An Independent Epidemiological Review on Panama disease tropical race 4 on an infested banana property in northern Queensland

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EXECUTIVE SUMMARY and KEY RECOMMENDATIONS

The discovery of Fusarium wilt Foc TR4 on a Cavendish banana plantation in Tully on 2 March 2015 has caused considerable concern and disbelief among growers, researchers and industry role players in Far North Queensland. Fusarium wilt TR4 is known as a serious disease of banana in several Asian countries, and has been found in the Northern Territory in 1997. The detection of the disease in the main banana production area of Australia prompted Biosecurity Queensland (BQ) to verify its geographic distribution, to contain the disease on the affected property, and to prevent it from spreading to non-infested areas. BQ staff thus embarked on an extensive tracing programme, linking the infested premises (1IP) and a suspect premises (2SP) owned by the same family with other banana farms in the Tully-Innisfail area and the rest of Queensland through the movement of planting material, shared contractors, machinery, packing houses and packing workers, water flow and vehicle movement. Properties neighbouring 1IP were considered as a high risk. An extensive surveillance program was then launched on commercial banana farms, residential properties and public land linked to 1IP. Fusarium wilt TR4 was found at nine detection sites on 1IP, but on no other banana property in the state of Queensland. 1IP was purchased by the Australian Banana Growers Council (ABGC) in October 2016, who now controls access to and manages the land. All bananas were destroyed, the farm fenced-in, and natural regrowth left uncontrolled to reduce soil movement of soil. Due to the activities of BQ, ABGC and the Department of Agriculture and Fisheries (DAF), producers have become more aware of the threat of Foc TR4 to banana production, and more than 91% of farmers were trained in biosecurity. Many farms had been fenced in. Despite these interventions, two key questions remain unanswered: (1) How was Foc TR4 introduced into Far North Queensland, and (2) where has it potentially spread to. To address these questions, and maintain the attentiveness of growers in Far North Queensland, the following recommendations need to be considered:

1. To continue surveillance for at least another 12 months.
2. Surveillance of non-banana-growing areas, especially the creeks flowing off 1IP.
3. Additional tracing to connect 1IP with Fusarium wilt TR4-affected properties in the NT.
4. State government and ABGC support to introduce affordable biosecurity measures.
5. Aerial surveillance to improve detection of diseases and grower irregularities.
6. Guidelines to deal with future detections and reintroductions of Foc TR4 into the area.
7. An investigation into the history of the index blocks prior to 2009.
8. Detailed investigation on the planting of the index blocks, and information on the identities and working history of temporary workers and backpackers.
9. The scaling-up of research efforts.

ABBREVIATIONS

ABGC .....Australian Banana Growers Council Incorporated
ASQ ..... AgriScience Queensland
BQ .....Biosecurity Queensland
DAF .....Department of Agriculture of Fisheries
Foc..... *Fusarium oxysporum* f. sp. *cubense*
IP ..... Infested premise
NSW ..... New South Wales
NT ..... Northern Territory
SP .....Suspect premise
TR4 ..... tropical race 4
UQ .....University of Queensland

CLARIFICATIONS

In this document, Panama disease in Far North Queensland is called Fusarium wilt TR4, the responsible fungus is called Foc TR4, and the collective name of all forms of the fungus (races 1, 2 and 4) is referred to as Foc.

The owner of the index blocks on 1IP prior to 2009 is referred to as the ‘original owner’, and the owner of these blocks between 2009 to 2016, before the property was purchased by ABGC, is called the ‘former owner'

AIMS AND OBJECTIVES

The primary aim of the review was to assess all information pertaining to the positive detections of Fusarium wilt tropical race 4 (TR4) on 1-IP and to provide an assessment of the possible source, history, and distribution of the pathogen and the current spread minimisation measures. The objectives were:

1. To review the historical practices and current situation on 1-IP, including:
    - Farming practices
    - Irrigation practices
    - Planting and production history
    - Potential sources of disease
    - Detections on 1-IP
    - Movement patterns pertaining to equipment and people
2. To examine tracing and any other relevant information to identify the potential pathways whereby Fusarium wilt TR4 may have been introduced into Queensland, and to identify how the disease may spread to other properties. Assess this information to deduce:
    - How long has the pathogen been present on the farm?
    - If the first blocks where disease was detected are the index blocks on the farm?
    - What the likely source of introduction was?
    - How widespread can we assume the pathogen to have spread on the farm?
    - How is it most likely to have spread?
    - What is the likelihood that the pathogen spread off-farm prior to detection?
    - What is a likely timeframe for symptom development following disease spread off 1IP?
    - What the likely surveillance timeframe is to lift quarantine from a property that shared machinery and farm management, without any farm biosecurity measures, but where the disease has not been detected on susceptible banana hosts?
    - What the risk of the dam on the property poses for spread through irrigation water?
    - Could other measures be adopted to minimise further spread off 1IP?
    - A pattern in disease development to do targeted surveillance and early detection?
    - The level of risk of the dam, Travelling Dairy Creek and other drainage lines pose as a source of spread off-property? How can this risk be minimised?
    - The risk downstream where growers pump water out of the Tully River, or for extractive industries such as sand dredging? How can this risk be mitigated?
    - Changes in the destruction protocol that minimises risk of disease spread.
    - How you would prioritise surveillance, or target any additional surveillance across the industry not currently being addressed.

PROGRAMME

Date	Time	Activity	People involved
Wednesday 1 March	10:00 – 12:00	Travel Cairns to Moresby	Schedule 4 - CTPI
	14:00 – 16:50	Introduction to review	
Thursday 2 March	09:00 – 10:00	Early response staff	
	10:00 – 11:00	Surveillance and tracing	
	11:00 – 12:00	Operations, surveillance, compliance	
	18:00 – 22:00	Dinner with ABGC board	
Friday		1IP farm visit	
		Informal discussion	
Monday	09:00 – 13:00	Banana researcher and extension staff	
	14:00 – 16:00	Integration of information	
Tuesday	10:00 – 12:00	Owners of affected farm	
	12:00 – 13:00	Grower and neighbour	
Wednesday	09:00 – 11:00	Wrap-up meeting	
	11:30 – 13:00	Former ABGC chairman	
Thursday	09:00 – 16:00	Brisbane based scientists TR4 diagnostic laboratory	
Friday	09:00 – 12:00	Brisbane-based researchers	
	13:00 – 15:00	University of Queensland	
Saturday	18:00	Depart to South Africa	

BACKGROUND

In Australia bananas are produced on more than 700 farms in Queensland, New South Wales, Western Australia and the Northern Territory (NT) (Fig. 1) (Horticulture Australia, 2014; www.australianbananas.com). The total growing area is approximately 13 000 ha, with an average annual production of between 330 000 and 350 000 tons. Farmers are earning about 500 million AUS dollars annually, depending on seasonal factors such as cyclones and disease outbreaks (Horticulture Australia, 2014). Most bananas (90-95%) are produced under tropical conditions in Far North Queensland, mainly in the Tully, Innisfail, Atherton Tablelands and Lakeland areas. Production in the NT was expanding rapidly in the 1990s due to large investment by Queensland growers who wanted to take advantage of the better winter fruit quality and escape cyclone damage (Walduck and Daly, 2007). Since the discovery of Fusarium wilt TR4 in the region production has declined, and today only one large commercial banana farm remains. Bananas are also produced in the subtropics of southeast Queensland, northern New South Wales (NSW) and Western Australia. All bananas produced are sold on local markets and there are no imports, mainly due to the risk that pathogens and pests pose to the local industry (Horticulture Australia, 2014). Approximately 95% of Australian bananas comprise of Cavendish cultivars, with Lady Finger, Goldfinger, Ducasse, Red Dacca, Succrier and Pacific Plantain forming the remaining 5% of the market. Research, development and marketing for the industry is funded through a compulsory industry levy on the sales of banana, partly subsidised by the Australian Government (Horticulture Australia, 2014).

