	Your cropping practices could be improved
Reduction	●●●	●○○	○○○	Keep on top of infected plants
Resistance	●●●	●●●	●○○	Consider changing to tissue culture and alternative cultivars
Commitment	●●●	○○○	○○○	You are using current best practice

FIGURE 15 Risk ratings by principle for Supriyadi's farm

Commitment scored low in terms of risk because Supriyadi had a disease monitoring system and good information connections. Prevention, protection and reduction were regarded as moderate risks for the farming systems, with some good practices in isolating areas of his farm, managing soil pH and isolating infected banana plants. His use of vegetative planting material and some susceptible cultivars, and the location of the farm, were regarded as high risk due to climatic stress periods during the year.

Source: Fusarium Wilt Risk Management Tool

Through his integration of various management practices, Supriyadi can still grow bananas with a moderate risk of Fusarium wilt spreading across the farm. He tries to keep up with information through a trusted local source, to help with his decision making. Due to his resource limitations for his farm, he is restricted in what he can implement in the short term, but he intends to continue to grow multiple banana cultivars and look after his soil.

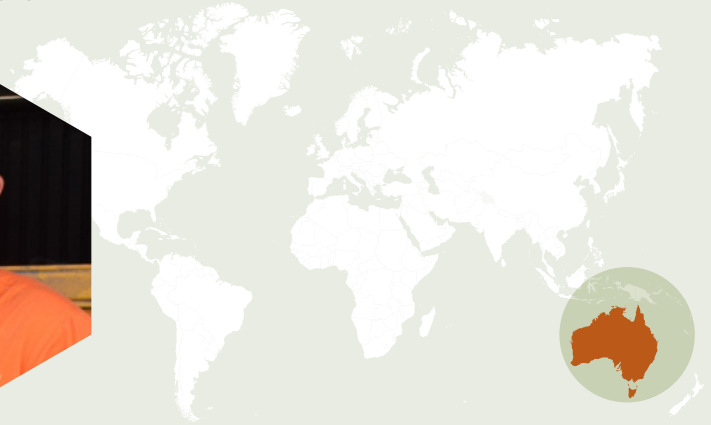
In Indonesia, bananas are commonly grown in rotation with or intercropped with vegetable crops such as *kangkung* (*Ipomoea aquatica*).

case study

●●●○ Scenario 3: **Incursion**

Bolinda Estates

Tully, Queensland, Australia



Jason Vipiana, Farm Manager, Bolinda Estates
Photo: Supplied

Bolinda Estates is one of the largest banana farms in north Queensland. It is owned by the Mackay family, who have 4 generations of banana-growing experience.

Fusarium wilt was first detected on a remote part of the property in 2017. This first area was declared a 'no-go' zone and was separated from the rest of the farm.

Since the first incursion of Fusarium wilt, early detection and eradication of infected plants has been a priority. Getting people on board was important to the family. Everyone associated with the farm, whether in the field, packing shed or managerial operations, is heavily invested in on-farm biosecurity and keeping the number of infected plants as low as possible. Field workers know the symptoms of Fusarium wilt and know what to look for, allowing early detection, and they know who to report to.

Based on the Bolinda farm management team's response to the questions posed by the Fusarium Wilt Integrated Risk Tool, there is a low risk of rapid Fusarium wilt spread. Their attention to maintaining on-farm biosecurity practices is helping them keep on top of the number of infected plants. Regular inspections across the farm look for signs of infection, and any infected pseudostems are quickly destroyed to help keep disease incidence low.

The team at Bolinda does not rely on farm biosecurity alone. Their attention to improving soil biological relations has been at the fore. Their soil management practices aim to maintain a neutral soil pH and optimise fertiliser inputs. They have actively tried to increase soil microbial diversity by encouraging plant diversity and using amendments that stimulate active microbial communities to help protect their bananas.

