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Seeing Green

Plants, Pests, Pathogens, People and Pharmaceuticalisation in Thai Mandarin Orchards

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Abstract

Medical professionals' and policymakers' fear of antimicrobial resistance (AMR) has largely been directed toward antibiotic use in medicine and animal agriculture. In Thailand, however, the use of antibiotics in citrus orchards has raised some concern over their 'appropriateness' and there have been calls for reduction—if not complete cessation—of their usage. We explore the emergence of antibiotic use for citrus greening disease (CGD) as part of shifting assemblages of plants, pests, pathogens, and people, as well as of varying climates, technologies, and farming practices. We suggest that rather than being a threat coming from outside orchards, CGD pathogenicity repeatedly emerges from within, and in Thailand appears to have increased alongside, the intensification of agricultural practices. We document how, when antibiotics emerged in the mid-20th century, their 'pharmaceutical efficacy' was insufficient to trigger their widespread adoption. Rather, the pharmaceuticalisation of orchards continues to be entangled with the expansion and intensification of mandarin agriculture, and also with the affordability of antibiotics, dissemination of relevant knowledge, and availability of equipment for their injection. Current proposals to reduce antibiotic use risk not taking sufficiently seriously the importance of their role in sustaining intensive orchard practices—and profits.

Keywords

Anthropocentrism, Huanglongbing, Injections, Antibiotic resistance, Residues.

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Introduction

On 31 January 2018, Thailand convened its first National Forum on antimicrobial resistance (AMR) in Bangkok. The forum, titled ‘Making the World a Safer Place: The Threats of Emerging Infectious Disease’, was part of the international Princess Mahidol Award Conference. Packed into a large conference room, participants listened to various presentations on AMR. One study attracting participants’ attention examined pharmaceutical pollutants in various water sources. Data from water sampling revealed the contamination of rivers, underground water, and tap water by sewage from animal farms and hospitals. Those pollutants included not only antibiotics, but also caffeine and various painkillers. In concluding her talk, the researcher from the Ministry of Natural Resources and Environment said, ‘Now we know why when we felt ill, like when we got a cold, and then went to see the doctors, we were often told to drink lots of water. It is because the necessary medications are in the water: antibiotics, painkillers and all’.

The audience responded with peals of nervous laughter. The notion that pharmaceutically contaminated water might be medicinal seemed to trouble most of us in the room. Later in 2018, during one of our field visits to a citrus orchard near Chiang Mai, in northern Thailand, its owner, Arun, told us jokingly:

> If you have a cold, just eat some more mandarins and you will recover. Not because they contain Vitamin C, but because they also have ampicillin … I even give oranges[1] to our workers when they have a sore throat. The antibiotics we use in our farm are human medicine after all.

We were already familiar with the use of antibiotics in mandarin orchards in Thailand since, a few years earlier, we had been startled to first see a series of videos of them being ‘injected’ into tree trunks (Kon Hak Kok 2016). The images of workers using electric drills to pierce dozens of holes into mandarin tree trunks and then ‘inject’ antibiotic solution into the punctured trees using medical syringes shocked us. Our unease at seeing the ‘injection’ of antibiotics into citrus tree trunks, and hearing jokes about medicated mandarins, reminded us of what Mary Douglas referred to as ‘matter out of place’ (Douglas [1966] 1984). We had come to associate antibiotics and injections as medicines for particular bodies (Cunningham 1970): humans and animals. ‘Injecting’ antibiotics into tree trunks seemed to trespass the boundaries of our presumed ‘natural’ categories. Admittedly, our reading and fieldwork on antibiotics at the time had not taken us into plant science and agricultural literature. However, as we inquired further, we found that antibiotic use in plants went back almost as long as its use in humans

1 We refer to citrus fruits that are orange in colour as ‘oranges’ and differentiate particular varieties by using their specific names, e.g., ‘sweet orange’.

and livestock. In 1944, the crude culture filtrate of *Penicillium notatum* was found to be effective against crown gall (Brown and Boyle 1944); later, in the 1950s, when bacterial infection caused severe damage to the worldwide fruit industry (particularly apples and pears), approximately 40 antibiotics were promptly authorised for use as plant disease remedies. By 1955, streptomycin had been registered for commercial use in the United States (McManus et al. 2002). And over the past 50 years antibiotic use in crops has continued to expand: a recent study of antibiotic use in crops in 32 low- and middle-income countries, collected from an international database, showed that their use was recommended for over 100 crops by local agricultural advisors, mostly employed by ministries of agriculture (Taylor and Reeder 2020).

As citrus fruit has grown to become the second largest global fruit commodity after apples, it has also been reported that the industry faces increasing threat from citrus greening disease (CGD) (Hu, Jiang, and Wang 2018). CGD is a bacterial infection, known as Huanglongbing, which has now been detected in more than 50 countries (CABI 2021). Although attempts to treat CGD with antibiotics started in the 1970s, widespread use did not emerge until the 2000s and only started to attract critical policy attention in the late 2010s. This followed over three decades of attempts by the World Health Organization (WHO) and others to encourage greater scrutiny—often in alarmist and condemnatory manners—of the use of antibiotics in medical and veterinary practices, with the aim of ‘safeguarding’ them for human health (Kirchhelle 2020; McManus et al. 2002). In 2016, this culminated in a tripartite agreement between the WHO, the Food and Agriculture Organization (FAO), and the World Organisation on Animal Health (OIE). This agreement made the ‘One Health (OH) approach’ an intrinsic part of the organisations’ joint AMR Global Action Plan—and, consequently, of any subsequent National Action Plan (WHO 2015; WHO, FAO, and OIE 2016). Analysis of international health documents by Kamenshchikova et al. (2019) highlights that they designate humans ‘as those who experience the burden of AMR’, and animals and environments as potential reservoirs of zoonosis and AMR genes, which threaten future human health (7). These policy documents address most explicitly antibiotic use in animal agriculture. Plants are largely absent and, when they are referenced (e.g., in FAO 2021), this is typically in passing sentences, or lumped together as part of ‘the environment’, with the same condemnatory approach as is taken to antibiotic use in livestock production. This judgement about antibiotic use in plants emerges from and serves as a rationalisation for OH approaches to expand security concerns within global health, resulting in a greater range ‘of subjects and populations it enacts, protects, disciplines, and controls’ (Ticktin 2019).