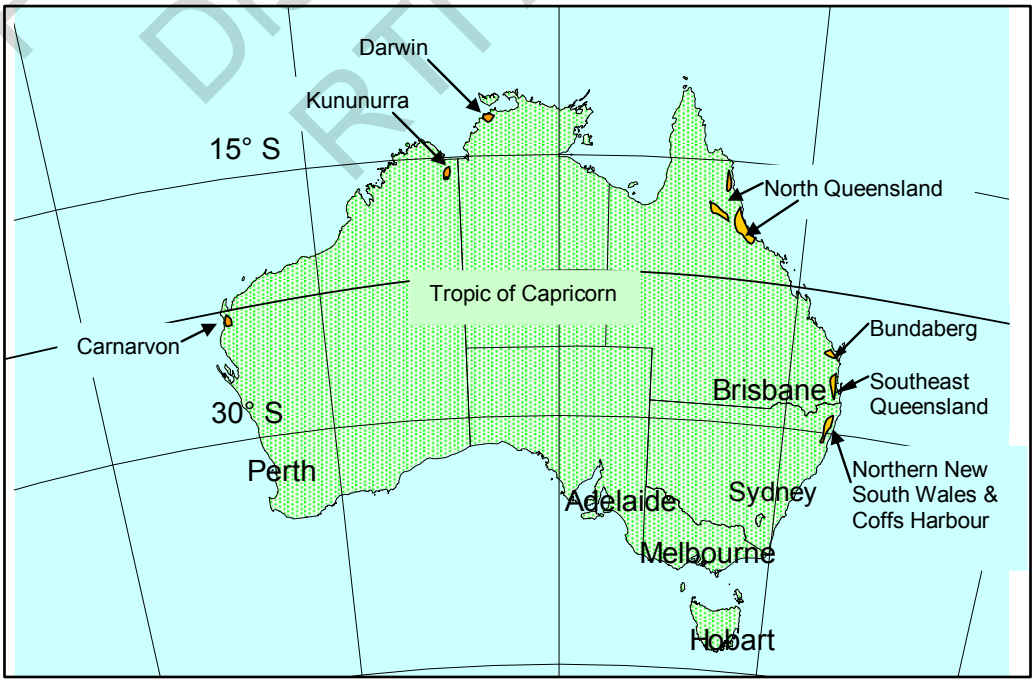

Figure 1. Banana production areas in Australia.

Fusarium wilt is not a new disease of bananas in Australia. In fact, the first record of the disease globally came from Australia (Bancroft, 1876). Most banana varieties grown in the country are affected by the Fusarium wilt fungus *Fusarium oxysporum* f. sp. *cubense* (Foc). Foc race 1 affects Lady Finger, Ducasse and Sucrier bananas throughout eastern Australia and at Carnarvon in Western Australia, while Foc subtropical race 4 causes disease to Cavendish bananas in northern NSW and southern Queensland (Moore *et al*., 2000). Strains related to Foc race 1 has also caused localised disease outbreaks in Cavendish bananas in poorly drained clay soils in Carnarvon (Pegg *et al*., 1995). Foc race 1 and subtropical race 4 do not affect Cavendish bananas in the tropics, and has not been reported on Cavendish bananas in Far North Queensland and the NT.

Foc tropical race 4 (TR4), causal agent of Fusarium wilt TR4, was found at Berry Springs near Darwin in the NT in 1997, and in the next 6 years spread to all the commercial Cavendish production areas near Darwin (approximately 500 ha). Infected planting materials (suckers and bits) are an important means of long-distance spread, but the introduction of tissue culture bananas in the 1980s (Krikorian and Cronauer, 1984) was a major intervention to prevent pathogen dissemination. After Foc is introduced into a banana field, the disease will develop and inoculum will build up rapidly. The movement of planting material, soil or water from Foc-infested sites provides an opportunity for the fungus to be moved to new areas. Prevention of introduction and early detection of the disease, thus, are essential actions for banana Fusarium wilt management (Ploetz, 2015). Strict containment and quarantine measures implemented in the NT, however, were unable to contain Fusarium wilt TR4, which has spread to non-commercial and backyard banana plantings within the Darwin region (NT Plant Biosecurity report, 2012). Quarantine restrictions in the NT were thus lifted in 2011. Today, Lambells Lagoon is the only commercial Cavendish banana farm still in production.

Foc TR4 is considered a global threat to banana production because of its wide host range and the dominance of Cavendish bananas as traded banana. The Australian banana industry is particularly vulnerable to the fungus as banana production in the country consists almost exclusively of Cavendish bananas, and because production is greatly concentrated in Far North Queensland. For this reason the Queensland Government, in collaboration with the Australian banana industry, developed biosecurity guidelines to minimise the risk of diseases and pests, and to respond effectively to deal with diseases such as Fusarium wilt TR4, Freckle, Black Sigatoka and Bacterial Wilt. A national banana industry Biosecurity Plan was developed to identify and mitigate foreign threats (Plant Health Australia, 2009). For producers, a Farm Biosecurity Manual was developed with practical information to protect plantations against foreign pests (Plant Health Australia and the Department of Employment, Economic Development and Innovation, 2009).

REVIEW OF THE BQ PROGRAMME AND ACTIVITIES

Introduction

On 3 March 2015, Fusarium wilt TR4 was discovered on a commercial Cavendish banana farm located in the Tully Valley in Far North Queensland (Fig. 2). This property, and a second property linked through family ownership and shared machinery, were immediately placed under quarantine by Biosecurity Queensland (BQ). BQ established a Fusarium wilt TR4 incident response program to respond to the pathogen incursion. The management of the disease later transitioned from an incident response to a managed program in October 2015.

After the original detection of Fusarium wilt TR4 at the infested property in Tully, eight more detection sites were discovered on the same property (Fig. 2). These sites were very randomly distributed, with no particular pattern. In October 2016 the infested property (1IP) and an associated property (2SP) were purchased by the Australian Banana Grower's Council Inc. (ABGC), and all banana plants destroyed. No detections of Fusarium wilt TR4 were found on any other banana property in Far North Queensland despite an extensive surveillance program, including 2SP, which were under quarantine due to shared ownership and operation.

Schedule 4 - CTPI

Figure 2. The Fusarium wilt TR4 infested premise (1IP) and a suspect premise (2SP) in the Tully Valley. The nine detection sites are indicated as red dots.

This review on Fusarium wilt TR4 in Far North Queensland is based on the interpretation of available information, and is based on people's recollections, perceptions, explanations and understanding. People interviewed during the review process include DAF staff and researchers, farmers including the former owners of the affected farm, researchers from other agencies and the ABGC.

Tracing

One of the most puzzling questions facing BQ, ABGC and local producers was how Fusarium wilt TR4 was introduced into 1IP, particularly into Index Blocks 1 and 2, where the disease was first discovered (Fig. 3). These blocks were purchased from their former owner in August 2009, and planted with bananas in 2011. Poor quality bananas are visible in Index Block 1 in aerial pictures taken in July 2007 (Fig. 3). These could be survivor plants following the damage caused by Cyclone Larry in March 2006. Index Blocks 1 and 2 were severely affected by nematodes before, and were left fallow between the late 1990s to early 2000s. At the time of purchase in August 2009, no bananas were present on Index Blocks 1 and 2, despite records from a banana tissue culture company that plantlets were ordered for planting in June 2009.

