Health Security
Volume 19, Number 5, 2021 © Mary Ann Liebert, Inc.
DOI: 10.1089/hs.2020.0153

Agricultural Crop Security: Exploring US Federal Readiness and Response Capabilities

Rebecca Mackelprang and Douglas C. Friedman

A large-scale agroterrorism attack on the United States would likely have severe economic and social consequences. In particular, the destruction of crops with pests or pathogens could cause substantial damage to food, economic, and social stability, with relatively little health risk to the perpetrators. The tools of engineering biology could enable a well-trained, nefarious actor to amplify their desired impacts through the development of disease-intensifying traits. In the United States, plant health emergencies are handled first at the local and state levels, then escalated to include the support and leadership of the US Department of Agriculture (USDA) and other federal agencies. We used publicly available documents and interviews across government, academia, and industry to explore the strategic and tactical approaches of the US federal government to detect and respond to plant agroterrorism. In this article, we discuss the agroterrorism preparedness and response capabilities at 3 levels of federal response: (1) within the Plant Protection and Quarantine program of the Animal and Plant Health Inspection Service at the USDA, (2) between USDA components, and (3) between federal agencies. We outline the approaches currently taken and identify opportunities to strengthen these approaches.

Keywords: Agroterrorism, Biosecurity, National strategy/policy

Introduction

Humans have engaged in biological warfare for millennia. In the sixth century BCE, Assyrians poisoned enemy wells with rye ergot, a fungus that grows on grains and produces compounds that attack the central nervous system. In 1984, an outbreak of *Salmonella* at salad bars in Oregon sickened 751 people. While initially thought to be accidental, the outbreak was ultimately attributed to members of the Bhagwan Shree Rajneesh cult, which sought to sway county election results.[1] Since the summer of 2020, residents of all 50 US states began receiving mysterious, unordered packages of seeds by mail.[2] Although the seeds were most likely part of a "brushing scam"—in which sellers ship products to individuals who did not order them and then pose as the recipient to write fake, positive reviews—the US Department of Agriculture (USDA) encouraged recipients not to plant them out of concern they might be noxious weeds or carry pests or pathogens that could damage US agriculture.

No evidence has been found to suggest the seeds were part of an agroterrorism attack. However, the USDA's public recognition that seed packets sent by mail could damage US agriculture called attention to our vulnerabilities. In 2019, 10.9% of US employment was related to the agricultural and food sectors, and food, agriculture, and related industries contributed about US$1.109 trillion to US gross

Rebecca Mackelprang, PhD, is a Postdoctoral Scholar and Douglas C. Friedman, PhD, is Executive Director; both at Engineering Biology Research Consortium, Emeryville, CA.

domestic product.[3] A successful act of agroterrorism could threaten human life, health, and wellbeing by obstructing food supply chains, causing economic loss, damaging the environment, and inducing lasting psychological or emotional effects on the population. In this article, we use "agroterrorism" to refer to deliberate action taken to harm agriculture, whether by a state or nonstate actor. While our focus is mostly on biological threat agents, agroterrorism also includes chemical, radiological, and nuclear threats.

As seen during the early weeks of the COVID-19 pandemic in the United States, emergencies can cause erratic food purchasing behavior.[4] A diminished food supply coupled with consumer stockpiling could have serious implications for food access while straining all components of the food supply chain. Environmentally, acts of agroterrorism could damage soils, non-targeted plants, wildlife, and waterways. Biological agents are difficult to completely eradicate and could therefore damage production of the targeted crop on an ongoing basis and could suppress related wild plant hosts that are susceptible to the same agents. Domestic consumers might feel fear and confusion, causing a loss of trust in the food supply and governmental response capabilities while also facing higher prices for food and crop-derived products.

Despite these possible outcomes, attacks on agriculture are seemingly rare and accusations are difficult to substantiate.[5] However, a lack of historical precedent of serious known incidents is not necessarily predictive of future threats, especially as enabling technologies continue to develop.

In this study, we sought to identify factors that contribute to the plausibility and severity of a potential crop agroterrorism attack, then identify the roles and responsibilities of the federal government in plant agroterrorism preparation, recognition, and response. We analyzed federal strategies and the tactics that support them within USDA's Animal and Plant Health Inspection Service (APHIS) Plant Protection and Quarantine (PPQ) program, between relevant USDA components, and between federal agencies (Figure 1). We conducted interviews with personnel at diverse government agencies and with experts in the private sector and academia. In this article, we describe the strategies and tactics that currently guide federal agroterrorism preparedness efforts and highlight opportunities to strengthen them.

Methods

We gathered information through research and analysis of publicly available materials, including government manuals, plans, memoranda of understanding, and peer-reviewed research.[6,7] In addition, we conducted interviews with 15 individuals within and outside of government agencies including the USDA Department of Management and Agricultural Research Service, US Department of Energy, US Department of Homeland Security, US Office of Science and Technology Policy, and the US Federal Bureau of Investigation (FBI). Outside of government, we consulted experts in agriculture, biosecurity, and academia.