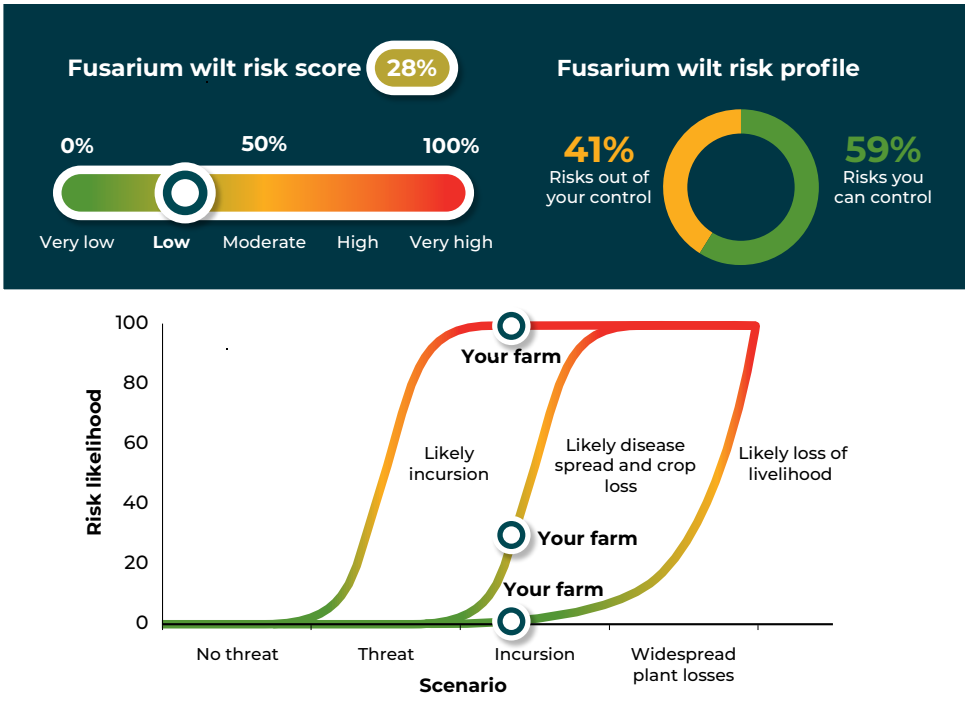


FIGURE 16 Overall Fusarium wilt risk score and risk profile for Bolinda Estates

The Fusarium wilt risk score for Bolinda (top) was regarded as low. As an incursion of Fusarium wilt had occurred, the risk of an incursion remained at 100%, but the risk of spread and the risk to loss of livelihood were both regarded as low. Many of the risks (41%) were regarded as beyond the control of the farm in the short term.

Source: Fusarium Wilt Risk Management Tool

Plants that have suspicious symptoms are clearly marked and identified. Samples can then be taken to test for Fusarium wilt.

Principle	Integrated disease management risk			
	Low	Medium	High	Comments
Prevention	● ○ ○	○ ○ ○	○ ○ ○	You are using current best practice
Location	● ● ●	● ● ●	● ○ ○	You have a high inherent risk of Fusarium wilt entering your farm
Protection	● ● ○	○ ○ ○	○ ○ ○	You are using current best practice
Reduction	● ● ○	○ ○ ○	○ ○ ○	You are using current best practice
Resistance	● ● ●	● ● ○	○ ○ ○	Use only clean planting material
Commitment	● ● ●	○ ○ ○	○ ○ ○	You are using current best practice

FIGURE 17 Risk ratings by principle for Bolinda Estates

Prevention, protection, inoculum reduction and commitment all scored low in terms of risk, with current best practice being implemented at Bolinda. Resistance was regarded as moderate risk for the farming systems due to the use of susceptible cultivars. The location of the farm was regarded as high risk due to periods of climatic stress and the farm layout.

Source: Fusarium Wilt Risk Management Tool

Everyone associated with the farm keeps up to date on the disease trends and best practices, and shares their knowledge and experience with other banana growers.

The farm management team found it useful to work through the Fusarium Wilt Integrated Risk Tool:

- 'It makes you think whether you are doing it or not or should be doing it.'
- 'It helped to compartmentalise actions and provides another way of looking at Fusarium wilt management.'

The farm's resistance practices were rated as moderate risk because susceptible banana cultivars are still grown across the farm. The team were aware of developments in new cultivars but were not at the point of testing them on the farm.

Because Fusarium wilt was detected in multiple isolated areas, it became difficult to control movement and to leave infested areas last during farm operations. However, any machinery used in land preparation is thoroughly washed and cleansed before it is moved to new areas.

Through crop management, the team tries to reduce climatic impacts on plant growth, but there are still times when banana plants experience environmental stress. By remaining vigilant and proactive, Bolinda is well positioned to slow disease spread, allowing banana production to continue in the face of Fusarium wilt.