The history of banana production in the index blocks from March 2006 to August 2009 is unclear with the currently available information. After the premises was purchased in August 2009, tissue culture banana plants from a tissue culture nursery, known as Schedule 4 - were planted in November 2011 and August 2012 in Blocks 1 and 2, respectively. Tracing information has linked this company with deliveries of tissue culture plants to banana farms in the NT of Australia. The southern, up-hill section of Index Block 1 at 1IP was planted with tissue culture plantlets from a tissue culture nursery, known as Schedule 4 - CTPI in 2014, and the other banana blocks purchased in 2009 on the north side of the farm, was planted with suckers from 1IP.

Schedule 4 - CTPI

Figure 3. Aerial image of the index blocks, marked with a yellow circle, in July 2007.

The first plantings of bananas at Index Blocks 1 and 2 in 2011 and 2012, respectively, initially showed signs of stress and poor establishment. This was attributed to possible nematode damage because of the history of the pest in these blocks. In 2013, plants with yellow leaf symptoms were observed in the same area. The former owners believed that this was caused by lightning, and the symptoms were not reported. In 2014, plants were again observed with yellow leaves, and this was attributed to Erwinia corm rot; a bacterial disease of banana that is common in the Tully Valley. In the last week of February 2015, an ABGC leaf spot monitor visited the property and observed suspicious symptoms from the road in the index blocks. Samples were collected from which *Erwinia* was initially isolated. Further investigation of the collected material resulted in the isolation of *Fusarium* isolates, which later proved to be Foc TR4. In the next 2 months, 12 positive detections of Fusarium wilt TR4 were confirmed in Index Blocks 1 and 2 which were planted with tissue culture bananas from the tissue culture company. Another 18 plants were observed to show external symptoms of the disease. All plants in Index Blocks 1 and 2 were thereafter killed by injection with glyphosate, and the diseased plants cut down and treated with urea. In the next 20 months, eight more detections occurred randomly on the farm (Fig. 2; Table 1).

Schedule 4 - s.41

Table 1. Dates of detections of Fusarium wilt TR4 at 1IP.

Detection site number	Detection date	Detection site number	Detection date
1	March 2015	5	May 2016
2	August 2015	6	July 2016
3	October 2015	7	September 2016
4	April 2016	8	November 2016

Tracing activities to determine the possible spread of Foc TR4 from 1IP started in March 2015, using a risk pathways methodology. The most likely suspect premise (2SP) was about 1.5 km away, and was owned by the family that owned 1IP (Fig. 2). The farms regularly shared machinery, thereby making 2SP a highly suspect property. For this reason, 2SP, in addition to 1IP was placed under quarantine after the discovery of Foc TR4 at 1IP. The trade of banana fruit from both properties was suspended temporarily, after which trade resumed under a strict biosecurity protocol and daily supervision of farming operations by BQ staff. Despite frequent surveillance visits, no cases of Fusarium wilt TR4 were found on 2SP up to the time that the farm was purchased by ABGC in November 2016.

BQ staff embarked on an extensive tracing programme, linking 1IP and 2SP with other banana farms in the Tully-Innisfail area and the rest of Queensland through the movement of

planting material from 1IP, shared source planting material, shared contractors, machinery, shared packing houses and packing workers, proximity and water flow, labour and service outsourcing and vehicle movement (Fig. 4). To obtain all required information, tracing questionnaires were developed for growers, farm workers, nursery operators and contractors. The tracing process has been ongoing as new and more detailed information has become available or as properties have ceased banana production.

Properties neighbouring 1IP were considered as a high risk. Not only were these farms poorly protected against pathogens and pests due to a lack in biosecurity measures, but shortcuts for people travelling in the local area were often taken through neighbouring farms and machinery was shared. Where disinfection processes were in place, Farmcleanse®; a product believed to disinfect vehicles, machinery and equipment; was used. Farmcleanse®, however, was subsequently proven ineffective in destroying Foc spores, most likely due to a formulation change in recent times.

Schedule 4 - CTPI

Figure 4. Tracing activities linking 1IP with growers, farm workers, nursery operators and contractors showed a high level of connectedness across the banana industry.

Surveillance and Destruction

An extensive surveillance program was launched on commercial banana farms, residential properties and public land linked to 1IP, as identified in the tracing activities, and in response

to public reports of disease. The surveillance was performed according to specific protocols developed by BQ, and the frequency depended on the risk associated with properties surveyed. 1IP was initially surveyed monthly, with other properties surveyed at longer intervals based on risk status. In the initial phases of the response, surveillance was undertaken on 1IP, 2SP and all linked properties, by walking every fourth row. A minimum of two samples were collected for every block, even in the absence of symptomatic plants, to provide evidence of absence (Fig. 5). The collection of samples was later reduced to only sampling those plants that displayed both external and internal symptoms, with symptomatic plants being sent to Brisbane for diagnosis.

Schedule 4 - CTPI

Figure 5. Sampling performed on 1IP included both symptomatic and asymptomatic plants.

The frequency of surveillance on 1IP was increased to 2-weekly visits in December 2015, and the intensity increased to the inspection of every second row. In total, 1IP was surveyed 25 times before the plants on the farm were destroyed. Sampling from symptomatic plants was initially destructive, but the protocol was modified in November 2015 to involve the removal of a small windows of pseudostem (Fig. 6). In early 2017, a new surveillance strategy was introduced whereby the frequency of sampling on properties at risk were reduced. This was done to include once-off surveys of all commercial banana properties in Far North Queensland without any known tracing links to 1IP.

Figure 6. Internal symptoms of Fusarium wilt TR4 of plants found at 1IP detection sites 2-9.

Fusarium wilt TR4 was found at nine detection sites on 1IP (Fig. 2 and 5). Two blocks at Detection Site 1 were fenced in and plants destroyed by glyphosate injection on a 10-ha area. At Detection Site 2, the infected and 20 neighbouring plants were fenced in and killed by glyphosate; five plants at either side in the same row, as well as five plants in each adjacent row. After 5 days the plants were cut down, treated with urea, and covered by plastic sheets. Plants at Detection Sites 3-9 were destroyed according to a 10-m protocol https://www.daf.qld.gov.au/data/assets/pdf_file/0004/379138/QLD_Biosecurity_Manual_2016.pdf), treated with urea, and covered with plastic sheets. The urea was used to kill chlamydospores, based on research that showed their effect on the survival structures in banana pseudostems and the upper 15 cm of soil. Imidacloprid was also injected in rhizomes to prevent the movement of fungal spores by banana weevils. Fumigants were not used, as they were not considered safe. None of the plants killed were moved from the areas where they were found, and the destruction zones were fenced in with animal-proof fences.

Research on Fusarium wilt TR4

The introduction of Foc TR4 into Far North Queensland has rejuvenated Australia's long history of research on banana Fusarium wilt. The Queensland Government's Department of Agriculture of Fisheries (DAF), which includes BQ and AgriScience Queensland (ASQ), has worked with ABGC to develop research programs that were targeted to meet short term,

medium term and long terms industry needs to mitigate the risk of TR4, manage it and, in the longer term, live in the presence of the disease (DAF, 2017). At least two important projects were established on Fusarium wilt TR4 in Far North Queensland, including a project to fill knowledge gaps on the disease (early detection, destruction protocols, containment, application of sanitisers) and a longer-term project on management practices (resistance, soil microbiology, remote sensing). A Panama disease Growers Kit and a manual on Best Practices to Manage Panama disease Foc TR4 were also developed, and biosecurity training workshops were presented to growers and other parties who may access banana farms.