While current estimates of antibiotic use in plants are quantitatively modest relative to human and animal use (McManus et al. 2002), antibiotic ‘injections’ into

mandarin trees in Thailand have come to light and the practice has awoken unease not only in us but also among Thai policymakers, especially given that Thailand was an early adopter of the OH approach as intrinsic to its AMR National Action Plan (Sumpradit et al. 2017; Tangcharoensathien et al. 2017). This concern about antibiotic use in orchards tends to emphasise it as unnecessary and as a potential contributor to resistant human pathogens, food residues, and environmental contaminants (Taylor and Reeder 2020; Chanvatik et al. 2019). This became particularly evident in Thailand's Antibiotic Awareness Week campaign in 2018, which used images and stories of mandarin trunk 'injections' as examples of alarming, 'inappropriate' use of antibiotics and of the need for a reduction in their use—generally, but also specifically in orchards.[2] This framing of antibiotic injection in orchards as 'inappropriate' (i.e., as 'matter out of place') appeared to us insensitive to how farmers, their plants, and the continued successful productivity of their mandarin orchards is inseparable from the emergence of CGD and the necessary adaptation of antibiotic treatment practices for infected trees. Such calls for awareness raising and related policies reflect medical rationales for how and where antibiotics should be used—what, elsewhere, anthropologists have critically described as medicalisation (e.g., Abraham 2010, 604; Chuengsatiansup, Sringernyuang, and Paonil 2000) or what Hinchliffe describes as a 'one world-ist metaphysics' (2015; see also Green 2012)—which risk reducing the presence of antibiotics in mandarin orchards to the reasoning and imperatives of medicine. In other words, these medical rationales do not adequately engage with who and what has come to depend on antibiotic practices in orchards, or with the feasibility and potential consequences of their reduction or complete absence for mandarin farmers, their plants, and the continuation of large-scale, intensive production for consumers.

Our article attempts to engage with these challenges and solutions. We build on the work of anthropologists and other scholars who have carefully attended to how antibiotics are entangled with different practices including (but also importantly beyond) medical encounters between patients and healthcare providers. This work includes the analysis of how antibiotics have (via pharmaceuticalisation) come to serve as 'quick fixes' for care, hygiene, and human productivity (Biehl 2007; Chandler, Hutchinson, and Hutchison 2016; Denyer Willis and Chandler 2019), as well as similar challenges faced in animal agriculture and aquaculture (Hinchliffe, Butcher, and Rahman 2018; Fortané 2019). Anthropologists have also described how antibiotics have become essential infrastructure for not only medical, public, and global health practices (Chandler 2019), but also various forms of animal agriculture (Kirchhelle 2020).

2 This can be seen in coverage of this event by Thai press, e.g., Thai Post (2018); ThaiPBS (2018); The Nation Thailand (2018).

Our article extends the conceptual and empirical developments of these articles to mandarin orchards. We also take inspiration from material-semiotic approaches to pharmaceuticals (Hardon and Sanabria 2017), as well as from other explorations of AMR and antibiotic use in the contexts of agriculture (Hughes, Roe, and Hocknell 2021); pathogenicity (Hinchliffe et al. 2016); and plant growth and productivity, that emphasise these phenomena as emergent, assemblages of more-than-human relations that are 'rich with history, economy, cultural practice, and aesthetic values' (Reisman 2021, 404). Thus, we explore CGD pathogenicity, orchard productivity, and pharmaceutical effectiveness of antibiotics as phenomena whose expressions and potential identification are bound up with human practices, while not being wholly reducible to them. In other words, our research has sought to decentre farmers, plant scientists, and orchard workers (humans) as the protagonists and instead attend to the ways they are always already entangled in shifting assemblages of plants, bacteria, climates, soils, and availability of particular technologies—that is, among groupings of humans and non-humans. This approach has allowed us to historically and anthropologically situate antibiotic 'injections' into mandarin tree trunks as phenomena that emerged to militate against CGD in Thailand and to challenge the *a priori* synchronic judgements of such practices as inappropriate or out of place.

To do so, we have explored historical materials on plant antimicrobial use, tracing the development of mandarin orchards and CGD in Thailand. We have visited many orchards in different provinces (including Chiang Mai, Phrae, Pathumthani, and Sukhothai) and interviewed fifteen growers, who owned mandarin orchards farmed using either chemical or organic techniques—and have often owned orchards in more than one province over the course of their lives. To better understand mandarin trees and their entanglement with labourers, farming practices, soils, climate, antibiotics, and other chemicals, we also observed and examined orange trees, attempting to attune ourselves to the development of CGD and its treatment. Additionally, we interviewed plant pathologists working at government departments and universities. Finally, to understand the role of markets, we interviewed wholesalers in local areas and a wholesale market in Bangkok.

Our article is divided into three parts. In the first, we trace the initial emergence of CGD and its pathogenicity as it is entangled with agricultural practices and pests. We also explore some of the early instances of experimentation with pharmaceuticalisation of orchards in the form of antibiotic injections. The second part of the article describes how certain intensive approaches to agriculture have been central to the success of mandarin orchards, as well as to the emergence and spread of CGD in and across Thailand. In describing this, we reveal the assemblages that underpin farmers and plant pathologists' rationalisation of

antibiotics as a prerequisite for the survival of their orchards. The third part of the article explores how the realisation of antibiotic effectiveness in mandarin orchards was contingent not just on their pharmaceutical properties but also on an assemblage of knowledge, the availability and affordability of requisite technologies, and the technical possibilities orchard growers were able to derive from tinkering with such technologies. Our final section concludes with reflections on current proposals to reduce or completely stop antibiotic use, viewing these as akin to attempts to medicalise mandarin agriculture—that is, reducing questions of antibiotic use in orchards to human medical concerns. Such proposals risk a failure to take sufficiently seriously the importance of antibiotics currently to sustaining orchard productivity and profitability. This situation has arisen in part because the proposals to reduce or eliminate this use of antibiotics fail to sufficiently acknowledge how their emergence and feasibility as pharmaceutical solutions to CGD are entangled with the shifting assemblages of intensive agriculture and interspecies relations—which have come to drive and are mobilised to rationalise the adoption of such solutions in the first place.

Seeing green for the first time

In the 1960s, when mandarin trees' leaves grew yellow and their young fruits started to drop en masse in northern Thai provinces, farmers suspected their orchards were suffering from a plant disease that was already familiar to them: *bai kaew* (mottled leaves). Farmers' suspicions were initially confirmed by visits from Department for Agriculture (DOA) staff, who presumed the symptoms were indicative of nutritional deficiencies associated with *bai kaew* (Prommintara 2005). Farmers' attempts to rid their orchards of *bai kaew* met with limited success, however, and it was not until 1971, when the DOA began to collaborate with Ralph Eduard Schwarz (a German plant pathologist working for the FAO), that nutritional deficiencies were ruled out as the cause of the drop in mandarin yields.

Schwarz had been working on diseases in citrus trees in South Africa since the early 1960s and had recently begun to focus on a novel disease which had symptoms similar to those of *bai kaew*. In South Africa, the disease had initially been identified in the 1930s and was believed to be due to mineral toxicity; it was named 'citrus greening disease', after mandarins failed to ripen. In 1967 it was identified as being transmissible via grafting and attributed to a virus; a similar discovery had been made a decade earlier by Kung Hsiang Lin in China, where the disease became known as Huanglongbing, becoming its official name in 1995 (Bové 2006). This means of transmission was highly problematic for farmers, since grafting, an ancient practice of joining 'scion' or budwood to rootstock of citrus trees, was (and continues to be) one of the most common methods of propagating citrus trees. By using different cultivated varieties (or cultivars) for rootstock and

scion, a number of desirable characteristics can be incorporated into a single tree. As scions are supported by rootstock, selection of citrus cultivars for rootstock is crucial. Some are more tolerant than others of climatic stresses, soil conditions, pests, and diseases. While rootstocks account for the trees' vigour, scions or budwoods are critical for fruiting characteristics. Thus, while this mode of asexual propagation was the source of many varieties of mandarin, it also became recognised as facilitating the spread of a deadly citrus disease. Further investigation by Schwarz (1968), Bové (2014) and various other plant pathologists in East Asia in the early 1970s using electron microscopes initially mistakenly identified the pathogenic agent as a mycoplasma, a bacterium without a cell wall (ibid.). It was not until 1984 that this was corrected, confirming the presence of a cell wall and classifying it as a Gram negative bacterium. Further investigation established two different species of the *Candidatus* Liberibacter bacterium in Asian (known as *Ca.* L. asiaticus or CLas) and African contexts. Since the 2000s, other species known to affect trees in the Americas have been identified (Williams, Bleau, and Orosa 2020).