Factors in Agroterrorism Risk

Engineered Pests or Pathogens

Negative outcomes of plant agroterrorism could be compounded by the use of bioengineered pests or pathogens. Engineering biology—which uses biology, chemistry, engineering, computer science, and related disciplines to build biological systems—has advanced significantly in the last 2 decades. Access to tools such as affordable DNA synthesis, genome editing, and predictive modeling have increased the complexity of the networks, cells, and organisms that can be designed or engineered. With these tools, it is feasible that plant pathogens or pathogens that target fragile pollinator species could be engineered to be more pathogenic, virulent, or transmissible than their wild-type counterparts. For example, a microbial pathogen could be transformed with avirulence genes to evade plant immune responses. Species of *Aspergillus* that produce aflatoxins—potent toxins that infect crops, such as maize, millet, and groundnut, and cause acute and chronic health issues—could be modified to produce higher toxin levels because their biosynthetic gene cluster is well characterized.[8,9] Insect vectors could be engineered for enhanced pathogen transmission. Common treatments such as insecticides or herbicides could be rendered ineffective by engineering resistance or tolerance, which in many cases is determined by single alleles. Ongoing research on pathogen biology, plant-pathogen interactions, and the improvement and application of tools of engineering biology to a greater number of species will reduce the barriers to such work. Successfully engineering a pathogen for such traits, however, is insufficient by itself for launching an agroterrorism attack. Aspects of weaponization, such as growing a pest or pathogen at scale, successfully transporting it to dispersal sites, and disseminating it under the conditions required for pathogen success require additional expertise.[10]

Actors with Agroterrorism Capabilities

Understanding which individuals or groups have the capacity to commit an act of agroterrorism is useful for defining the threat landscape and developing deterrence and prevention strategies.[11] State actors with developed research programs have the technological capabilities, and some (including the United States) had biological weapons programs in the mid-20th century.[12,13] These programs were in decline by the 1970s, in compliance with the Biological Weapons Convention. Since then, molecular biology, genetics, bioengineering, and synergistic technologies have rapidly advanced. Capabilities among states to develop biological weapons are now greater—if a state is willing to violate the Biological Weapons Convention.

Nonstate actors with substantial resources can also recruit or develop expertise to build biological weapons. In November 2001, for example, a raid of a home in Kabul, Afghanistan, uncovered gas masks, laboratory equipment, training materials, plans and booklets about anthrax and information about Plum Island, which houses a federal research center dedicated to the most severe animal diseases.[14] (That research is currently moving to the new state-of-the-art National Bio and Agro-Defense Facility in Manhattan, Kansas.) Other nonstate actors, such as drug cartels, may have the resources and influence to develop biological weapons and could potentially do so if it supported their goals.[15]

Domestically, individuals or groups may see an attack on agriculture as an opportunity to gain publicity without physically harming other people, thereby preserving a sense of morality. Or for a group that objects to certain agricultural practices, destroying farms and crops that use those practices may focus national attention on their cause. At the individual level, a single neighbor, relative, or employee could be capable of obtaining and spreading diseased plant material, although such occurrences would not require a federal interagency response.

Federal Agroterrorism Defense Capabilities

Strategies and Tactics Within the Plant Protection and Quarantine Program

We use fictional vignettes throughout the article to illustrate possible responses to an act of agroterrorism (Box 1).

A new, unexpected, or unknown plant pest or pathogen in an agricultural setting might be detected in various ways, including by private growers or through national or state surveys or monitoring (Figure 1).[16] Initial steps of a response vary by state, but a disease incident is generally reported at the county or state level. A cooperative extension agent or county or state plant health official may then visit the site to collect samples for molecular diagnostics.[17,18] Cooperative extensive agents work within the Cooperative Extension System, which is supported by USDA's National Institute of Food and Agriculture and operates through land-grant universities to communicate actionable research and provide education to those involved in food and agriculture. While individual state departments of agriculture each have their own operating procedures, the PPQ program would be notified of a new pest or pathogen in the United States, a pest or pathogen found outside its endemic range, or a pest or pathogen displaying unexpected symptoms. PPQ's National Identification Services would then confirm the diagnosis.[16]

Such occurrences are not atypical; new plant pests and pathogens enter the United States regularly, and PPQ has robust emergency response systems in place to diagnose, limit the spread, and treat or eliminate diseases. For example, *Ralstonia solanacearum* race 3 biovar 2 is a bacterial pathogen—and a US federal select agent determined to potentially pose a severe threat—that has been detected in imported geraniums in greenhouses in the United States several times, most recently in the spring of 2020.[18,19] If the disease were to escape from greenhouses, it could seriously damage important agricultural crops including potato, tomato, eggplant, and pepper.[20] PPQ actions included partnering with officials from state departments of agriculture to find, isolate, contain, and destroy infected and exposed plants, which led to the eradication of the disease in each case.[21] PPQ's strategy for pest exclusion, prevention, preparedness, response, and recovery is outlined in its *National Plant Health Emergency Management Framework*.[22] It describes the structure of PPQ and the responsibilities of subcomponents in meeting emergency objectives, including detection and diagnostics, resource and personnel mobilization, and incident command systems. PPQ's *Emergency Response Manual* serves as a field reference for personnel involved in plant health emergencies.[16]

Evidence of agroterrorism might be noticed at different points during disease response operations depending on variables such as the mechanism of attack; when, where, and how many times the disease was introduced; the amount of time since introduction; the strain's phenotypes; and the training of plant health first detectors, first responders, and diagnosticians. The location of an outbreak might have physical evidence such as signs of trespassing, equipment use, discarded protective equipment such as gloves or masks, or unidentified drones. The time it takes for a pest or pathogen to successfully establish macroscopic disease can be lengthy, during which such evidence may fade.