The initial isolations and provisional identification of Foc TR4 in Far North Queensland were done by ASQ in Mareeba, before the identity of Foc TR4 was confirmed in Brisbane. The Mareeba team have also helped with initial surveillance efforts and the collection of samples. The BQ Foc TR4 team in Brisbane is responsible for diagnostics, protocol development and containment efforts. Other agencies, for example The University of Queensland (UQ) and interstate agencies, are also involved in various elements of research. New molecular markers are being developed by UQ for the rapid and accurate detection of Foc TR4. Banana varieties and mutants are being tested for resistance to Foc TR4 in a field experimental site in the NT.

Site visit (local area and infested farm)

1IP is situated on the northern periphery of the banana production area in the Tully Valley (Fig. 7). At the time of the first Fusarium wilt TR4 detection, it was a premises of approximately 241 ha, with 210 ha under cultivation. The original farm had been planted with bananas for many years. In August 2009, a new section on the western border of the farm (Fig. 3) was purchased and planted with bananas in 2011, 2012 and 2014. In March 2015, Fusarium wilt TR4 was first detected in the block planted with tissue culture in 2011, followed by eight more detections that occurred randomly on 1IP (Fig. 2). In October 2016, 1IP was purchased by ABGC, who now controls access to and manages the land. All bananas were destroyed by injection with glyphosate, and the farm is being fenced-in (Fig. 8). Weeds and other natural regrowth is not being controlled to assist with soil stabilisation and to reduce the movement of soil. Machinery and appliances that were not specific to banana farming on the property were cleaned, disinfected and inspected before movement from the land to be sold in non-banana growing states in Australia. No vehicles are allowed on and off the premises, except in exceptional circumstances and only after cleaning, disinfection and inspection.

Schedule 4 - CTPI

Figure 7. Schedule 4 - CTPI

Figure 8. Schedule 4 - CTPI

Schedule 4 - CTPI

Schedule 4 - CTPI

Figure 9.

Schedule 4 - CTPI

Bananas are not grown on the land bordering 1IP to the west. Yet, there is a risk that Foc TR4-infested water and soil can be moved from 1IP onto this land along Ten Mile Creek. Water is often overflowing from the dam situated below the original Foc TR4-detection sites into Ten Mile Creek (Fig. 10). If this water is contaminated with Foc TR4, the fungus might also be introduced onto the neighbouring property. It would be impossible to detect Foc TR4 onto this property in the absence of bananas, as no reliable test is currently available to detect Foc TR4 in soil and water. It is, however, uncertain how Foc TR4 inoculum will survive in water and on land in the absence of bananas, and if the weeds and other vegetation in these sites could contribute to its survival. From these sites the fungus could potentially spread to other banana-growing areas (secondary spread).

Figure 10. During the rainy season, water flows down the slopes of the original Fusarium wilt TR4-detection site (top of picture) into a dam that overflows into Ten Mile Creek.

While it is unlikely that bananas will be grown next to Ten Mile Creek, Travelling Dairy Creek flows through a neighbouring banana farm Schedule 4 - Cl on the south-eastern border of 1IP (Fig. 11). Two factors could have safeguarded the neighbouring premises from Fusarium wilt TR4 thus far. The land between the two farms is relatively flat, and Foc TR4 has not been detected on 1IP in the vicinity of 3AR and Travelling Dairy Creek. An embankment has been constructed to prevent water from flowing off 1IP into the neighbouring farm, although flooding from 1IP into Schedule 4 - cannot be prevented during heavy rains and cyclones.

Figure 11. Fusarium wilt TR4 has not been found in a banana plantation on the south-eastern border of 1IP. Heavy rains and water flowing down Travelling Dairy Creek (background) can, however, potentially move soil from the infested property onto the Foc TR4-free farm.

Prior to the first detection, the owner of Schedule 4 - CTPI had many linkages to 1IP, including using shared farm roads and sharing machinery. The neighbouring farmer has since introduced improved biosecurity measures by reducing the number of entrances from five to two, farm zoning, wash-down facilities, restricting the movement of machinery and by controlling visitors and issuing them with boots when entering the farm (Fig. 12).

Producers in Far North Queensland have become more aware of the threat of Foc TR4 to banana production due to the activities of BQ, ABGC and DAF, which include the media, internet, noticeboards and workshops (DAF, 2017). More than 91% of farmers in the Tully-Innisfail and Mareeba area were trained in biosecurity up to March 2017. Many farms had been fenced in, zones have been demarcated, and boots are issued to all visitors. However, there is still a high percentage of farms that have implemented no or minimal measures. Some farmers still dispute the presence of Fusarium wilt TR4 in the area. Sand extraction companies and other businesses also take out sand from the Tully River. Such sand is then used for cement production, potting mix, and top dressing on lawns and headlands in banana plantations.

To minimise the risk of TR4 spread in the Tully area, a wash-down facility, owned by a telecommunications company, is used to clean vehicles used by a telecommunications company and BQ (Fig. 12). In the Innisfail, Mareeba and Lakeland areas, BQ uses the local government wash-down facilities relevant to each area. These wash-down facilities are not open to the general public or other businesses. There are car wash facilities in each town. Businesses are encouraged to use these or have their own.

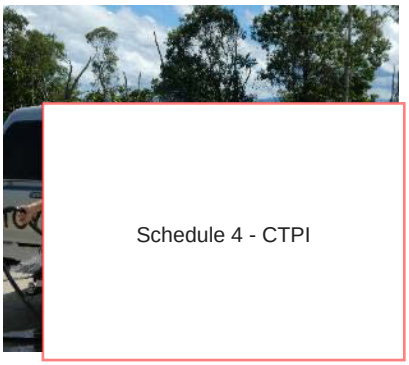

Figure 12. Biosecurity measures in Far North Queensland has been significantly improved following the detection of Fusarium wilt TR4 on a banana farm in the area.

Perceptions of the former owner

The property owner at the time of Fusarium wilt TR4 detections on 1IP has shared information on the history of the index blocks. These blocks were planted with bananas before the farm was purchased. Some plants looked unhealthy, but not with typical Fusarium wilt symptoms.

There is no suggestion that the property was sold for any reason other than a business-related decision. The original owners moved all their machinery with them to their other banana farms. The machinery was not washed properly before it was moved. In fact, it was dirty. Yet, the disease never developed on any other areas where this machinery was later used.

The bananas planted in the index blocks in 2011 were the first tissue culture plantings on the farm. Only the machinery of the new owner was used during plantings. Planting began in the area that would later develop the most severe symptoms of Fusarium wilt TR4, and then proceeded clockwise around the dam. If the original site was infested at the time of planting, then soil would have most likely been moved to the fields that were subsequently planted, including the field on the opposite side of the dam. Yet, the disease was never observed there. Symptoms of disease showed up approximately 6 months before the outbreak was identified as Fusarium wilt TR4. A single plant was destroyed by the owner, and it is believed that the cause of the symptoms was Erwinia corm rot. In February 2015, a leaf spot inspector was contacted by the owner to take a look at sick plants in the same block. Two samples were collected for analysis, of which one was positively identified as Foc TR4.