Around the same time, plant pathologists in South Africa, India, and the Philippines also identified Asian and African species of citrus psyllids as a vector for CGD. Psyllids are plant-feeding hemipteran (commonly known as 'true bugs'), considered to be one of the most primitive insects. When psyllids feed off the sap from infected citrus trees, they become infected themselves. CGD-infected psyllids have been found to have higher fertility than those not infected, leading to a higher overall reproductive output. In laboratories, psyllids infected with CLas grow faster, produce more offspring, and tend to forage more often than those uninfected (Killiny et al. 2017). Psyllids ingest CLas into their bodies when they feed on infected plants. CLas then multiply in their digestive system and when infected psyllid fly to a healthy plant, they transmit CLas as they feed.

The discoveries of the bacterial cause and mode of transmission of greening disease led to experiments with antibiotics in various countries in attempts to treat and eliminate it, including spraying and dipping citrus grafts and buds in solutions of the antibiotic oxytetracycline-HC1 (e.g., Martinez, Nora, and Armedilla 1970; Su and Chang 1976). Schwarz and his colleagues experimented by injecting citrus tree trunks with the antibiotic tetracycline hydrochloride (Schwarz and Van Vuuren 1971) and this was noted to produce the best results: a single injection was reported to significantly reduce the percentage of diseased fruits, with effects observable several years later (Da Graca 1991).

Schwarz's arrival in Thailand in 1971 was too late for orchards like Kamnan Chul's, one of the country's major mandarin producers, located in the central-north province of Phetchabun, whose orchards collapsed following the loss of 30,000

trees. As part of his visit between 1971 and 1973, Schwarz assisted with a survey of CGD in 10 Thai provinces. The survey identified greening disease and psyllids in almost all trees in orchards in the provinces of Nan, Phetchabun, and Chanthaburi (the largest producer at the time of the survey), as well as Fang district in Chiang Mai province. CGD and psyllids were found to be relatively low in other farms in Chiang Mai province, and next to no psyllids or CGD were found in orchards in the vicinity of Bang Mod (in Bangkok province in central Thailand), or in the south of the country. The FAO collaboration with the Thai Department of Agriculture concluded that: 'The scattered distribution of citrus together with the apparent inability of psylla to disseminate widely appear to be the main reasons why greening has not become pandemic in Thailand' (Schwarz, Knorr, and Prommintara 1973, 137). The report went on to recommend further investigation of psyllid distribution, natural barriers (such as separating orchards by rubber plantations), exclusionary quarantine areas, and tolerant varieties of mandarin (Ibid.).

At the time, antibiotics were not recommended as a solution for CGD, largely due to their cost and the technical difficulties of administering them. Thus, while antibiotics emerged as a possible solution to CGD in the scientific literature of the 1970s, their adoption in countries like Thailand was intimately entangled with an assemblage of practices and entities that shaped their uptake and 'pharmaceutical effectiveness', some of which we will go on to explore in this article. Furthermore, as we describe in the following sections, the potential presence of CLas bacteria in mandarin trees, and knowledge of it as the pathogenic agent causing CGD, as well as its role in the devastation of their orchards, were never self-evident to farmers or plant pathologists; rather, they emerged and became visible through these shifting assemblages.

Intensification, CGD pathogenicity and endemicity

Bang Mod's blemished mandarins

Around the late 1960s, when Kamnan Chul's orchard was struggling, many farmers in Bang Mod (an area in Bangkok province in central Thailand) were not only shifting away from cultivating rice and coconuts to cultivating mandarins, due to drops in yields of the former and the higher profits of the latter relative to the costs of production, but also expanding their existing mandarin orchard productions. Bang Mod's variety of mandarins, s*om-kaew-wan* (literally 'green sweet orange'), was already one of the most prized in Thailand. The relatively hot climate in the central region was said to contribute to the fruit's partly greenish peel. But Bang Mod's mandarins had another unique characteristic: their peel had brown blemishes, which was taken as a symbol of their quality and desirable taste. Located at the Chao Phraya River delta, adjacent to Bangkok, growers believed

that the brackish water that enriched the alluvial soils partly contributed to the unique sweetish taste of their mandarins. However, this was not all. Wat, one of the mandarin growers we interviewed, now 63, recalled his family's eight rai (12,800 m^2) orchard in Bang Mod and their shift in 1976 from growing coconuts to more profitable mandarins. They, like other farmers in the area, planted their mandarin rootstocks in raised bed gardens to avoid flooding during the monsoon rains. Once the rootstocks were a year old, they would get budwoods from a plant nursery in Bangkok-Noi district and graft them to their rootstocks. Wat said that at that time they used few pesticides and other chemicals, as Bang Mod had neither severe diseases nor pests, 'not even common fruit flies'. Farmers did spray their orchards with insecticides to kill off rust mites (*Phyllocoptruta oleivora*) which would infest and feed on the peel of their fruit. Wat and other farmers learnt many or most of their growing techniques from their antecedents and friends, rather than from government officials or chemical companies. Such techniques included temporarily stopping spraying insecticides for roughly 50 days after their trees flowered, which they had found allowed the rust mites to feed on the peel of their mandarins and led them to develop their characteristic brown blemish, as well as contributing to their sweet tangy taste.

Within a decade, increased incomes derived from their mandarin production enabled many farmers, including Wat, to expand their orchards (Dangbupha 1993). In 1974, just prior to Wat's shift to mandarins, the estimated coverage in Bang Mod reached a peak of 30,000 rai (48 km^2) (Kanjanakaroon 2008). Despite this expansion, most mandarin orchards were around just 5–10 rai (8,000–16,000 m^2). The scale of mandarin production per orchard was relatively small compared to Kamnan Chul's orchard in Phetchabun province (which was still the largest orchard at the time) since farmers generally still grew other fruits such as mulberry and grapes alongside mandarins. However, after nearly two decades of booming mandarin production, the end of the thriving Bang Mod mandarin orchards was precipitated through a series of climatic and environmental disasters. In 1982, 30% of trees were lost due to flooding, and drought in 1986 contributed to twig dieback. The greatest damage to Bang Mod's mandarin orchards, however, occurred in 1992, following a combination of droughts and seawater intrusion, plus water and soil contamination caused by effluents from nearby factories. Finally, an expansion of the manufacturing industry in the area and a consequent surge in land prices led many farmers to seek affordable and fertile lands elsewhere to expand their mandarin production beyond Bang Mod, with some completely abandoning their existing lands (Dangbupha 1993). Just as the success and growth of Bang Mod's orchards was entangled with their proximity to the Chao Phraya river delta and Bangkok, so too was its collapse, precipitated by the hot climate, alluvial soils, raised-planting beds, and rust mites.