Epidemiological evidence must therefore also be collected. Such evidence may include an outbreak with atypical disease presentation or phenotypes, the absence of a known insect vector for a vector-driven disease, the presence of multiple unexpected diseases in a geographic location, simultaneous outbreaks of the same disease in different

Box 1. Vignette, Part 1

"Knee-high by the 4th of July!" The corn this year has far surpassed the checkpoint of the old adage. Of course, there's still plenty to do around the farm. A grower heads out for the day to check on weed growth within and surrounding the field. She is surprised and concerned to see long chlorotic stripes developing on the leaves of some plants. It doesn't quite look like any of the corn diseases she's familiar with, so she snaps a few pictures with her phone and sends them to the state plant health office. She asks for help identifying the disease and requests a consultation on treatment options.

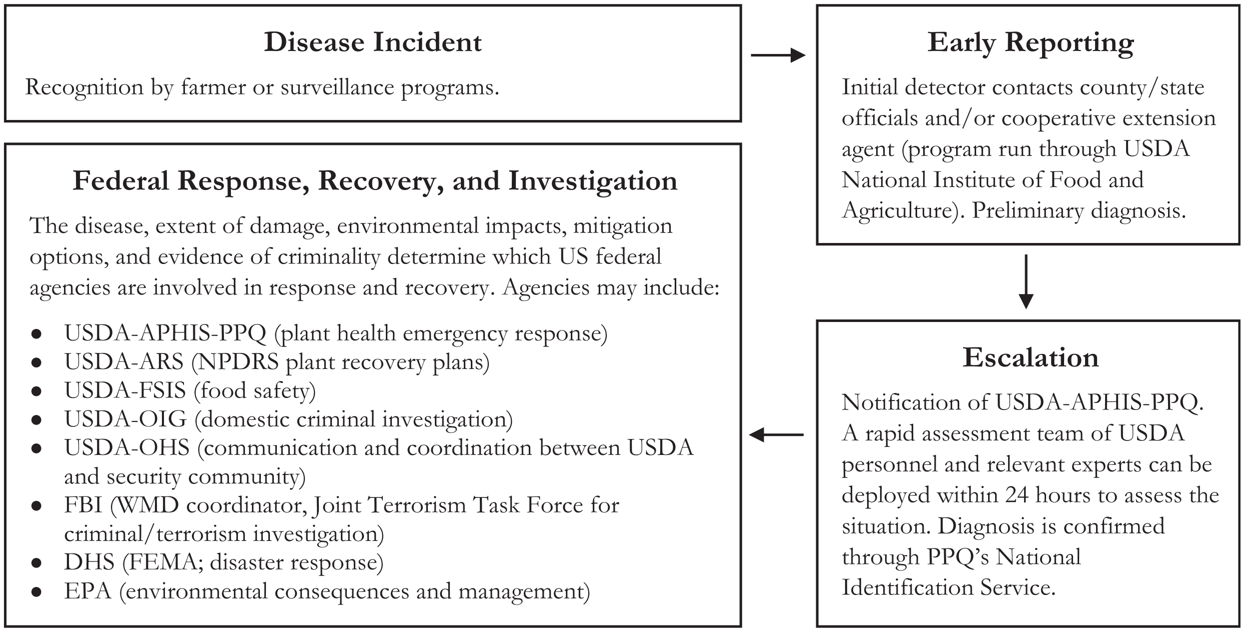

Figure 1. Escalation of plant pathogen response. An emerging plant disease might first be recognized by private growers or through plant pest surveillance programs. A grower might notify county or state plant health officials or a local cooperative extension agent. If initial investigation and preliminary diagnosis suggest a new or high-consequence pathogen is present, USDA's Plant Protection and Quarantine program would be notified and its National Identification Service would work to confirm the diagnosis. Many federal agencies would be involved in response, recovery, and investigative efforts depending on the pathogen and circumstances of its appearance. Abbreviations: APHIS, Animal and Plant Health Inspection Service; ARS, Agricultural Research Service; DHS, Department of Homeland Security; EPA, Environmental Protection Agency; FBI, Federal Bureau of Investigation; FEMA, Federal Emergency Management Agency; FSIS, Food Safety and Inspection Service; NPDRS, National Plant Disease Recovery System; OHS, Office of Homeland Security; OIG, Office of Inspector General; PPQ, Plant Protection and Quarantine; USDA, US Department of Agriculture; WMD, Weapons of Mass Destruction.

regions without a clear link, unexpected pathogen success given environmental conditions, and the report of missing or stolen pathogen samples from a laboratory.[23,24] Laboratory techniques can further elucidate disease origins. Whole genome sequencing could identify signatures of engineering such as selection markers, and comparative genomics could be used to identify likely regions of origin for the pest or pathogen, although neither method alone could conclusively distinguish between accidental or intentional release. Other techniques might be more useful for suggesting intent. For example, mass spectrometry can identify the abundance of given isotopes in a sample. Because isotope distribution varies around the planet, this technique could indicate whether a pathogen was grown in a particular region before being transported to a different region. The opportunity for isotope analysis would decrease over time as the pathogen reproduced in its new environment.