The former owners of 1IP were sceptical about the diagnosis and identification of Fusarium wilt TR4 at the farm. The pictures provided to them of the internal symptoms in the pseudostem were not always clear, which made them think that the cause was Erwinia rather than Foc TR4. They also questioned the identification process, as cultures were stored away when they visited Brisbane to see the identification process. According to the grower, no-one showed them any materials or explained the identification process, as the researchers were not there. They further wondered whether the cause of the disease could have been Foc race 1, which is widely present in northern Queensland, and which were previously shown to cause disease of Cavendish bananas in India. The former owners also asked why the soil in the infested block could not have been tested for the presence of Foc TR4. Finally, they were curious why Fusarium wilt TR4 developed so rapidly in the NT, and not on their farm. This, and the reasons for the random pattern of the outbreaks, were explained to them.

The discovery of Fusarium wilt TR4 on 1IP Schedule 4 - CTPI

Schedule 4 - CTPI

Schedule 4 - CTPI Box checking to ensure that bananas left the property clean was cumbersome and time-consuming, and later became even more intense. Continuous entrance control, and the temporary suspension of the operation made things very difficult Schedule 4 - CTPI

Schedule 4 - CTPI

Schedule 4 - CTPI They care about the local banana industry, and hope the Fusarium wilt TR4 will not be discovered on other farms. They particularly worry about the spread of the disease to the farm of a former neighbour who often used Dingo Pocket road.

Some banana growers in the Tully-Innisfail area felt that the former owners were not always compliant after the discovery of Fusarium wilt TR4 on their farm. They also believe not enough was done to contain and deal with the disease, and that the fencing-in of the property was unnecessarily slow. Water movement off 1IP is of particular concern, as flooding during heavy rains might overflow the embankment built to prevent water from flowing off 1IP. On the other hand, some farmers still doubt that Foc TR4 was ever present in the Tully Valley, and it is sometimes tough for ABGC to rectify the rumours and misinformation. Certain farmers are worried about complacency when BQ stops or reduces their activities.

ASSESSMENT OF THE BQ PROGRAMME AND ACTIVITIES

After the first detection of Fusarium wilt Foc TR4 in Far North Queensland on 3 March 2015, BQ introduced containment measures that restricted the movement of people and vehicles on 1IP and 2SP, as the two properties were linked by shared ownership and operations. A multi-facetted strategy was developed, which included tracing activities to determine pathways of disease introduction and spread, linkages to 1IP, surveillance across linked properties, responding to public reports of disease, rapid destruction of diseased plants and inoculum reduction, increasing community awareness and support, education of grower and supply chain/service providers, and scientific research.

The objective of the tracing process was to determine spread pathways on and off 1IP with planting material, by contractors, with machinery movements, and/or other activities with the potential to spread the disease. In total, almost 100 commercial banana-growing properties were connected to 1IP for the past 5 years. Contractors, agri-businesses and properties without bananas linked to 1IP were excluded from the surveillance program as Fusarium wilt TR4 cannot be detected on properties without bananas. Fusarium wilt TR4 was found only on 1IP. This properly, therefore, was bought by ABGC in November 2016, where after all banana plants were killed by glyphosate injection.

Information provided by BQ; as well as that obtained during the review process from ABGC, banana growers, industry associates and scientists; was used to assess the BQ program and activities, the potential means of introduction, distribution and future spread of Foc TR4. The review will also attempt to provide advice and guidance on issues related to the epidemiology of Fusarium wilt TR4 in Far North Queensland.

- **How long has the pathogen been present on the farm?**

  It is presumed that Foc TR4 was introduced onto 1IP at least 5-24 months before it was discovered. The reasons for this presumption are:

  - The time between the first and subsequent detections of Fusarium wilt TR4 at 1IP was longer than 5 months which indicates that, if the fungus was moved to new areas on-farm, it took the disease at least this time to develop. If the fungus was moved from the 1st detection site before symptom appearance, this time could be longer.
  - Plants with yellow leaf symptoms were observed in the index blocks in 2013 and 2014. At the time these symptoms were believed to have been caused by lightning and Erwinia corm rot, respectively. Erwinia corm rot is a bacterial disease that is common in the area. Retrospectively, one could argue that the yellow leaves observed in 2013 and 2014 were potentially caused by Fusarium wilt TR4, as external symptoms of lightning, Erwinia corm rot and banana Fusarium wilt look somewhat similar. If Foc TR4 was introduced during planting in 2011, or was present in the soil at planting, and the symptoms observed in 2013 was caused by Foc TR4, the Fusarium wilt TR4 symptoms would have taken approximately 24 months to appear. This hypothesis changes, however, if the introduction of the fungus took place after the field was planted.
  - NOTE: There are recollections that nematodes caused damage to bananas in the index blocks pre-2007. There is, however, no proof that Foc TR4 was present in these blocks.

- **Are the first blocks where disease was detected the index blocks on the farm?**

  All available circumstantial evidence suggests that the first blocks where Fusarium wilt TR4 was detected are the index blocks. The reasons are:

  - The time sequence of positive detections indicates that at least 30 plants with symptoms were observed at this site, with 12 positive confirmations, 5 months before the disease was detected at the 2nd site.
  - Only two detection sites (4th and 5th detection sites), apart from the original detection site, contained more than a single diseased plant (Fig. 2), and these were found more than 1 year after the 1st detection. The presence of more than one diseased plant at the 5th detection site could potentially be explained by the on-farm movement of machinery. When visiting this area (Block DI-5), machinery often turned sharply to the right when going back and/or returning to the machinery shed (see Fig. 13), which could have caused soil attached to machinery to be dropped-off in this area (see Fig. 8).
  - There is a possibility that symptoms observed in the index blocks in 2013 and 2014 might have been Fusarium wilt TR4. At the time, however, the yellow leaf symptoms were believed to be caused by lightning damage and Erwinia corm rot, respectively (see section on 'How long has the pathogen been present' above).

Schedule 4 - CTPI

Figure 13. Four plants with Fusarium wilt TR4 were detected at the 5th detection site, where machinery made a sharp turn to return to the shed.

- **What was the likely source of introduction?**

  The source of a soil-borne fungal disease can often be inferred from the distribution pattern and means of spread of the disease at and after its discovery. For Fusarium wilt Foc TR4 in Far North Queensland, there must have been an existing source from where Foc TR4 had been moved. For the following analysis, the assumption was made that the fungus was introduced at the first detection site because of reasons provided above. The possible sources, and their likelihood for introducing Foc TR4 onto 1IP, follow:

  - Contaminated planting material: This option was considered because of the common transmission of Foc TR4 with planting materials (Stover, 1962). Plant transmission appears to be unlikely, as tissue culture plantlets were used for the planting of the block where Fusarium wilt TR4 was first detected, and tissue culture bananas are considered Foc-free (Viljoen, 2002). If, however, such plantlets were contaminated with Foc TR4 after the *in vitro* multiplication process, one would have expected the disease to be widely spread in the block within 6-12 months, and not after 2-4 years, which was the time from planting to the first observation of yellow leaves in 2013 (see above) and confirmation of Fusarium wilt TR4 in 2015. Tissue culture plantlets are considered highly susceptible to Fusarium wilt (Smith *et al*., 1998). One would thus expected the disease to be also present on other farms planted with plantlets from the same nursery.
  - Contaminated water: This is highly unlikely, as the dam supplying irrigation water to the index blocks must then first have been contaminated with Foc TR4 from elsewhere. There are, however, no other banana farms or TR4-contaminated areas draining into it. Also, one would then expect the pathogen to have be more widely spread on the farm as a result of contaminated irrigation water.