The rise and decline of Rangsit's orchards

Fifty-four-year-old Ake, who at a peak owned 100 rai (160,000 m^2) of mandarin orchards, comprising about 4,000 trees, recalled nostalgically:

> Every morning after I calculated what we needed for the day, I would take pesticides, insecticides, or equipment to the land and then go pick up my workers and leave them to work. At three in the afternoon, I would then take them home. I rarely worked in the orchard myself, except when we ran out of workers.

Like some other growers in Bang Mod around 1976, Ake had expanded his family orchard productions into the Rangsit canal area in Pathumthani province, taking advantage of the affordable land, most of which was dedicated to rice farming, and where only a few other mandarin orchards were in operation. Following the devastation of the floods in 1975, 1978 and 1982, many cultivators attempted to restore and expand their orchards. In 1982, Wat's family expanded their orchards of 8 rai (12,800 m^2) in Bang Mod to 90 rai (0.14 km^2) in Rangsit—eventually, after eight years, reaching a total of 210 rai (0.36 km^2) in the latter. Ake and Wat, like other growers, brought with them their grafts and stems from the same Bangkok-Noi source, trying to replicate the former successes of Bang Mod. Although the resulting mandarins lacked Bang Mod's unique rustic characteristics, the total area of orchards in the Rangsit district reached 200,000–250,000 rai (320–400 km^2): almost 10 times that of Bang Mod's extension at its peak in the 1970s (Paradornuwat 2003). Farmers also sought ways of further intensifying their mandarin production by planting trees closer together and increasing spending on and routine use of fertilisers—as well as pesticides, fungicides, and other chemical products designed to minimise loss of yields to pests such as thrips, rust mites, and citrus leafminers. By the late 1980s, Rangsit was the nation's major producer, growing 80% of all mandarins consumed in the country (Soontravanich 1997). Ake recalled: 'If you owned 100 rai (1600 m^2) of oranges, when you went to Talad Thai market [the nearby wholesale market], you wouldn't pay a thing. The wholesalers would treat you to everything you wanted, because they wanted your fruit'. Wat said he similarly experienced a fourfold increase in his family's average annual income during this time.

But in 1989, as many young trees were blooming in Wat's orchards, typhoon Era (also known as Gay and Kavali) hit Thailand, flooding Bangkok and nearby provinces. Rangsit was particularly badly affected. According to Wat, 'The trees were extremely fruitful that year. We were just about to harvest when Era hit this area. The flood destroyed most of our trees'. Ake's family orchards were also devastated. The Ministry of Agriculture and Cooperation responded, issuing an order to the Department of Agriculture Extension (DOAE) to help the growers

replant and expand their plantation (Office of Agricultural Economics 1996); this assistance was later part of the DOAE's effort to materialise the government's Eighth National Economic and Social Development Plan (1997–2001). The Plan designated 33 provinces for expanded citrus production and introduced a Guideline for Mandarin Development that aimed for annual increase in yields by 10,000 rai (16 km^2) per year so as to meet increased demand. According to Santi, a former DOA researcher who had been assisting the growers at the time, to do so adequate graft stems had to be procured and distributed to the farmers for replanting. Farmers had customarily acquired graft stems from plant nurseries around Bangkok-Noi district, but the nurseries were unable to keep up with Rangsit growers' urgent demand. The DOAE also attempted to assist farmers through acquiring grafts from northern provinces, such as Phetchabun, Chiang Mai, and Naan, many of which came untested for diseases and pests.

A few years later, in 1995, growers were shocked when they began to see their seemingly healthy young mandarins consistently fall from their trees (Kaje 2013). Wat recounted: 'The provincial agriculture officers came to visit us and tried to sell us pesticides and other chemicals. But they didn't tell us what the problem was'. Farmers, including Wat, tried various chemical and natural pesticides, but noted they had little noticeable improvements on the health of their trees. Fifty-eight-year-old Thida, who owned 50 rai (0.08 km^2) of mandarin orchards, said she had even experimented with fermenting tilapias (a freshwater fish that is farmed in Thailand) in huge water jars mixed with galangal, lemongrass, and other spices. She said, 'The smell was really bad, and it was very expensive; 10,000 baht per jar [over 220 GBP]. We sprayed it on the trees with the hope that fruit would not fall off. It didn't work'. Without effective solutions and no clear explanations for the rapid decline of their orchards' productivity, some farmers began to suspect that a gas power plant nearby, which had started operation in 1998, was to blame. They speculated that hazardous pollutants had caused their fruit to fall from the trees. A year later, some of the farmers mounted protests and 762 growers attempted to sue official authorities responsible for ensuring the power plant adhered to environmental standards. Ake also joined in the demonstration. He had invested in expanding his farms by taking a loan from the bank, and ultimately ran into millions of baht of debt when his own mandarins fell prematurely.

In an effort to address the growers' complaints, the power plant provided the DOA with financial support to investigate the problem. With the collaboration of Kasetsart University, the DOA conducted an experiment by growing mandarins in close proximity to the plant. Some were grown in the open air and others under mosquito nets. The experiment lasted two-and-a-half years. The trees that grew under the net were healthy, while those growing uncovered were found to have approximately 30 Asian citrus psyllids on each tree, together with symptoms of

what they identified as CGD. The central administrative court ruled that the defendants had not overlooked their responsibilities and that it could not be scientifically proven that the power plant had caused the fruit to fall.

According to DOA researcher Santi, it was clear to him from the beginning that the source of devastation to the Rangsit orchards was not the power plant, and that the decline in orchard production went further back:

> A few years ago [following typhoon Era], a number of farmers brought infected mandarin trees and planted them in their orchards. From these infected mandarins, they produced grafting stems which were also infected. These infected stems were supplied to the government and the government distributed them to Rangsit farmers. That was when it all began.

The grafts that the farmers and the DOA had acquired from northern provinces to replant their orchards following typhoon Era had arrived, unbeknown to any of them at the time, infected with CGD. Santi also noted that farmers in Rangsit had stopped spraying their orchards with pesticides twice a week as they did not believe DOA's advice. Instead, they started to try other methods, one of which was applying effective microorganisms (EM), which some of them believed would also kill insects. According to Santi, EM is an organic fermented fertiliser and not a pesticide, and so the farmers' shift in spraying practices may also have led inadvertently to increases in psyllid and the spread of CGD.

Along with making attempts to directly redress the devastation that occurred for farmers like Wat, Thida, and Ake in the wake of Typhoon Era, Santi and other members of the DOA, together with various international agricultural consults from the FAO (Schwarz, Knorr, and Prommintara 1973), and Thai-German Technical Cooperation Program (Oudejans 1999; GIZ 2016) had been conducting extensive field surveys of orchards across Thailand since the late 1980s. Amongst the conclusions were the stark observations of Roistacher (1996), who was responsible for reporting on the economics of living with citrus greening disease:

> In my lifetime of involvement with citrus virus and virus-like diseases, never have I witnessed such severe destruction of citrus as seen in this consultancy visit through Thailand. This destruction of citrus by the greening disease has been ongoing in Thailand for over 30 years and has been well documented by others*. I believe there is a tendency to accept and accommodate the disease and to live with it* (our emphasis, Roistacher 1996, 279).