Interviews with USDA officials suggested that wide-scale training on agroterrorism recognition and response might be a low priority within PPQ because the vast majority of plant disease outbreaks are caused by natural (eg, hurricanes carrying disease across borders) or accidental (eg, imported products carrying disease) events. Furthermore, efforts to contain an outbreak would be similar regardless of its origin. However, there are differences between natural, accidental, and deliberate events that can be recognized and require different responses, such as increasing surveillance to a wider geographic area, increasing treatment areas, involving law enforcement, setting up checkpoints or roadblocks, delaying treatment to allow time for the gathering of evidence, using more advanced diagnostics, or optimizing treatment plans to overcome engineered pathogen resistance or tolerance to standard treatments.[25,26] If PPQ wants to optimize its detection, response, and attribution capabilities, it should incorporate comprehensive training for plant health responders and diagnosticians to increase their awareness of agroterrorism signs and the unique partnerships and actions necessary for a successful response.

The FBI Weapons of Mass Destruction Directorate conducts 2-day Animal/Plant Health Joint Criminal-Epidemiological Investigations Workshops that support the development of relationships between local USDA personnel, state departments of agriculture, and law enforcement. Workshops communicate triggers for involving law enforcement and strategies for working together.[20] Workshops are limited in the number of individuals that can be reached and opportunities should be taken to expand training.

To further increase capacity for investigating and identifying agroterrorism, forensic plant pathologists should be incorporated into 1 or both of PPQ's 2 main functional areas—field operations and science and technology—or, at minimum, the USDA should establish partnerships with forensic plant pathologists in academia or industry. Forensic plant pathology is still an emerging field, but graduate training programs such as Oklahoma State University's Institute for Biosecurity and Microbial Forensics are training specialists who can use scientific, analytical methods to work toward attribution of plant disease crimes.[23] Scientists in these positions would develop protocols for collecting evidence for criminal investigations including plant, soil, and water samples, and they would be trained on how to appropriately handle that evidence, laboratory testing, and analysis.[23] They would collaborate with PPQ scientists already working on deployable detection and diagnostic capabilities, increase agroterrorism awareness and consideration throughout PPQ, and train plant health responders to identify nefarious activity and assist in forensic investigations. Because attribution of these crimes may be difficult, costly, and have serious implications for international relationships and national security, it is essential that the science and research necessary to support this work are established in advance of an actual attack.[25]

Strategies and Tactics Within USDA

As illustrated by the vignette in Box 2, the escalation of a plant health emergency necessitates the involvement of components across USDA to plan, implement, and coordinate the response to a plant health emergency (Figure 1). The readiness of these agencies to respond to an act of agroterrorism is coordinated by USDA's Office of Homeland Security, the security focal point within the agency. One of its major functions related to agroterrorism is tracking USDA fulfillment of Homeland Security Policy Directive-9 (HSPD-9) requirements. In 2004, the George W. Bush Administration issued HSPD-9, *Defense of United States Agriculture and Food*, which calls for vulnerability assessments from USDA and the US Food and Drug Administration (FDA), the development of mitigation strategies that protect the food system, and coordinated response capabilities involving local, state, federal, and private-sector partners.[27]

We were unable to find publicly available documentation of coordinating efforts between USDA components for HSPD-9-related activities and requirements and, therefore, did not include it in our review. In 2011, the Government Accountability Office recommended the development of a USDA-wide strategy for HSPD-9 implementation.[28] In 2015, the office now known as USDA's Office of Homeland Security acted on this recommendation by developing a tracking document to compile activities in fulfillment of HSPD-9 activities.[29] A 2018 audit of 3 USDA components—APHIS, Agricultural Research Service, and Food Safety and Inspection Service—found that APHIS and the Agricultural Research Service should communicate vulnerability assessment activity to the Office of Homeland Security and that all 3 components should improve their tracking and implementation of corrective actions.[30] A strategy that supports more intercomponent collaboration and planning may facilitate a more cohesive response to a major agroterrorism incident. For example, HSPD-9 requires the expansion and continuation of vulnerability assessments in the food and agriculture sector, which must be updated every 2 years.[27] An assessment that focuses on current connectivity capabilities between USDA components and identifies opportunities for coordination and collaboration could strengthen the unity of a USDA response to agroterrorism.

USDA connectivity and coordination could be especially valuable in response to an outbreak of an engineered pest or pathogen, pulling in USDA components such as APHIS, Agricultural Research Service, Food Safety and Inspection Service, and the National Institute of Food and Agriculture. Engineered pests or pathogens may produce toxic metabolites, mate or exchange genetic material with wild counterparts, resist standard pesticide treatments, or cause a host of other issues best addressed by coordination and collaboration between these components. As research advances year by year, the variety of traits that may be engineered and the specific pests and pathogens that can be engineered also continues to advance. An assessment led or supported by USDA that considers the culturability, availability of genomic engineering tools, genome accessibility and annotation, current understanding of genetic virulence factors, environmental conditions conducive to growth, plant host species, and the ability to produce and transport the pest or pathogen at scale could be an important tool for identifying disease agents that a nefarious actor might select to engineer for disease-intensifying traits. USDA's National Plant Disease Recovery System develops plans to support recovery efforts from plant pathogen threats[31] and could use the information from such an assessment to develop recovery plans for individual or grouped pathogens that pose a particular engineering risk. As a result, USDA would