●●●● Scenario 4: **Widespread plant losses**

Sularmi

Gunungkidul, Yogyakarta, Indonesia

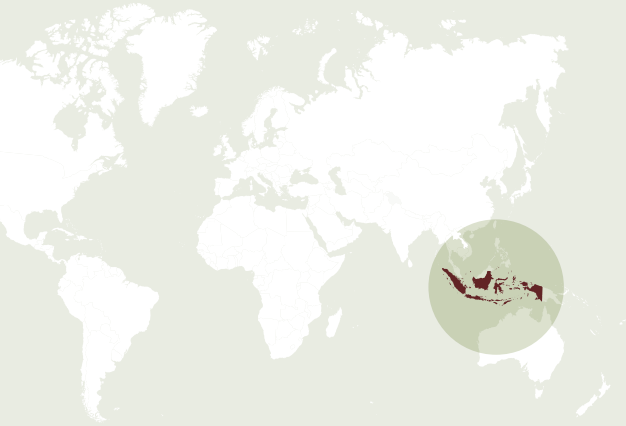
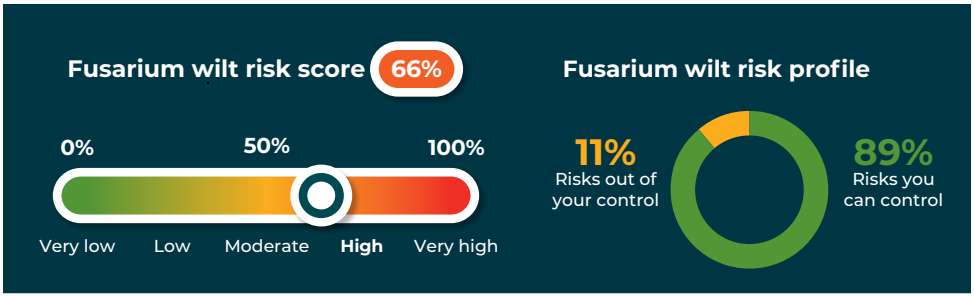


Photo: Supplied

As a smallholder banana grower, Sularmi is in a difficult position. She relies solely on bananas for her farm income, growing 4 varieties – Kepok Kuning, Raja Putri, Pisang Susu and Tanduk. While some varieties have resistance to Fusarium wilt, the disease has become widespread on her farm. This means she has a high risk of losing her livelihood due to the disease. Her options to reduce inoculum are restricted by the scarcity of resources, such as spare land for crop rotations or access to clean planting material. Unfortunately, Sularmi's position is not uncommon among smallholder banana growers trying to manage the disease on their farms.

The Fusarium Wilt Integrated Risk Tool highlighted to Sularmi the risk the disease poses to her banana growing. She has limited options on how she can manage her land, having no alternative but to replant into infected soil using vegetative planting material that is likely to be infected with Fusarium wilt. She is unable to expand the area where she grows resistant varieties, making her even more vulnerable to livelihood losses. She could improve her soil health by increasing crop diversity and managing soil microbial activity, but she cannot afford to do so. Similarly, she is struggling to reduce the disease inoculum, being unable to afford to grow resistant crops in rotation with banana for any effective duration.

For many smallholder banana growers, the most valuable cultivars (such as Pisang Raja) are susceptible to Fusarium wilt and, like Sularmi, they cannot afford to stop growing bananas long enough to reduce the disease inoculum.