The field survey reported that Thailand had a national average production of 12.5 tonnes of mandarin per hectare, significantly lower than the 50–90 tonnes of other countries in 1994 (ibid.). This was attributed in large part to the wide presence of

CGD in Thai orchards, which led to rapid declines in the productivity and profitability of trees after 5–8 years. This early loss was dramatic—occurring very considerably earlier than the 100-plus year productive lifespan of some recorded mandarin plants, and earlier than the 12 years that Roistacher (1996) cites as the minimum to ensure profitable returns for growers in the long term. Thailand's Department of Agriculture Extension (DOAE) and foreign consultants also noted that Thailand was 'the only large mandarin producing country in the world using marcotting[3] to propagate mandarin trees. The present technique for all practical purposes guarantees production of nursery trees already infected with greening' (Ibid., 279). Tree nurseries were implicated in the spread of CLas-infected grafts and thus also in creating and maintaining its endemicity. The field survey also noted insufficient disease monitoring, awareness, and control measures to address its psyllid vector. Much of the survey's recommendations echoed what the DOA and Schwarz had recommended nearly three decades earlier (Schwarz, Knorr, and Prommintra 1973), but which subsequent orchard growers had not followed; nor had relevant government agencies established sufficient regulations, guidelines, or subsidies for mandarin production.

The report on the power plant ruling and the findings from the Thai–German Technical Cooperation Program came too late for Rangsit's farmers to save their orchards. The pathogenicity of CGD for the Rangsit mandarin orchards arose from the interplay of biotic and abiotic processes, many initially unknown to farmers at the time. Densely planted orchards devastated by a tropical storm, mandarin growers' desires to quickly restore their orchards, and government relief assistance which unknowingly distributed infected grafts from other orchards, provinces and plant nurseries, constituted an assemblage that was favourable for a CGD outbreak in Rangsit's mandarin orchards and, more generally, the conditions of its endemicity in Thailand. Those who could still afford to sought out new land for their orchards in other provinces, including Kampaeng Phet, Prachinburi, Pichit, Lopburi, Nakornsawan, Chiang Mai, Phrae, Nan, and Sukhothai.

Intensified farming and citrus greening endemicity in Chiang Mai and Kampaeng Phet

Before his family went bankrupt, Ake converted their orchard into a shrimp farm and in 2001 he bought 40 rai (64,000 m^2) of land for his orchards in Kampaeng Phet province in northern Thailand, which had formerly been used to cultivate rice. Wat also moved his mandarin production from Rangsit to Kampaeng Phet around a year later, buying 30 rai (48,000 m^2) of land. Like other farmers, they both brought

3 Marcotting, also known as air layering, is a means of cloning woody plants, like mandarins, that may not easily create roots from cuttings. A small cut is made into a stem, which is then wrapped in humid growing medium until strong roots sprout from the stem, at which point the stem is cut below the roots and planted in the soil or potted.

with them scions (shoot s or twigs intended to be used to form a graft) from Rangsit and attempted to boost their yields to make up for their losses. They doubled the number of trees in their orchards with two-row planting, and reduced spacing between rows from 3.5 metres (as in Bang Mod) to 2.5 metres. Furthermore, all the growers we talked to had been employing a mandarin blooming method that induced their trees to fruit twice or even three times a year; the fruit preferably harvested once during Chinese New Year (usually around February) and a second time at the Chinese Ghost festival (typically mid- or late August). These practices increased their harvest yields, although perhaps not as much as some of them had hoped. Orchard growers in other provinces also followed similar intensive growing practices. According to the Office of Agricultural Economics, mandarin orchards reached a record total area of 479,322 rai (766 km^2) in 2005, with the largest-producing province, Chiang Mai, contributing 16% of the total yield (Office of Agricultural Economics 2013). However, unbeknown to farmers we talked to, they were also creating the conditions for intensified CLas pathogenicity.

Citrus psyllids can fly and have been found to travel up to 2 km in 12 days by means of successive short flights—and can be carried even further by winds (Williams, Bleau, and Orosa 2020). Their foraging is stimulated by volatile olfactory signals as well as visual stimuli emitted by their favoured host plants (Wenninger et al. 2009). Growers who planted their trees closer together were unwittingly facilitating the ability of infected citrus psyllids to differentiate their preferred host trees from surrounding vegetation (Patt and Sétamou 2007) and thus spread CLas bacteria in their orchards. Furthermore, farmers' practice of mandarin bloom stimulation, which induced mandarin trees to bloom more frequently and to produce new shoots, created favourable environments for psyllids to mate, lay eggs, and develop their colonies (Grafton-Cardwell, Stelinski, and Stansly 2013). Thus, farmers' more intensive growing practices facilitated not only the reproduction and spread of psyllids, but also of CLas pathogenicity.

Mandarin growers in Kampaeng Phet began to experience the negative consequences of their intensified orchard practices around 2008, when they started to notice considerable drops in the quality and size of their yields. Thida, whose family had relocated their orchards from Rangsit to a 50-rai (80,000 m^2) plot in Kampaeng Phet province, told us: 'We were told [by other growers] the disease would not come back again and that the soils were great here. Four years later, we were still harvesting a lot of fruits from mandarin trees, but in the fifth year, the fruits started to fall from our trees'. Wat had a similar experience, with fruit falling from his trees five years after he arrived in Kampaeng Phet. While Thida, Wat, and Ake suspected their orchards were once more infected with CGD and that they should purchase disease-free grafts, they did not know how to identify whether or not a graft was infected, and nor did they have any means of effectively treating

infected trees. Ake said he was advised by the DOA to cut down all the trees which had falling fruits, but he didn't want to, as he had invested a lot in his trees. In the end, Ake and Wat's Kampaeng Phet orchards went out of business. Wat abandoned mandarin production and Ake and Thida returned with their families to Rangsit and invested the money they still had to try to grow mandarins there again. Ake tried to grow a different variety of mandarin called *Keaw dam nern* (partially named after a district in Ratchaburi province), which he was told was resistant to disease; however, after seven years the fruit in his orchards started to fall again.