> Box 2. Vignette, Part 2
>
> The state plant health official thinks the disease is new to the region and sends samples to a National Plant Diagnostic Network laboratory. He notifies state plant health leadership and the USDA PPQ program. State plant health and federal officials investigate the scene and begin to survey the region, finding additional emergent cases. Laboratory results show that the plants are infected with a fungal disease not previously found in the United States, but is known to cause serious damage to corn in other regions of the world. Federal plant health officials enlist their forensic plant pathologist colleagues to collect evidence and work toward understanding how the outbreak originated. The USDA begins to receive reports from plant health officials in other states. Additional components of the department become involved in coordinating the response to this outbreak and investigating its origins.

be better aware of the actual risk of the release of a bioengineered pest or pathogen, could consider opportunities for mitigation, and would be positioned to rapidly mobilize response and recovery efforts.

Interagency Connectivity

The size of the United States government and the distribution of expertise and stakeholders across agencies necessitates thorough emergency response plans that can be rapidly and efficiently implemented when necessary (Box 3). Such plans must align with each other and be accessible, understood, and practiced by the personnel responsible for implementing them. The *National Response Framework*[32] and the Response Federal Interagency Operational Plan support responses to all-hazards incidents. An all-hazards approach to emergency planning incorporates the infrastructure and capabilities required to respond to a range of emergency situations. As agriculture is subject to many diverse types of emergencies (eg, weather, natural disasters, pests and pathogens), an all-hazards approach is especially useful. It is important that less likely events such as agroterrorism are fully incorporated. The *National Response Framework*[32] guides the integration of federal capabilities with the private sector and state, local, tribal, and territorial governments to support scalable and flexible responses. The *Response Federal Interagency Operational Plan*[33] describes how federal agencies should deliver on response capabilities using the structure of the *National Response Framework*.

A Food and Agriculture Incident Annex to the Response and Recovery Federal Interagency Operational Plan was published in late 2019 and addresses federal roles and responsibilities specific to incidents involving food and agriculture.[34] Branch 4 of the Food and Agriculture Incident Annex addresses unique considerations for the response to intentional uses of chemical, biological, radiological, or nuclear agents against food or agriculture.[34] Other guiding policy for response to intentional food and agriculture incidents includes HSPD-9 and the National Agriculture and Food Defense Strategy, both of which recently underwent interagency review.[27,35] Because relevant information to agroterrorism response efforts are distributed across strategic and tactical plans, the FBI, USDA, FDA, US Department of Homeland Security, US Environmental Protection Agency, and other relevant agencies should undertake joint training exercises. Several of these agencies lead their own efforts (eg, Animal/Plant Health Joint Criminal-Epidemiological Investigations Course, InfraGard, Fusion Centers) that incorporate food and agricultural security. Joint training exercises should clarify the actions and responsibilities of each agency and help identify areas where policy is unclear or overlapping before a national emergency.

The Defense Against Agroterrorism Working Group may be well situated to host or support such interagency training and exercises. The working group brings representatives together from 36 offices and agencies across government—including representatives from the intelligence community—to identify and evaluate agricultural threats, increase the sharing of information about threats, and develop tools to improve interagency responses (Box 4).[36]

> Box 3. Vignette, Part 3
>
> The fungal pathogen has now been reported on corn in 8 states. At least 1 drone with the capacity to disperse fungal spores has been recovered from an affected field. Meanwhile, the diagnostic laboratory sequences the fungus's entire genome, which shows some surprising features. While it is similar to strains found elsewhere in the world, there are a few regions of its genome with previously unknown variations, including a novel genotype that could increase spore resilience and the presence of a virulence-associated gene from a related fungal species. Scientists across the USDA are trying to determine if the genomic differences could have occurred naturally and are working to understand how easily the fungus can be genetically manipulated. The USDA has activated the National Response Framework and the FBI, US Environmental Protection Agency, and US Department of Homeland Security are now directly involved in investigation, response, and recovery efforts.

> Box 4. Vignette, Part 4
>
> The USDA finds that the fungal strain in the United States is most related to a strain in a country whose farmers compete with US farmers for corn export markets. The fungus has devastated US corn production and will affect fresh and processed food supply chains, meat prices because of feed limitations, farmer decisions and livelihoods, and international trade relationships. The USDA and US Department of Homeland Security are working to identify possible routes of entry—deliberate, natural, or accidental—for the pathogen. The USDA and the Environmental Protection Agency are working with farmers to contain the pathogen. The USDA is working with state partners and the Federal Emergency Management Agency to manage the consequences of the outbreak for farmers, their crops, and their property. The FDA and USDA are working to keep food supply chains as stable as possible. The FBI is leading the ongoing criminal investigation.