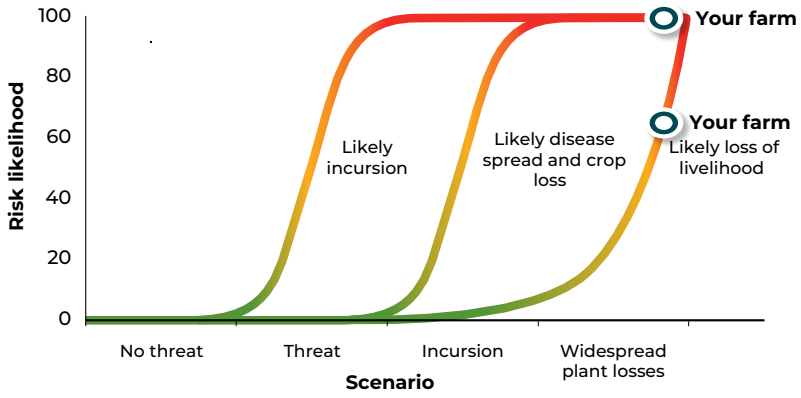
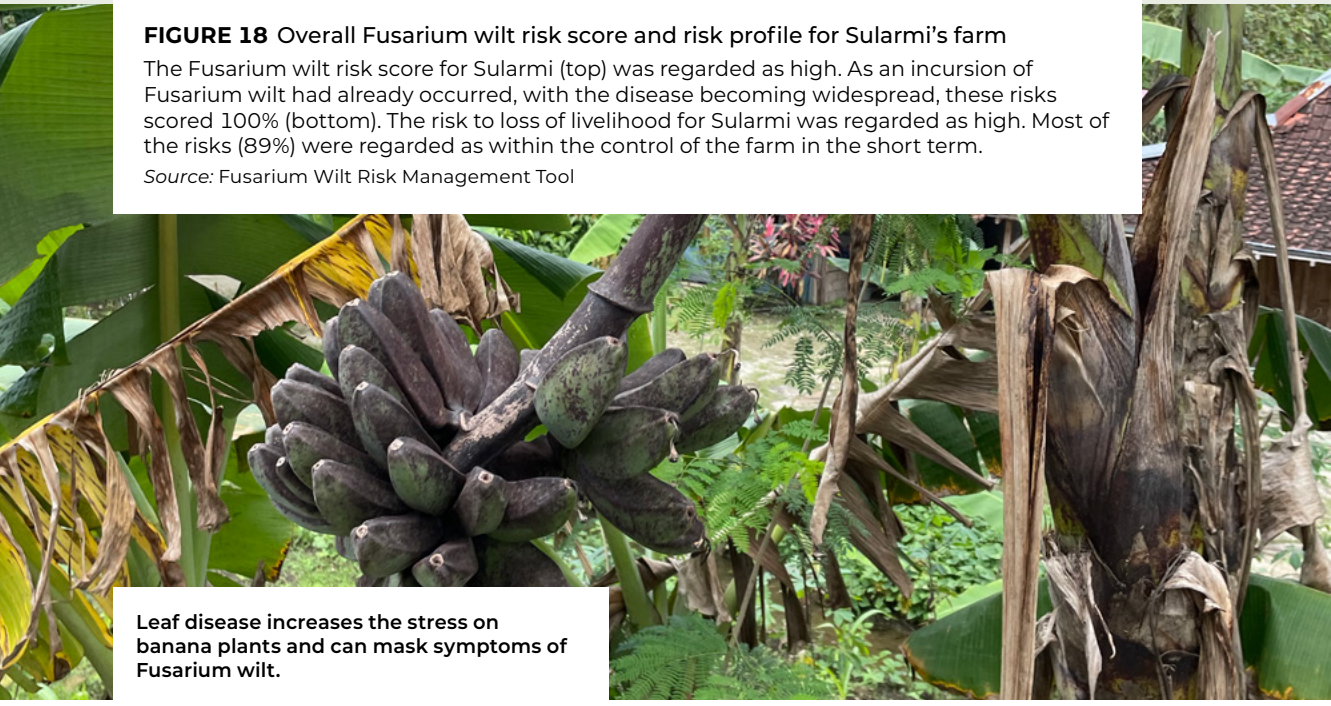


FIGURE 18 Overall Fusarium wilt risk score and risk profile for Sularmi's farm

The Fusarium wilt risk score for Sularmi (top) was regarded as high. As an incursion of Fusarium wilt had already occurred, with the disease becoming widespread, these risks scored 100% (bottom). The risk to loss of livelihood for Sularmi was regarded as high. Most of the risks (89%) were regarded as within the control of the farm in the short term.

Source: Fusarium Wilt Risk Management Tool



Leaf disease increases the stress on banana plants and can mask symptoms of Fusarium wilt.

Principle	Integrated disease management risk			
	Low	Medium	High	Comments
Prevention	●●●	●●●	○○○	Your disease prevention practices could be improved
Location	●●●	●●●	●○○	You have a high inherent risk of Fusarium wilt entering your farm
Protection	●●●	●●●	●○○	Your situation and management places your livelihood at risk
Reduction	●●●	●●●	●○○	You need to manage infected plants to protect your livelihood
Resistance	●●●	●●○	○○○	Use only clean planting material
Commitment	●●●	●●○	○○○	Your staff and social contacts are important to maintain your livelihood

FIGURE 19 Risk ratings by principle for Sularmi's farm

Prevention, resistance and commitment for Sularmi were scored as having a moderate disease risk. Though she was able to implement some disease management practices, more was required to prevent and to reduce the impact of Fusarium wilt. Location, protection and reduction were regarded as high risk for the farming systems as Sularmi was unable to implement an effective crop rotation period and stop growing bananas long enough to reduce disease inoculum. She also relies on vegetative planting material to re-establish bananas on her farm, increasing her disease risk.