Meanwhile, at a national level, mandarin yield had also declined dramatically between 2006 and 2010. In 2006, mandarins totalled 871,644 tonnes from a cultivated area of 424,514 rai (680 km^2); by 2010, this had dropped to 280,190 tonnes from 147,673 rai (237 km^2) (Office of Agricultural Economics 2013). Chiang Mai province had in 1997 itself likewise reached its peak mandarin orchard coverage at 92,791 rai (148 km^2), and by 2010 had experienced a rapid drop to 27,706 rai (44 km^2) (idem.). Unlike when they were farming in Rangsit, Wat, Ake, and Thida knew about CGD by the time they began their orchards in Kampaeng Phet, including how the disease was transmitted via grafting and psyllids, and about measures to control its spread. But they still lacked ways and means to treat infected trees. They were still unable to identify CLas-infected grafts or trees before they became unhealthy and it was too late to rescue them. At the time, Thailand was also still propagating mandarin plants through marcotting and there was no mandatory national certificate system to guarantee the sale of disease-free grafts. Thus, farmers' attempts to eliminate psyllids as possible vectors of infection by using pesticides were insufficient to stop the spread of CGD. Similar vector control measures were also required for other locally grown families such as *Dok kaew* (orange jasmine) and *Ma fai* (Burmese grape), which were also hosts to psyllids. Additionally, stopping CGD would also require nationally coordinated measures or collaboration among orchards to address the transmission of CLas bacteria, which already appeared to be widespread, if not even endemic to orchards and nurseries. Furthermore, farmers were not overly keen on removing infected trees, especially when there were increasingly so many, as this would leave them with low mandarin yields. The intensified agricultural practices—such as nurseries, grafting, mandarin blooming, and denser planting of trees (the conditions through which farmers sought to increase their mandarin yields)—were the same that favoured high psyllid reproductivity, infection, and spread of CLas bacteria. Thus, the pathogenicity of CGD for any particular orchard emerged from a complex assemblage of plants and psyllids, and one that was inseparable from intensified orchard practices, the seeking of new land for orchards within and across provinces, the limited availability of resources and coordination measures (state or otherwise) to address the use of infected grafts, and from a lack of understanding and awareness of how these all came together.

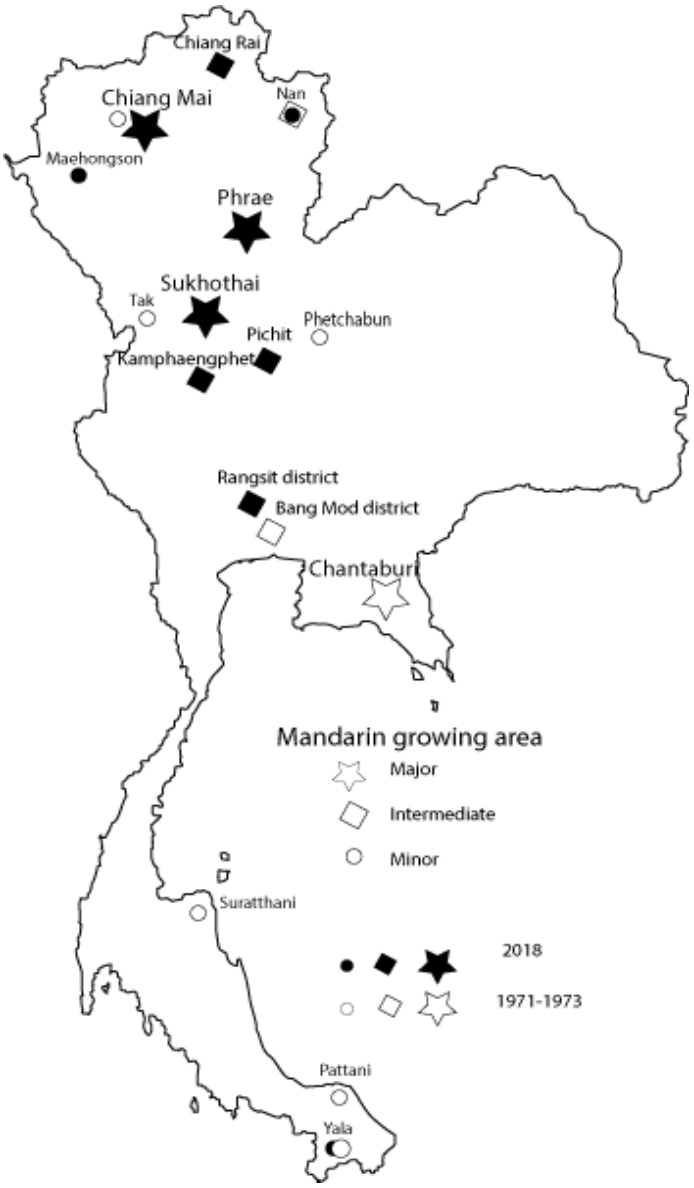

Figure 1. Map of major mandarin growing areas in 1971–1973 and 2018. Source map: ChristianBier, CC BY-SA 3.0. Source data: Schwarz, Knorr, and Prommintara 1973; Office of Agricultural Economics 2019.

Antibiotic angels: Realising antibiotics' pharmaceutical potential

As mandarin fruits which had grown only to the size of limes started falling in Rangsit *en masse*, Ampaiwan Paradornuwat, a plant pathologist and specialist in citrus disease, returned to her research on the use of antibiotics to treat mandarin trees infected with CGD. Two decades earlier she had completed her masters thesis on this very topic, sampling orchards across Thailand for traces of the

disease and experimenting with antibiotic treatments (Puengjesda 1977). During their work in the 1970s, the FAO and DOA had not mentioned antibiotics to farmers as a viable option to address CGD (Schwarz, Knorr, and Prommintara 1973). This was in part due to the lack of available, affordable, and practical equipment at the time, as well as to the observations the specialists had made of some toxic side-effects from the application of tetracycline in trees. Instead, they recommended psyllid control, and trimming, pruning, and removing infected plants. Later, through nationally funded research projects at Kasetsart University, Ampaiwan worked with a few orchard growers in Chiang Mai province to develop effective means of injecting antibiotics and promoting the elimination of CGD. At first, the mandarin growers she met were unenthusiastic (Kaje 2017). Pairin, another plant pathologist and citrus specialist working in Chiang Mai, told us that, 'The injection technique we used in the past [the 1990s] was conducted by drilling holes into individual tree trunks, into which we then injected antibiotics, but this was not practical for growers, because of technological limitations'. According to Pairin, farmers were still struggling to incorporate antibiotic injections into their practices by the early 2000s.

Pairin explained that farmers needed to lay power cables to supply electricity for the electric drills, and not only did they feel this was impractical, but the cost of doing this for each and every orange tree—in addition to the cost of the wired drills themselves—was still prohibitively expensive for growers. In their attempts to find manageable ways to treat their trees with antibiotics, Pairin and mandarin growers encountered another hurdle. Trunk injections required syringes that were strong enough to withstand the pressure of pushing antibiotic fluids into trees. Pairin and her colleagues had acquired a few prototypes from Florida and Taiwan which were pressurised containers specifically constructed from stainless steel. Parin recalled:

> We didn't have high quality materials to make equipment that could hold the pressure … Not only did we lack equipment, but mandarin growers normally planted 60 trees per rai [1,600 m^2], and an individual orchard would also be around 100 rai [160,000 m^2]. How many tonnes of antibiotics would be needed?

She found that drilling each tree with approximately 5–8 holes and inserting an equivalent number of syringes was sufficient to deliver the treatment. However, it was extremely labour-intensive and required a large volume of equipment and antibiotics—much of which, particularly syringes, continued to be unaffordable and insufficiently durable.

Although Ampaiwan only conducted her experimentation with antibiotics in a few orchards in Chiang Mai, other growers heard about the research through word of mouth from the orchard owners who were participating in her studies. Arun, whose

testimony we have already recounted, was one of them. He explained how he and other growers began to experiment by themselves with the application of antibiotics into some of their own trees, after their orchards started to experience severe CGD in 2007. Their efforts included trying to find alternatives to the syringes that Ampaiwan was experimenting with, which were in limited supply in Chiang Mai at the time. He recounted:

> At first, we used 20 syringes per tree. Later, we increased it to 40–50 syringes for every new branch, though we were recommended to inject into the main trunks only. But most of us growers started to use 2-inch PVC pipes, instead of syringes, with their own formulas [concentration of solution].