Discussion

In this article, we discuss the agroterrorism preparedness and response capabilities at 3 levels of federal response: within USDA-APHIS-PPQ, between USDA components, and between federal agencies. We also offer recommendations for strengthening preparation and response (Table 1). These recommendations include (1) providing comprehensive training to plant health first responders so they are prepared to recognize the signs of criminal or malicious activity at the site of a plant disease outbreak and adjust response actions accordingly; (2) developing forensic plant pathology tools that help plant health officials recognize and attribute criminal activity; (3) evaluating and

Table 1. Agroterrorism Preparedness and Response Recommendations for US Government Readiness

Within USDA-APHIS-PPQ	• Provide plant health officials with comprehensive training for recognizing and responding to agroterrorism events • Support the development and use of additional forensic plant pathology tools through collaboration between PPQ scientists and forensic plant pathologists, possibly through their incorporation into PPQ Science and Technology and/or PPQ Field Operations
Within USDA	• Assess and improve as necessary the ability of USDA components to collaborate and coordinate internal response efforts to agroterrorism • Assess the threat landscape of engineered agricultural pathogens and develop plans for response
Between federal agencies	• Ensure all federal stakeholders are trained on relevant agroterrorism response and recovery strategy and assess coordination gaps through training exercises

Abbreviations: APHIS, Animal and Plant Health Inspection Service; PPQ, Plant Protection and Quarantine; USDA, US Department of Agriculture.

expanding USDA capacity for component coordination during an agroterrorism event; (4) assessing technological capacity for crop pests and pathogens to be engineered; and (5) providing cohesive, clear, and fully disseminated guidance and policy for federal agroterrorism responses to all agencies and personnel involved.

At the PPQ level, robust emergency frameworks are already in place and are activated regularly in response to naturally occurring plant health emergencies and novel pathogen detections.[16,22] Focusing on recognition and response to suspected acts of agroterrorism in training and awareness efforts, which are codified and supported in field guides and frameworks, could ensure that these highly skilled PPQ personnel have the tools they need to act efficiently in the national interest. Such personnel and their efforts may benefit from the incorporation of forensic plant pathologists into PPQ.

The use of an engineered plant pest or pathogen could amplify the negative consequences of an agroterrorism attack. As is clear through public discourse around genetically engineered foods, organic foods, pesticides, and other food and agriculture-related topics, many Americans are deeply invested in the growth and production of their food. An outbreak of an engineered pest or pathogen could spread and intensify public concern about biotechnology in the food system. Furthermore, effects could ripple out from agriculture to the broader bioeconomy, leading to shortsighted, reactionary policy responses. On the other hand, failure to recognize that an outbreaking pathogen has been engineered could result in ineffective or inefficient attempts to contain or control it using standard techniques to which it could be engineered to evade. Therefore, understanding which plant pests or pathogens have been characterized such that their engineering is feasible is important. USDA could strengthen this understanding by conducting or supporting a threat assessment, building a database, or other avenues.

It is important to note that engineering biology could have an important mitigating role in the response to an agroterrorism incident. The Defense Advanced Research Project Agency's Insect Allies program is "pursuing scalable, readily deployable, and generalizable countermeasures against potential natural and engineered threats to the food supply with the goals of preserving the US crop system."[37] The program supports research to counter biotic and abiotic plant challenges in a single growing season using insect vectors to transmit plant viruses. While all current research is conducted in closed facilities, future work could potentially be deployed in the field. Such applications are still far from reality; they could be used to harm crops as easily as to benefit them, and any use would raise important environmental and ecological questions to address.

Implementing these recommendations would require modest programmatic changes and stable investment. The ongoing work of the Defense Against Agroterrorism Working Group can be leveraged and expanded upon to design, develop, and implement training within PPQ and between federal agencies. The development of additional forensic plant pathology tools could be supported through additional research funding to USDA or external researchers, and it would take only 5 to 10 additional personnel to incorporate forensic plant pathologists strategically across USDA.

In the wake of the terrorist attacks of September 11, 2001, the US federal government attempted to develop and strengthen many of its federal emergency preparedness plans and procedures for terrorist events, including agroterrorism. The frameworks for agroterrorism readiness built and updated since that time generally continue to guide and structure emergency responses in a meaningful way, although some efforts have not been maintained. Current and future initiatives can be maintained through strategic inclusion and codification in national plans such as the National Defense Strategy and supported through a cultural appreciation of the importance of security awareness. To be maximally effective, each individual who might be involved should understand these frameworks and the personal role they might play in a response. Important efforts such as those of the Defense Against Agroterrorism Working Group should continue to support collaboration across government and ensure that training and preparation are extended to all who may participate in an agroterrorism response.

Conclusion

Accidental and natural introduction of plant diseases can have devastating economic consequences, such as the outbreak and spread of huanglongbing, or citrus greening disease, in the United States, which has more than doubled the cost of Florida's citrus production while output has fallen by 75%.[38] Deliberate introductions could potentially have even more severe consequences. A wide range of potential actors, targets, and strategies could be part of an act of agroterrorism against the United States. It is essential that the US government—and the world—are prepared to respond swiftly and effectively to attacks on agricultural systems.

Determining the appropriate commitment of resources to prepare for an unlikely or rare event is difficult. The general national emergency response systems within the United States do not always work as planned but are nevertheless an important backbone for agroterrorism strategy. Relatively minor additional investments in personnel and planning may have a disproportionately large impact on enabling the detection of agroterrorism and coordinated responses within USDA and between federal agencies. While it is impossible to know if conditions will call for this expertise to be put in action, the severity of the consequences of such an attack necessitate that the risk be taken seriously and prepared for adequately.

Acknowledgments

This material is based upon work supported by the US Department of Homeland Security under Grant Award Number 19STFRG00011-01-00. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the US Department of Homeland Security.