- Contaminated vehicles and machinery: This is unlikely, as such vehicles and machinery must have been in contact with the source of Foc TR4. The tracing records show no evidence that either the owner, neighbours, visitors or contractors had been in contact with a source contaminated with Fusarium wilt TR4.
- Tissue culture company vehicles and materials: To introduce Foc TR4 onto 1IP, a tissue culture company must have been in contact, in some form, with a Foc TR4-infested property. Two tissue culture companies provided plantlets for planting at the first detection blocks at 1IP. In November 2011 and August 2012, Schedule 4 - plantlets were planted in Index Blocks 1 and 2 where Fusarium wilt TR4-affected plants were later discovered. Plantlets from Schedule 4 - were planted on a section of Index Block 1 in 2014 where the disease did not develop up to the time that this block was killed with herbicide injection in 2015. Links between the Schedule 4 - company and a Foc TR4-infested properties in the NT was established, but without evidence that Foc TR4 was moved to 1IP with trucks or on other materials from the NT, such as planting bags or delivery materials. Fusarium wilt TR4 was also not detected in the Schedule 4 - nursery. There were no cases of Fusarium wilt on any other farm in Far North Queensland planted with plantlets from this company.
- Farm workers: Most of the field workers at 1IP were long-term employees with no connections to the NT. Some backpackers were employed by the former owners of 1IP, but limited records on their earlier employment could not link them to Foc TR4-infested properties in the NT or to Foc TR4-affected Asian countries.
- Contamination of blocks before 2011: The index blocks were purchased in 2009 and planted with bananas in 2011. The history of banana production on these blocks between 2007 and 2009 is unclear. Yellow leaf symptoms of banana plants were first observed in these blocks in 2013 and again in 2014, but these were attributed to lightning, Erwinia corm rot and possibly nematodes. Such symptoms could also have been caused by low levels of Foc TR4 in soils that were left fallow for many years, if the disease was present there previously. An aerial picture of 2007 showed significant damage to the index blocks, which could be attributed to cyclone damage from Cyclone Larry in 2006 and/or nematode problems (Fig. 3). While it might be speculated that these plants could have suffered from Fusarium wilt TR4 also, other properties owned by the original owners of these blocks were not affected by Fusarium wilt TR4, despite the sharing of farm equipment and field staff on all their properties. The likelihood of disease presence prior to 2009 thus appears to be low, but the history of these blocks need to be further investigated (see Recommendations section).
- On farm training by defence force: Visits of defence force members to 1IP was irregular, and they never entered the index blocks. Surveillance of their property showed no evidence of banana pests and diseases. Their hygiene management is also very robust.

- **How widespread can we assume the pathogen to have spread on the farm?**

  The randomness of outbreaks after the discovery of Fusarium wilt TR4 at 1IP indicates that the fungus is most likely to be widespread on the farm. The probability that more detections would have been made if all bananas were not killed, and that disease incidence would have increased considerably over time, therefore, is high. Without banana plants, inoculum pressure in soils will be reduced, but the fungus will not be eradicated (Rishbeth, 1955). *Fusarium oxysporum* forms chlamydospores that survive in soils for decades (Stover, 1962). It can also persist as saprophytes in organic residues, and as endophytes in the root cortex of non-host plants, including weeds. Their multiplication in non-hosts, however, will be slow compared to their reproduction in banana plants. The survival of *F. oxysporum* chlamydospores in non-cultivated soils might be suppressed by organic matter, microbial activity and exudates released by certain plants (Stoner, 1981).

- **How is it most likely to have spread on the farm?**

  The localised pattern of spread in the index blocks is consistent with the movement of the Fusarium wilt fungus with soil attached to shoes and plantation tools. The randomness of the other detection sites on 1IP indicates that Foc TR4 had been moved there by means of soil attached to the wheels and body parts of farm vehicles and machinery (Stover, 1962). It is unlikely that on-farm spread occurred due to the movement of planting materials and irrigation water, which would have resulted in a confined area linked to the source.

- **What is the likelihood the pathogen has been spread off-farm prior to us detecting the disease and implementing containment measures (pre-2015)?**

  The possibility is good that Foc TR4 has been moved off 1IP before it was detected in March 2015 when containment measures were implemented. This belief is corroborated by the fact that the pathogen was moved from the index blocks to eight other detection sites, of which three are situated on the opposite side of Dingo Pocket Road. Machinery used in the index blocks, as well as vehicles using the road below the index blocks, could have moved Foc TR4-contaminated soil to other areas. The road below the index blocks was often drenched with water flowing from the Foc TR4-infested fields. Two important issues remain unknown, and both can have an influence on the likelihood of pathogen spread:

  1. The date of Foc TR4 introduction onto 1IP, as the risk of spread off-farm would increase the longer the fungus was present in the index blocks before discovery.
  2. The site where the fungus could have been moved to, as this could be a non-banana growing area. In such a case, the dynamics of the environment would determine the survival of the pathogen and its possible later movement to banana fields.

It is possible that Foc TR4 could have been moved off 1IP after March 2015 too, as the muddy road below the 1st detection site was not closed and the farm not fenced in immediately. This would have allowed spread not only by vehicles, but also by feral animals visiting the area. There is also the possibility that fungal spores could have, and still can spread down Ten Mile Creek with water in the dam below the index blocks (Fig. 14).

Figure 14. The index blocks above the irrigation dam were not fenced in, and the road between the infested plantation and dam not closed for some time after the discovery of Fusarium wilt TR4 at 1IP.

- **What is a likely timeframe for symptom development (latency??) as a result of disease spread off 1IP to a site with susceptible bananas prior?**

  Latency, firstly, has to be defined. In plant pathological terms, latency is the ability of a pathogenic organism to be present but dormant in a plant without causing disease symptoms. Symptom development depends on several factors, including susceptibility of the host, inoculum load, virulence of the pathogen and environmental conditions favourable to disease development. Cavendish bananas are highly susceptible to Foc TR4, particularly when grown in monoculture production systems. I thus doubt whether infections would have been delayed for long following field infections, despite laboratory findings. If latency refers to dormancy in soils prior to root infection of susceptible plants, then this could take substantially longer. Infection rate is influenced by inoculum load and the means of spread (movement with soil, water or plants), as well as the transpiration rate of plants during the rainy season (Beckman, 1987). Symptom development in infected planting materials is rapid, and can be seen within 3-6 months after field planting. However, when Foc TR4 is

spread with soil attached to shoes, vehicles or equipment, symptom development is expected to be much slower due to the lower levels and unpredictable contact with banana roots, and symptoms could become visible only after 1-3 years (Stover, 1962).

- **What is the likely surveillance timeframe to determine the lifting of a quarantine from a property where disease has not been detected (but is suspected of being spread there through shared machinery and management in absence of farm biosecurity measures), and in the presence of susceptible banana hosts?**

  Surveillance started soon after the identification of Foc TR4 in Far North Queensland. No new outbreaks of Fusarium wilt TR4 has been found on any suspect premises since. It would be wise of BQ to continue surveillance for another 1-2 years, starting June 2017, but at less frequent intervals. After that, farm biosecurity should become the responsibility of land owners who should survey their own plantations. It must also be noted that Foc TR4 inoculum could have been moved to new areas, including suspect premises, but not necessarily into Cavendish plantations. Secondary movement of such inoculum could result in disease outbreaks when later moved into plantations.

- **What is the risk that the dam on the property is an ongoing source of further spread through irrigation water?**

  If bananas were still grown on 1IP, the irrigation dam could have been a major source of contamination of bananas grown at the farm. Even though all bananas at the farm were killed, the dam remains a risk for Foc TR4 spread off-farm. The reason for this opinion is that the catchment area of the dam is below the 1st detection site, and that the water from this area drains into the dam (Fig. 14). The water then overflows down Ten Mile Creek, before joining the Tully River. There might be many arguments why the risk is not high, including poor survival of Foc TR4 in water and the absence of banana farms along Ten Mile Creek. Yet, flowing water has always known to be an important source of infection (Stover, 1962), and this dam is thus considered an important risk area.