Source: Fusarium Wilt Risk Management Tool

For Sularmi to continue to make a living from bananas, she needs interventions and support to allow her to reset her banana farming system. The scarcity of resources available to her (such as land, finance and clean planting material) and the need for her to continue to grow high-value susceptible bananas – knowing they are most likely to rapidly become infected with Fusarium wilt – places her in a difficult situation. Unfortunately, this is a typical situation in which many smallholder banana growers in the Gunungkidul region find themselves. And it is not unique to Indonesia, but common to smallholder banana growers throughout Southeast Asia.

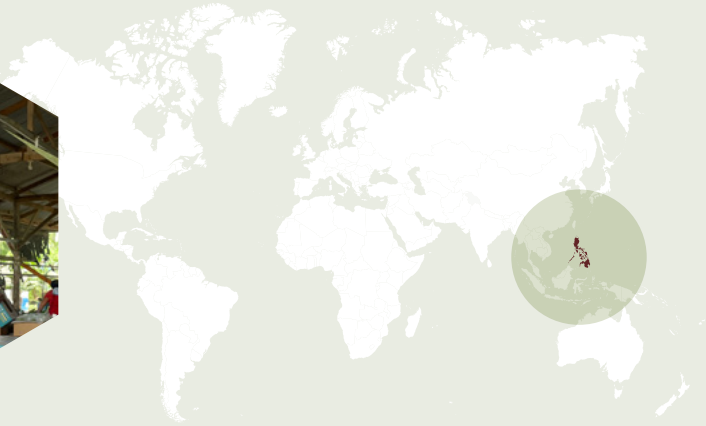
For smallholder banana growers, management of crop residue and sucker selection can be important for controlling Fusarium wilt.

case study

●●●● Scenario 4: **Widespread plant losses**

Arnold Dela Cerna

Davao del Norte, the Philippines



Having had widespread plant losses from Fusarium wilt on his 10-hectare farm, Arnold Dela Cerna is making a comeback, supplying the substantial Chinese banana market with fruit from the Cavendish cultivars Grand Nain and Williams.

Using an integrated disease management system to limit Fusarium wilt, he grows corn on infested land for at least 3 crops to reduce disease inoculum in the soil before replanting bananas. When he replants the land, he uses tissue-culture banana plantlets sourced from the provincial government office. He also ensures optimal soil pH and fertiliser applications at planting. As part of his Fusarium wilt management regime, he uses a *Trichoderma*-based biocontrol, which is also sourced from the provincial government office.

In his field operations, Arnold has a footbath which everyone must pass through before entering the field, and his workers use clean tools and equipment. He also credits his success in managing Fusarium wilt to regular field monitoring, which enables early identification and removal of any infected banana plants.

The farm is close to a major waterway, which he suggests was the source of the initial infection. He has since been able to divert some of the water away from his farm to help reduce reinfection from outside the farm.

Arnold Dela Cerna grows 3 crops of corn in rotation with banana to help reduce Fusarium wilt inoculum in the soil before replanting tissue-culture plants.