References

1. MacIntyre CR. Biopreparedness in the age of genetically engineered pathogens and open access science: an urgent need for a paradigm shift. *Mil Med.* 2015;180(9):943-949.
2. US Department of Agriculture (USDA) Animal and Plant Health Inspection Service. USDA looks into packages of unsolicited seeds. Updated May 19, 2021. Accessed September 14, 2021. https://www.aphis.usda.gov/aphis/ourfocus/planthealth/news-info/unsolicited-seeds/faq-unsolicited-seeds
3. US Department of Agriculture Economic Research Service. Ag and food sectors and the economy. Updated June 2, 2021. Accessed September 24, 2021. https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-theessentials/ag-and-food-sectors-and-the-economy/
4. Norton RA. Conclusions. In: Mauroni A, Norton RA, eds. *Agroterrorism: National Defense Assessment, Strategies, and Capabilities.* Montgomery, AL: United States Air Force Center for Strategic Deterrence Studies; 2020:183-200.
5. Caldas MM, Perz S. Agro-terrorism? The causes and consequences of the appearance of witch's broom disease in cocoa plantations of southern Bahia, Brazil. *Geoforum.* 2013;47:147-157.
6. Bayman P, Serrato-Díaz LM. Forensic phytopathology: a critical review. *Microbiol Spectr.* 2016;4(4):32.
7. US Food and Drug Administration, US Department of Agriculture, US Department of Homeland Security. *Food and Agriculture Sector-Specific Plan*. Washington, DC: Cybersecurity and Infrastructure Security Agency; 2015. Accessed July 17, 2021. https://www.cisa.gov/sites/default/files/publications/nipp-ssp-food-ag-2015-508.pdf
8. Bbosa GS, Kitya D, Lubega A, Ogwal-Okeng J, Anokbonggo WW, Kyegombe DB. Review of the biological and health effects of aflatoxins on body organs and body systems. In: Razzaghi-Abyaneh M, ed. *Aflatoxins: Recent Advances and Future Prospects*. London: IntechOpen; 2013. Accessed July 20, 2021. https://www.intechopen.com/chapters/38731
9. Caceres I, Khoury AA, Khoury RE, et al. Aflatoxin biosynthesis and genetic regulation: a review. *Toxins (Basel).* 2020;12(3):150.
10. Maras MH, Miranda MD. The weaponization of Ebola: a new risk in the wake of an outbreak? *Comp Strat*. 2016;35(1):72-79.
11. Oroszi T, Ellis D. The mindset of a terrorist. In: Mauroni A, Norton RA, eds. *Agroterrorism: National Defense Assessment, Strategies, and Capabilities*. Montgomery, AL: United States Air Force Center for Strategic Deterrence Studies; 2020:29-42.
12. Wheelis M, Rózsa L, Dando M, eds. *Deadly Cultures: Biological Weapons Since 1945.* Cambridge, MA: Harvard University Press; 2009.
13. Alibek K, Handelman S. *Biohazard: The Chilling True Story of the Largest Covert Biological Weapons Program in the World - Told from the Inside by the Man Who Ran It.* New York: Random House; 1999.
14. Vargo ME. *The Weaponizing of Biology: Bioterrorism, Biocrime and Biohacking.* Jefferson, NC: McFarland; 2017.
15. Casagrande R. Biological terrorism targeted at agriculture: the threat to US national security. *Nonproliferation Rev.* 2000;7(3):92-105.
16. US Department of Agriculture (USDA) Animal and Plant Health Inspection Service. *Emergency Response Manual*. Washington, DC: USDA; 2010. Accessed July 16, 2021. https://www.aphis.usda.gov/import_export/plants/manuals/emergency/downloads/epm.pdf
17. Colorado Department of Agriculture. *Plant Pest and Disease Emergency Response Plan.* Broomfield, CO: Colorado Department of Agriculture; 2010. Accessed July 16, 2021. https://www.colorado.gov/pacific/sites/default/files/Plant%20Pest%20%26%20Disease%20Emergency%20Disease%20Response%20Plan.pdf
18. Dickstein ER, Champoiseau PG, Jones JB, et al. Recovery plan for *Ralstonia solanacearum* race 3 biovar 2: causing brown rot of potato, bacterial wilt of tomato, and southern wilt of geranium. Published February 13, 2017. Accessed July 16, 2021. https://www.ars.usda.gov/ARSUserFiles/OPMP/NPDRS%20Recovery%20Plans/Recovery%20Plan%20for%20Ralstonia%20solanacearum%20R3b2_Final.pdf
19. US Department of Agriculture Animal and Plant Health Inspection Service. *Ralstonia*. Updated June 18, 2020. Accessed September 2, 2020. https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/plant-disease/sa_ralstonia/ct_ralstonia