Arun and other growers found that, with some tinkering, they were able to replace syringes with a combination of PVC pipes and tier-like valves that could withstand the high pressure required to 'inject' antibiotics into their mandarin tree trunks. They also found that these modifications cut their costs and allowed them to modify the quantities they injected and the speed with which they did so. However, farmers' abilities to realise the pharmaceutical effectiveness of antibiotics for their entire orchards continued to be limited until the early 2010s, when Chinese-made cordless drills, which were sufficiently powerful and affordable to farmers, became more widely available.

In 2013, Ampaiwan consolidated the findings from her research in a manual for mandarin growers (Paradornuwat 2013). It described the various activities growers need to attend to over the course of a year, including identifying the symptoms of CGD and the application of control measures, and shared the outcomes of her experiments with various antibiotics. Based on her studies in Chiang Mai, Ampaiwan concluded that ampicillin was the most effective CGD treatment and described the costs and methods of its application. She stated that to successfully treat an infected tree, approximately seven 60 ml syringes filled with antibiotic solution were required twice a year (ibid.). For grower Pon, 70, this was unattainable and unaffordable for his 30 rai (48,000 m^2), as this would mean approximately 10,000 syringes. Along with other mandarin growers in Phrae province, Pon improvised, first by converting plastic soda bottles into pressure tanks and attaching to them PVC pipes similar to those used by growers including Arun in Chiang Mai. Then, rather than tier-like valves, the Phrae farmers used rubber tube ends to insert into their trees (see Figure 2). Pon referred to this setup as an 'infusion' kit, as each bottle could hold and slowly introduce considerably more antibiotic solution into the tree at any one time, meaning they did not have to rely on countless syringes to 'inject' them. Mandarin growers not only tinkered with the equipment, but also the concentration, combination, and frequency of antibiotic use (Chanvatik et al. 2019). In practice, growers subsumed Ampiwan and Pairin's

scientific guidance into their situated experimentation and built on it using their consequent knowledge, shaping how their equipment and antibiotic ‘injections’—or, as they also described it, antibiotic ‘acupuncture’—came to be adapted to their orchards and the potential pharmaceutical effects of this practice realised. In doing so, through prophylactically and curatively ‘injecting’ their trees, growers were finally able to incorporate antibiotic practices into their intensive orchards, which they hoped would be sufficient to stave off damaging infections caused by CLas bacteria, instead of having to follow what to them were the more drastic and costly measures of removing or destroying their trees.

Farmers’ newfound abilities to turn antibiotics into affordable and feasible orchard practices arrived too late for many orchard owners. Some, like Ake, lost many if not all of their trees to CGD, ending up with large debts and facing bankruptcy. Following the devastation of his orchards, Ake sought assistance from a local NGO, which helped pay off his debts and shift his land in Rangsit to organic fruit growing, including—but not exclusively—mandarins. To growers that were able to afford and assemble the equipment and know-how to effectively inject or infuse antibiotics into their trees, and whose orchards consequently recovered, ‘antibiotics were angels’, to use Arun’s expression. Farmers who used antibiotics in this way described how thin and weak mandarin tree trunks became strong, pale and yellow leaves turned fresh green, and bruised and black fruits became a bright orange or green again. Furthermore, antibiotics were a common, easily acquired, and relatively unregulated medicine (Chuengsatiansup, Sringernyuang, and Paonil 2000; Sringernyuang 2000), as confirmed by farmers’ descriptions of their easy purchase in large quantities from pharmacies and private and wholesale vendors.

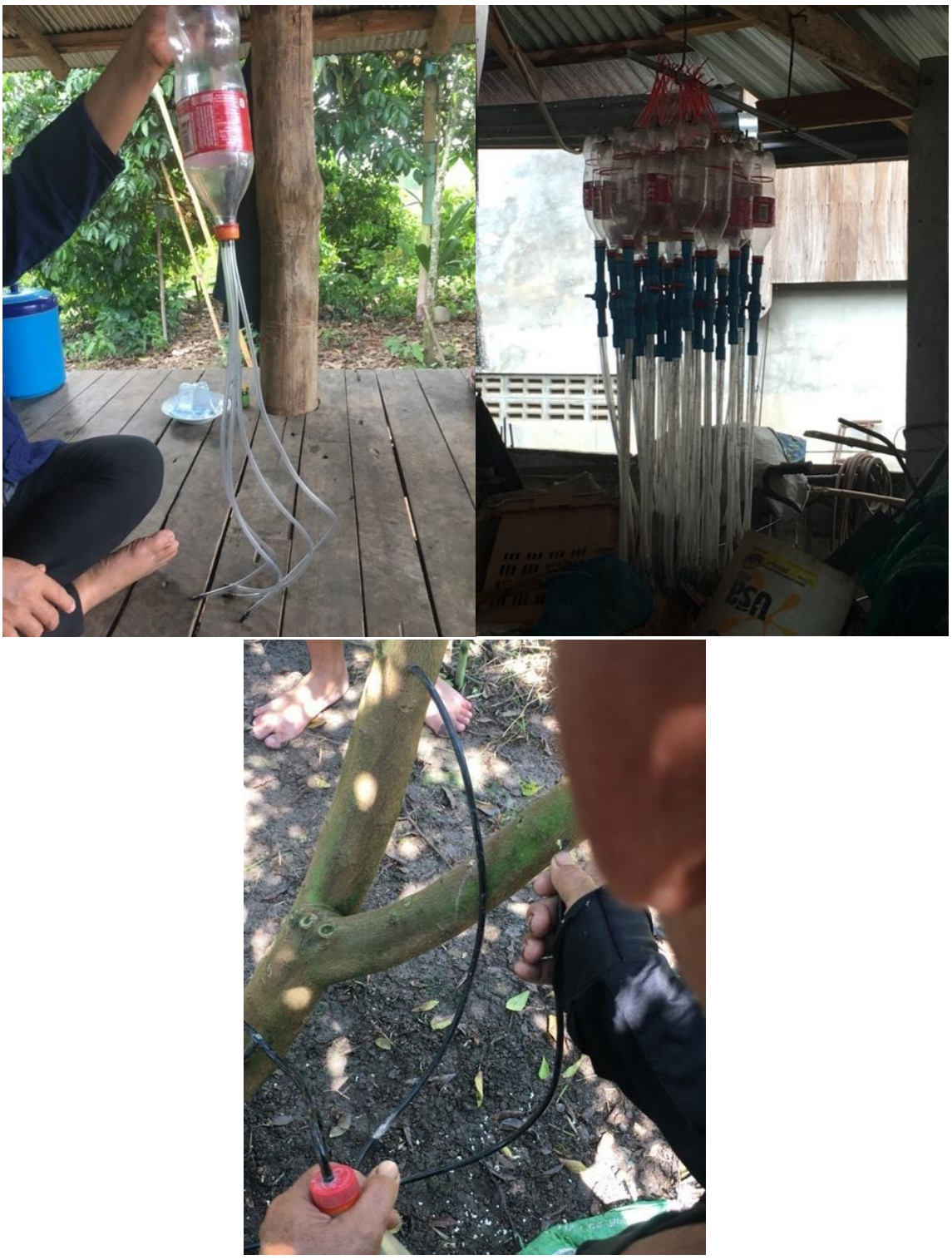

Figure 2. Left to right: Plastic soda bottles adapted for use as antibiotic infusion kit, with four tubes to connect to the mandarin tree; PVC pipes and valves are added to the bottle to control the solution; an electric drill is used to make holes on citrus tree trunks for tube insertion. Images by author Thitima Urapeepathanapong.