- **Could other measures be adopted to minimise further spread off 1IP?**

  1. The lack of fencing allows feral pigs to move around on 1IP. It is not only the sites where the disease was detected that are believed to be infested with Foc TR4, so it would be best if the entire farm could be fenced in with pig-proof fencing.
  2. Flooding can contribute to the movement of infested soils (Stover, 1962) and can cause damage to banana roots (Rishbeth, 1957), and this needs to be prevented where possible. The establishment of a ground-cover that prevents erosion and soil

movement, and that can be easily managed, would provide a better option to minimise spread of Foc TR4 off 1IP (Pattison *et al*., 2014) and protect banana roots.

3. Allowing weeds to grow uncontrolled is not a solution in preventing the dissemination of Foc TR4, as this will bring new pests to the premises that might need to be managed.

- **Is it possible to detect a pattern in disease development on the property that can inform targeted surveillance and early disease detection?**

  The outbreaks at 1IP were randomly distributed, making it difficult to draw conclusions and predict future spread for targeted surveillance. The only conclusion that can be drawn from the available information is that Foc TR4 was widely disseminated on 1IP, most likely by soil attached to shoes, vehicles and machinery, and that the fungus could be present in many areas on-farm where symptoms had not yet developed in banana plants.

- **What is the level of risk that the Dam, and Travelling Dairy Creek and other drainage lines off property pose as an ongoing source of further spread off property? How can this risk be minimised?**

  Movement of overland water flows has been implicated in the spread of Foc internationally (Stover, 1962; Su *et al*., 1986). Waterways and drainage lines, therefore, pose a great risk for the dissemination of Foc, particularly during flooding. Current efforts to dig canals and build embankments to redirect water flow might work in normal climatic conditions, but would not prevent water movement during flooding and cyclones. A ground cover that prevents erosion and the movement of soil may be more effective in stopping the movement of Foc TR4 with flood waters than drainage canals and dam walls. The movement of the fungus with water down Travelling Dairy Creek, obviously, depends on the presence of Foc TR4 in the area. Once the fungus is moved down Travelling Dairy Creek and Ten Mile Creek, it is not only the irrigation water that might be contaminated, but also sand from the banks of the creeks and the Tully River that is being used for other purposes.

- **What is the level of risk downstream in the Tully River to growers pumping water out of the river, or for extractive industries such as sand dredging? How can this risk be mitigated?**

  Research efforts to determine the role of water in disseminating Foc has been largely neglected, but circumstantial evidence indicates that contaminated rivers and irrigation ponds play an important role in the epidemiology of the banana Fusarium wilt pathogen (Stover, 1962; Su *et al*, 1986). The presence and viability of Foc TR4 in the irrigation dam on 1IP is unknown, but this water source should be considered a possible source for Foc

TR4 spread. Its flowing into Ten Mile Creek might contaminate downstream properties, even though these properties are not planted with bananas. It is difficult to predict whether fungal inoculum will be moved in water as far as the Tully River, or be present in the sand used for dredging. The closest known dredging site is 14 km downstream from 1IP, with water flowing through natural vegetation. This makes the dredging sites unlikely sources of Foc TR4. Research, however, is required to develop a reliable test for the detection of Foc TR4 in water and soil (sand).

- **Based on current knowledge of the 10-m radius destruction protocol being used on 1IP, is there anything you would change about the destruction protocol that can facilitate ongoing production while minimising the risk of disease spread.**

  All bananas on 1IP were killed, so the above question does not apply to this premises any longer. For future outbreaks, however, one must consider plant destruction as a management tool, which depends on the history of the disease and the significance of an outbreak. For new outbreaks, such as on 1IP, the initial response would be to prevent any risk of spread. This means that all diseased plants, as well as a large area that is potentially contaminated with the fungus, have to be taken out of production. Subsequent outbreaks will be contained based on the number of plants affected and their distribution. The more plants affected, the smaller the radius for destruction of healthy plants will become, until it is not possible to isolate the disease any further.

- **Based on tracing formation and surveillance undertaken to date, how would you prioritise surveillance, or target any additional surveillance across the industry not currently being addressed.**

  Overall, tracing and surveillance efforts were well planned and executed, and these efforts should be acknowledged. The key question of how Foc TR4 was introduced into the Tully Valley, however, remains and should be further investigated, as will be explained below.

RECOMMENDATIONS

The BQ programme on Fusarium wilt TR4 has focussed strongly on surveillance and tracing activities, along with awareness and containment efforts. Some key issues, however, require further consideration. These include the origin and mode of Foc TR4 introduction into Far North Queensland, the upscaling of research activities; especially the rapid and accurate detection of Foc TR4 in plants, water and soil; and a strategy to respond to future detections of the fungus. I will discuss each of these briefly, and make recommendations accordingly.

Surveillance and Tracing

The extent and detail of surveillance and tracing efforts has to be lauded. The amount of effort and work that went into this activity in the state of Queensland is staggering, and I have little else to add to improve on these efforts. The technical detail of techniques used for surveillance and tracing activities were sound. Two points that I would like BQ to consider, though, are:

1. That non-banana-growing areas along the creeks flowing off 1IP appear not to have been sufficiently investigated as possible sources of future dissemination off the Foc TR4. The sand dredging industry was mostly considered as a potential risk area, but what about the movement of vehicles, humans and animals along the creeks near IP1? The creek edges, in my opinion, would pose a greater risk for Foc dissemination in the Tully area than the movement of soil during weed clearing on IP1, for instance. Water flowing off the index blocks and down Ten Mile Creek might very well be contaminated with Foc TR4; to my opinion more so than down Travelling Dairy Creek, as no Fusarium wilt TR4 detections were reported near Travelling Dairy Creek. Yet, it is difficult to quantify the amount of risk the drainage lines from 1IP pose as there are many uncertainties, with a paucity in the literature on the survival and dispersal of Foc spores in water. One way to determine if drainage lines pose a risk of disease spread is to bait for the pathogen using live banana plants. This, in itself, presents risks which would need to be considered. Alternatively, PCR tests to detect Foc in soil and water is an option. These tests are still being developed, and further research is required before the tests can be considered reliable.
2. More tracing is required to connect 1IP with Fusarium wilt TR4-affected properties in the NT. The tracing should also include farms in the NT that have replaced bananas with other crops. Foc TR4 must have been brought to Far North Queensland from somewhere, and the NT is a more likely source than Asian countries where the Fusarium wilt fungus is found. Did anyone from the NT ever visit 1IP since 2011?

Awareness and containment

Significant efforts were made to create awareness about the threat of Foc TR4 to the Australian banana industry, and training was provided to growers on farm biosecurity to protect their properties. Some growers, and even consultants, still appear to be sceptical about the presence of Foc TR4 in Far North Queensland. Schedule 4 - CTPI Schedule 4 - CTPI This, and the possible consequences following with an incursion, might lead to an unwillingness of growers to report suspect plants and/or to hide the disease by replacing bananas with other crops. In addition, the introduction of biosecurity measures is not affordable to all growers. A clear strategy, thus, has to be developed and implemented to address potential cover-up and complacency, especially when BQ activities on Fusarium wilt Foc TR4 come to an end. Such a strategy should attempt to:

1. Maintain farmer vigilance by information sessions, grower meetings, industry publications and the provision of factual information to dispel rumours and inaccuracies;
2. Provide state government and ABGC support to assist growers to introduce affordable biosecurity measures, and the recognition of such efforts by grower organisations;
3. Introduce aerial surveillance as an alternative to field surveillance to improve detection of diseases and grower irregularities;
4. Continue monitoring banana plantations along drainage lines, especially when growers pump water from these drainage lines. The growers, themselves, need to remain vigilant with regard to early detection and reporting; and
5. Provide clear guidelines on the processes that will be followed with any future detections and reintroductions of Foc TR4 into Far North Queensland.