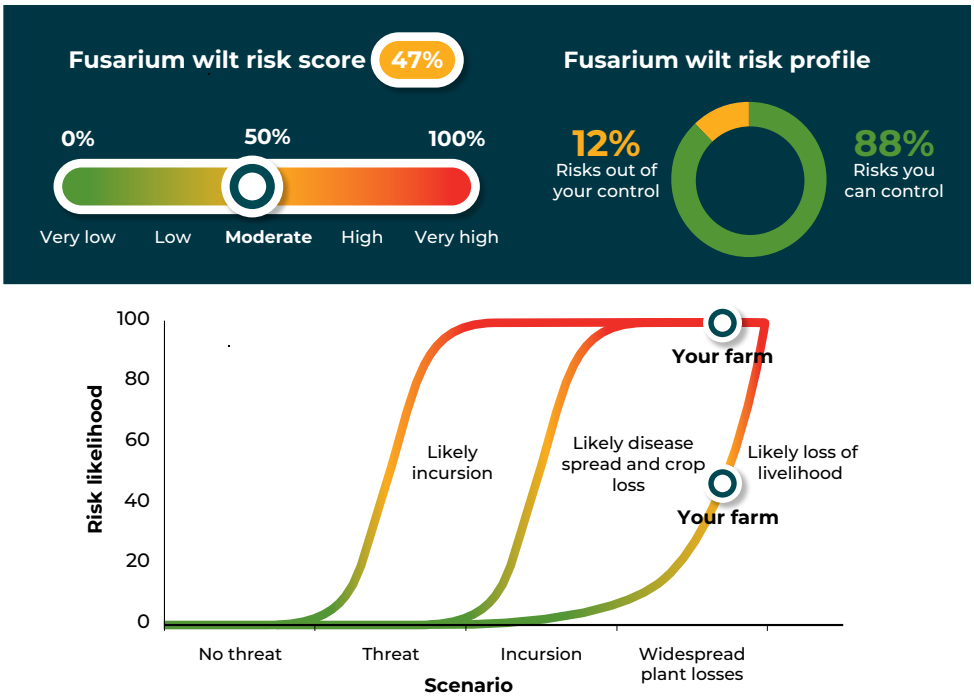


FIGURE 20 Overall Fusarium wilt risk score and risk profile for Arnold Dela Cerna's farm

Fusarium wilt risk on Arnold Dela Cerna's banana farm was considered moderate (top) with a moderate risk of loss of livelihood (bottom). The disease is already present on the farm, and was once widespread, so he is learning to live with the disease and keep his crop losses low.

Source: Fusarium Wilt Risk Management Tool

The people employed on the farm are all aware of the importance of managing Fusarium wilt and the threat it plays to their livelihoods in the industry. Arnold has been collaborating with the provincial government agricultural office in Davao del Norte, who have been able to advise him on how to manage Fusarium wilt. He is now happy to share his experiences with other growers.

Based on Arnold's responses to questions posed by the Fusarium Wilt Integrated Risk Tool, Fusarium wilt is now widespread on his farm, so the inherent risks of Fusarium wilt in banana production are very high. However, his management practice suggests there is a moderate risk of Fusarium wilt spreading, leading to crop losses, and posing a threat to his livelihood.

Principle	Integrated disease management risk			
	Low	Medium	High	Comments
Prevention	●●●	●○○	○○○	Your disease prevention practices could be improved
Location	●●●	●●●	●○○	You have a high inherent risk of Fusarium wilt entering your farm
Protection	●●●	●●●	○○○	Your cropping practices could be improved
Reduction	●●●	○○○	○○○	You are using current best practice
Resistance	●●●	●●●	○○○	Use only clean planting material
Commitment	●●○	○○○	○○○	You are using current best practice

FIGURE 21 Risk ratings by principle for Arnold Dela Cerna's farm

Arnold Dela Cerna uses an integrated program to maintain banana production, using the best practices of prevention, inoculum management, and informing people on the farm of the risks. Because of his location near other farms and waterways, and having no vegetation cover over the soil, he has a moderate protection risk. The resistance risk is regarded as high because he grows susceptible cultivars to ensure a premium price for his produce.

Source: Fusarium Wilt Risk Management Tool

By removing infected plants and establishing farming zones, he has limited further disease spread. He has also invested in improving his soil by adjusting soil pH before planting and increasing soil microbial diversity through the application of biocontrols. His attention to biosecurity measures, such as isolating infected plants and cleaning equipment, are also helping to keep Fusarium wilt under control.

Arnold has evaluated the adoption of resistant cultivars but they are unsuitable for the market he supplies. Therefore, his vulnerability to Fusarium wilt is increased, as indicated by the higher resistance risk score, by his having to grow more highly valued but susceptible cultivars.

By keeping in contact with the provincial agricultural office, he has been able to access more information on disease management. While his risk of livelihood loss is moderate, he has proactively reduced the potential for widespread disease spread and crop loss, allowing him to produce bananas in a continuous cropping system.

Arnold uses the best practices for preventing and reducing Fusarium wilt on his farm and keeping the people associated with his farm informed. The location of his farm and the lack of groundcover increased his protection risk score to moderate. And having to grow susceptible banana cultivars put him in a high-risk resistance category.

SECTION

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More reading

SECTION

5

More reading

Preventing Fusarium wilt

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