20. Champoiseau PG, Jones JB, Allen C. *Ralstonia solanacearum* race 3 biovar 2 causes tropical losses and temperate anxieties. *Plant Health Prog.* 2009;10(1):35.
21. Curlett H. PPQ eradicates *Ralstonia solanacearum* race 3 biovar 2 from U.S. greenhouses. US Department of Agriculture Animal and Plant Health Inspection Service. Published August 27, 2020. Accessed April 1, 2021. https://www.aphis.usda.gov/aphis/ourfocus/planthealth/ppq-program-overview/plant-protection-today/articles/eradicate-ralstonia-greenhouses
22. US Department of Agriculture (USDA) Animal and Plant Health Inspection Service. *National Plant Health Emergency Management Framework*. Washington, DC: USDA; 2019. Accessed July 16, 2021. https://www.aphis.usda.gov/plant_health/plant_pest_info/biosecurity/download/PHE-framework.pdf
23. Fletcher J, Barnaby NG, Burans J, et al. Forensic plant pathology. In: Budowle B, Schutzer S, Morse S, eds. *Microbial Forensics.* 3rd ed. Amsterdam: Elsevier; 2020:49-70.
24. US Federal Bureau of Investigation. *Animal - Plant Health Sector Defense: Awareness and Outreach*. Washington, DC: US Department of Justice. Accessed July 16, 2021. https://www.usaha.org/upload/Announcements/APH_Sector_Defense_Brochure_8_4_.pdf
25. National Research Council. *Countering Agricultural Bioterrorism*. Washington, DC: The National Academies Press; 2003. Accessed September 14, 2021. https://doi.org/10.17226/10505
26. Fletcher J, Bender C, Budowle B, et al. Plant pathogen forensics: capabilities, needs, and recommendations. *Microbiol Mol Biol Rev.* 2006;70(2):450-471.
27. Bush GW. Homeland Security Presidential Directive/HSPD–9—Defense of United States Agriculture and Food. In: National Archives and Records Administration, ed. *Public Papers of the Presidents of the United States: George W. Bush 2004. Book 1—January 1 to June 30, 2004.* Washington, DC: Administration of George W. Bush, US Government Printing Office; 2004. Accessed July 16, 2021. https://www.govinfo.gov/content/pkg/PPP-2004-book1/pdf/PPP-2004-book1-doc-pg173.pdf
28. Government Accountability Office (GAO). *Actions Needed to Improve Response to Potential Terrorist Attacks and Natural Disasters Affecting Food and Agriculture: Report to the Chairman, Subcommittee on Oversight of Government Management, the Federal Workforce, and the District of Columbia, Committee on Homeland Security and Governmental Affairs, U.S. Senate.* Washington, DC: GAO; 2011. Accessed July 17, 2021. https://www.gao.gov/assets/a322681.html
29. US Department of Agriculture (USDA) Office of the Inspector General. *Agroterrorism Prevention, Detection, and Response, Audit Report 61701-0001-21.* Washington, DC: USDA; 2017. Accessed July 17, 2021. https://www.usda.gov/sites/default/files/61701-0001-21.pdf
30. US Department of Agriculture (USDA) Office of the Inspector General. *USDA Agency Activities for Agroterrorism Prevention, Detection, and Response, Audit Report 50701-0001-21.* Washington, DC: USDA; 2018. Accessed July 17, 2021. https://www.usda.gov/sites/default/files/50701-0001-21.pdf
31. US Department of Agriculture Agricultural Research Service. Plant diseases that threaten U.S. agriculture: identified and prepared for under the National Plant Disease Recovery System. Updated March 12, 2021. Accessed April 1, 2021. https://www.ars.usda.gov/crop-production-and-protection/plant-diseases/docs/npdrs/
32. US Department of Homeland Security (DHS). *National Response Framework*. 4th ed. Washington, DC: DHS; 2019. Accessed July 17, 2021. https://www.fema.gov/emergency-managers/national-preparedness/frameworks/response
33. US Department of Homeland Security (DHS). *Response Federal Interagency Operational Plan.* 2nd ed. Washington, DC: DHS; 2016. Accessed September 14, 2021. https://www.fema.gov/sites/default/files/documents/fema_response-fiop.pdf
34. US Department of Homeland Security (DHS). *National Food and Agriculture Incident Annex to the Response and Recovery Federal Interagency Operations Plans.* Washington, DC: DHS; 2019. Accessed July 17, 2021. https://www.fema.gov/sites/default/files/2020-07/fema_incident_annex_food-agriculture.pdf
35. Parker HS, Marroquin J. U.S. federal policies and programs to combat agroterrorism. In: Mauroni A, Norton RA, eds. *Agroterrorism: National Defense Assessment, Strategies, and Capabilities.* Montgomery, AL: United States Air Force Center for Strategic Deterrence Studies; 2020:57-96.
36. US Government. An integrated approach to preparedness, detection, and response to agricultural threats: the experience of the United States. Presented at: Meeting of Experts on Assistance, Response, and Preparedness; December 3-6, 2019; Geneva, Switzerland. Accessed July 17, 2021. https://undocs.org/BWC/MSP/2019/MX.4/WP.1
37. Bextine B. Insect allies. Defense Advanced Research Projects Agency. Published October 4, 2018. Accessed September 10, 2020. https://www.darpa.mil/program/insect-allies
38. Animal and Plant Health Inspection Service, US Department of Agriculture. Citrus greening. Updated May 20, 2021. Accessed July 21, 2021. https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/citrus/citrus-greening/

Manuscript received September 1, 2020;
last revision returned April 1, 2021;
accepted for publication April 8, 2021.

Address correspondence to:
Rebecca Mackelprang, PhD
Postdoctoral Scholar
Engineering Biology Research Consortium
Emeryville, CA 94608

Email: bmackelprang@ebrc.org