Origin and mode of introduction

There are three likely scenarios for the introduction of Foc TR4 onto 1IP. These include:

1. The presence of Foc TR4 in the index blocks at the time of purchase in 2009,
2. The introduction of Foc TR4 at the time of planting, and
3. The movement of the fungus from a Foc TR4-affected field or country to the index blocks after its establishment.

Reasons to support or oppose each of the three scenario exist. If Foc TR4 was present in the index blocks at the time of planting (2011), after being left fallow for a long time, Fusarium wilt TR4 would have been limited to one or a few plants due to a low pathogen load in the soil. As inoculum increased the fungus would have been moved passively within the block to affect clumps of six to 20 banana plants within a relatively short time (Stover, 1962). However, one would then also expect that the machinery that were used to prepare these blocks would have

contaminated other blocks on-farm and other properties owned by the same owners. This did not happen, which makes this scenario somewhat unlikely.

The introduction of Foc TR4 at the time of planting, or shortly thereafter, at very low inoculum level would have also resulted in the same disease pattern as described above. Information on the movement of visitors, contractors and service providers at the time of planting, records of temporary employees and backpackers, and the causes of leaf symptoms observed in 2013 and 2014; reportedly caused by lightning and Erwinia corm rot, is lacking. This makes the accurate prediction of the time and cause of introduction difficult. What is certain, though, is that the fungus was present on 1IP for at least 5-12 months before it was discovered, as became evident in the sequence of subsequent detections.

It is important that each of the three scenarios for the introduction of Foc TR1 into the index blocks be further investigated. Firstly, the original owner of the index blocks needs to be interviewed, despite potential discomforts and complexities. Aerial maps should also be obtained of bananas planted on these blocks prior to landfall of Cyclone Yassi in 2006, if available. High-resolution maps of the index blocks between 2011 and 2015 need to be requested from NASA or other sources, and studied. Secondly, there should be detailed information available on how 9AR delivered their tissue culture bananas to 1IR in 2011; from the vehicles used to the names of people who made the delivery? Did the vehicles drive directly into the plantation? Were other service providers present and/or involved during planting? Did any of these people have connections with Foc TR4-contaminated properties in the NT? Finally, the identities and working history of temporary workers and backpackers employed at 1IP between 2011 and 2015 should be made available, even if this information is obtained from permanent employees of the former owners. Details of the planting and management of the index blocks should also be revealed; from field preparation, to planting, to the performance of plants in the first year of production; as such information could potentially provide vital information on the introduction of Foc TR4 onto 1IP. It might be useful to also interview the tenant who stayed in the dwelling situated between Index Blocks 1 and 2 before this house was occupied by family members of the former owner.

Upscaling of research activities

Studying and managing a disease such as Fusarium wilt TR4 is an evolving activity. One can only investigate the disease within a context of reputable information, and as new information becomes available, the investigation will change accordingly. Two vital pieces of information are still lacking; both with are essential for the management of 1IP and the protection of other commercial properties in Far North Queensland:

1. Where did the fungus come from, and how was it introduced; and
2. Where has the fungus spread to since the original introduction, and how.

These questions are difficult to answer. Foc has a life cycle that makes it unnoticeable before banana plants show Fusarium wilt symptoms. This is why a detective-like forensic approach, backed-up by sound scientific research, is needed to investigate and manage Fusarium wilt Foc TR4 in Far North Queensland.

Field research on Fusarium wilt TR4 in Far North Queensland is not allowed due to the risk of spreading the disease. Laboratory research on the detection, biology, pathogenicity and management of Foc is therefore executed in Brisbane. Laboratory research will, however, not necessarily uncover what happens in the field. Results on the survival of Foc in water and soil, the latency/asymptomatic colonisation of plants, and the treatment of contaminated materials with disinfectants and eradicators, such as urea, has to be considered in this context. The use of field sites in the NT and other Foc TR4-affected countries where Australians do research, such as the Philippines, could be of value to study the presence, survival, spread and management of Foc TR4 in banana fields. The development of molecular markers to accurately detect Foc TR4 in environmental samples (plants, water and soil) is an urgent priority, as is a strategy to collect potentially infested samples. Methods to reduce field inoculum and investigate the saprophytic survival of Foc TR4 in fields planted with non-host crops or overgrown by weeds will provide important information on the epidemiology and management of the fungus. Research on variety evaluation and crop production practices in the NT could be of immense importance for the Australian banana industry should Fusarium wilt TR4 become endemic to Far North Queensland. For such research, proper research funding will be required.

Strategy to respond to future detections

One of the greatest barrier in dealing with Foc TR4 globally is the lack of knowledge and vigilance. Australia is no exception. In Far North Queensland, ABGC; in collaboration with ASQ and BQ; has invested significant time and resources to inform growers and industry about the threat of Foc TR4 to the Australian banana industry. Still, many growers consider reports on the occurrence of Foc TR4 in the Tully-Innisfail area as unsubstantiated. Of those growers that recognise the threat, some cannot afford the costs to introduce proper biosecurity measures on their farms. The best way to protect banana growers against the pathogen, thus, was to fence 1IP in, kill all the banana plants, and control all access to the property. Despite these actions there are still opportunities for the dissemination of Foc TR4 off 1IP. These include the two creeks on the farm, of which Travelling Dairy Creek flows through a neighbouring banana farm. Travelling Dairy Creek has no buffering capacity, is shallow and

can flood its banks. The dam that buffers Ten Mile Creek will not be used for irrigation any further, and can thus much easier overflows its banks.

The next 12-24 months would be very important to ensure that no spread of Foc TR4 has occurred off 1IP. Surveillance, therefore, will need to continue for at least another 12 months, although the frequency of such surveillance can be reduced as proposed by BQ. This means that high-risk properties will be surveyed 4-monthly, medium-risk properties 6-monthly, and low-risk properties annually. If molecular markers become available for the detection of Foc TR4 in environmental samples, then these need to be used to also do targeted surveillance of banana-free areas and water. Methods to reduce inoculum levels in soil need to be investigated and used at 1IP. One of these would be to use ground covers on 1IP that promote soil biodiversity, thereby suppressing Foc TR4 inoculum, while simultaneously reducing soil erosion and the movement of contaminated soil on and off the property. The weeds on 1IP will have to be managed, even if aerial sprays is required, as their uncontrolled growth could lead to new problems such as the introduction of weed pests and vertebrates that might move the soil.

The effective containment of Foc TR4 on 1IP is of importance to the entire banana industry in Far North Queensland. It does, however, also cause some growers to believe that reports of Foc TR4 in the region was a scam. It is thus important to continue awareness raising and the implement of on-farm biosecurity measures. At an estimated cost of Aus$ 3000-8000/ha, it would be difficult for all growers to introduce biosecurity measures, and support will be needed to help these farmers to protect their properties using affordable biosecurity measures. As the prospect of Foc TR4 spread and/or re-introduction is likely, attempts to hide the disease and/or complacency should be prevented at all cost. To achieve this, clear protocols will need to be developed and explained to growers, as dealing with a second Foc TR4-contaminated property in Far North Queensland will be very different from dealing with the first case. Processes to act on future outbreaks should not be delayed by micromanagement.

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