This easy availability, they told us, also contributed to them not being overly worried about antibiotics affecting the safety of their mandarins for consumption. However, Arun and other farmers were uncomfortable with increasing attention being paid to their use of antibiotics, including discussions of potential residues in mandarins, fearing that this might negatively affect their sales and abilities to continue their antibiotic practices. One farmer, Kla, whose father had an orchard in Chiang Mai, described how he had previously tried to go organic, giving up pesticide and antibiotics completely. But he told us that not only was there not much demand for organic fruit, and they had consequently fetched low sale prices, but being surrounded by others' mandarin orchards that used chemicals and antibiotics made organic farming virtually impossible. He said not only did he believe his orchards were contaminated by these products from other orchards but also, because he was not using them himself, his orchards were saturated with CGD, psyllids, and other pests. After 18 years of trying, he felt it was hopeless and had started to use chemicals, including antibiotics, in his orchard growing practices again. Similarly, for Thida, after her yields collapsed in Kamphaeng Phet she returned to Rangsit and adopted the use of antibiotics into her mandarin growing practices. Despite mandarin production in Chiang Mai province having decreased from approximately 350,000 to 300,000 tonnes due to CGD, in 2017, with the help of 'antibiotic angels', one of the largest orchard owners in Thailand was optimistic: '[the] Mandarin industry in Chiang Mai is recovering … CGD is now under control' (Prachachartturakij Online 2017). For some like Kla and Thida, antibiotics had come to be essential infrastructure for their orchards' survival and the production of successful mandarin yields.

Conclusion

Our research shows how Thai orchards and their owners have come to depend on antibiotics as central infrastructure through which they can sustain their intensified orchard practices and their profits. This has partly emerged through farmers' everyday engagement with their mandarins and their attempts—together with plant pathologists—to address the many evolving and intertwined human and non-human challenges of growing them. In doing so, the findings from our fieldwork also reflect on how farmers' familiarity with and use of antibiotics are at odds with OH and AMR policies which, although not explicitly stating antibiotics as being exclusively for use in human medicine, seek to reserve their use predominantly for 'us' humans (Chanvatik et al. 2019). The fact that antibiotic injections have long been commonly used in Thailand (Cunningham 1970), and that plants are also affected by bacterial infections, was testament to farmers and plant pathologists of their potential to help mitigate or rid orchards of CGD. However, as we have documented, farmers' incorporation and effective pharmaceutical application of antibiotics in their orchards was not straightforward.

Antibiotic use in orchards took more than three decades to become established and was intimately entangled with the shifting availability of antibiotics, their affordability, and experimentation with equipment to readily administer them, but also with the emergence of CGD as a persistent and identifiable cause of mandarin yield decline. We describe this process as more-than-human pharmaceuticalisation because of how growers care for their mandarins and their orchards' productivity became dependent on antibiotics in ways that never relied on nor sought recourse from medical authority (i.e., medicalisation). This is not to say that farmers attend to the productivity of their orchards or the infection with CLas bacteria using antibiotics alone; they also depend on insecticides, pruning, new grafts, and moving their production elsewhere. Instead, it is to acknowledge that antibiotics form part of an assemblage—as Roistacher (1996) described in the 1990s and others have more recently, relative to the citrus industry in Florida in the 2000s (Williams, Bleau, and Orosa 2020), and almond cultivation in Spain (Reisman 2020)—in which growers have resigned themselves to adapting and living with disease. Here, we believe that it is more fruitful to describe CGD's pathogenicity as emerging from within Thai citrus agriculture and its associated practices and institutions within which it has come to be endemic, rather than a threat from 'the outside' (Ibid.). This means seeing CGD's pathogenicity—its threat to Thai farmers' productivity and profits—as similarly entangled with many of the very processes that have led to pharmaceutical injections of antibiotics as (rational) solutions for growers and plant pathologists in the first place. In other words, orchard intensification practices have co-facilitated CGD pathogenicity (e.g. planting trees closer together; creating favourable conditions for infected psyllid transmission; grafting of infected trees) and the establishment of its greater endemicity in Thailand (e.g., wide use of marcotting for mandarin propagation; lack of nationally mandated certificate system for disease grafts; movement and expansions of orchards growers across Thailand)—such that it has left farmers such as Thida, Kla, and Arun with no sense of sustainable, profitable alternatives to antibiotic injections in their farming practices.

From this perspective, WHO-directed policies and related One Health (OH) and AMR approaches that imagine the possibilities of continued mandarin productivity and profitability with a reduction or cessation in the use of antibiotics (Chanvatik et al. 2019), not only do not take seriously their infrastructural nature for the sustainability of Thai orchards, but also assume that CLas bacterial pathogenicity and the possibilities of antibiotic-injected mandarins are threats that exists outside the very agriculture practices, institutions, and increased interspecies relations (i.e., psyllid, mandarin plants and CLas bacteria) from which they have emerged (Helliwell, Raman, and Morris 2020). So just as antibiotic injections and pesticides may be imagined as ways of controlling or ridding orchards of unwanted non-human pathogenic practices, so too do OH and AMR policies risk following the

same limited engagement, in the form of advocating for a reduction or halt to orchard growers' antibiotic practices.

We are not advocating for antibiotic injections in mandarins; rather, we call for more careful reflection on what attempts to disentangle antibiotic injections from mandarin orchards will mean for farmers' livelihoods, their intensified agricultural practices, and consumer 'demand', as well as what such changes would require of governments. This means going beyond simply calling into question antibiotics as 'matter out of place' in orchards and mandarins, to critically engaging with the desirability and 'appropriateness' of the very intensive practices, scales of productivity, profit, and market demands that serve as rationales and drivers for the use of antibiotic injections, CGD bacterial pathogenicity, and the spectres of its future bacterial resistance to antibiotics. It also means bringing into this line of questioning the relatively unregulated nature of antibiotics in Thailand and how they have come to be deployed as common, unproblematic means of sustaining human and plant productivity in sectors where ill (citrus) health is endemic. The implication for policy may be that there is a need to respond more directly to farmers' desire for greater knowledge about how to use antibiotics 'correctly', as well as the development of national regulatory standards and infrastructure, including for certification of disease-free rootstock, testing of orchards for disease and of mandarins for antibiotic residues. These measures might contribute to some reductions in antibiotic use and costs to farmers, but are unlikely to result in substantial reductions due to the needs of intensive agriculture practices. Such substantial reductions would likely require longer term government interventions to promote alternative agricultural practices, such as crop diversification, agroforestry, and rotation, as well as a shift in consumer markets in favour of less intensively produced fruit.

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