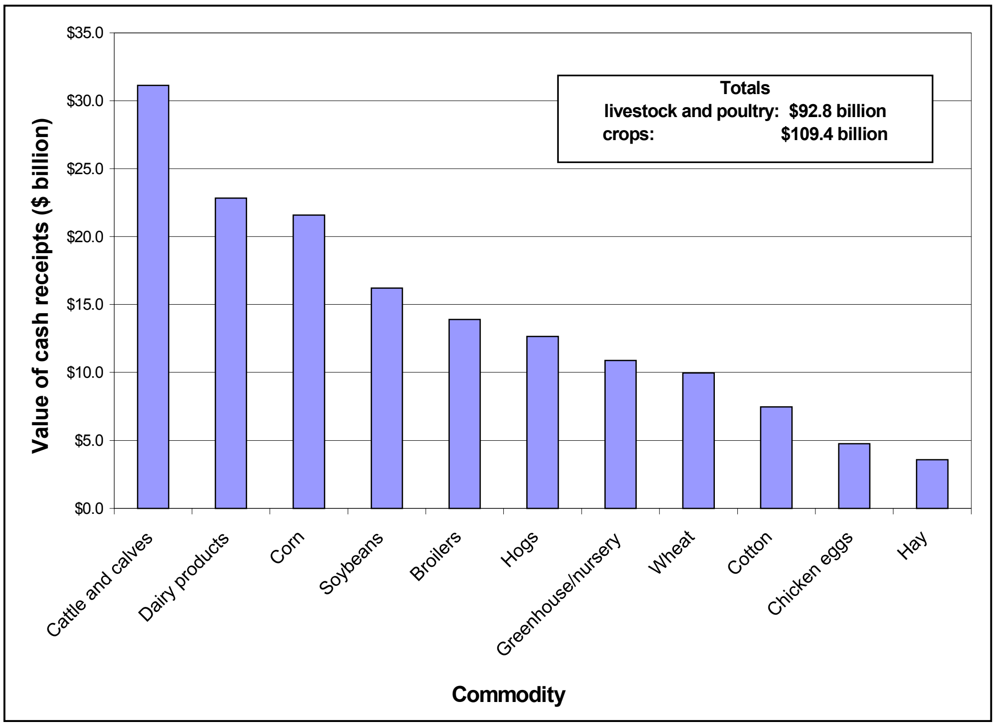
Note: The first section of the reading, pages 1-9, begins on this page.

The threat of biological weapons (BW) is usually associated with terrible outbreaks of human illness. Receiving substantially less attention from the media, however, is the fact that BW can also be used against agricultural targets as strategic economic weapons. Agriculture accounts for about 13 percent of the United States' annual gross domestic product.[1] In 1996 U.S. cash receipts for livestock, poultry, and crops totaled more than $200 billion.[2] An attack on agriculture could have enormous economic consequences.

Figure 1: Values of the Top 10 Agricultural Commodities, 1996.



Source: *Agriculture Fact Book 1998*, U.S. Department of Agriculture, Office of Communications, November 1998, pp. 43-44.

Americans enjoy some of the lowest food prices in the world, spending about 11 cents per dollar of disposable income compared to 50 or 60 cents per dollar in many other countries.[3] This is due in large

[1] Floyd Horn and Roger Breeze, "Agriculture and Food Security," in Thomas Frazier and Drew Richardson, eds., *Food and Agricultural Security: Guarding Against Natural Threats and Terrorist Attacks Affecting Health, National Food Supplies, and Agricultural Economics*, Vol. 894 (New York: Annals of the New York Academy of Sciences, 1999), p. 11.

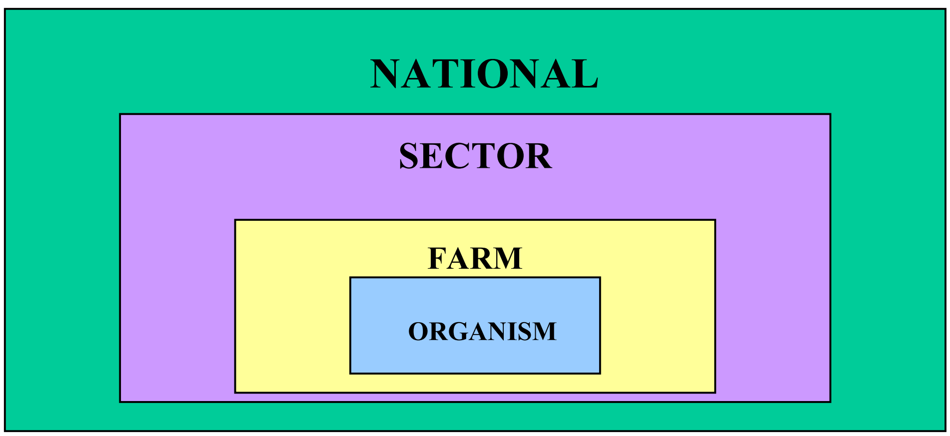
[2] *Agriculture Fact Book 1998*, U.S. Department of Agriculture, Office of Communications, November 1998, p. 43. Value of commodity cash receipts, 1996.

[3] The percentage of disposable income spent on food is decreasing. It was 13.8 percent in 1970, 13.4 percent in 1980, 11.6 percent in 1990, and 10.7 percent in 1996. *Ibid.*, p. 14. Also, Corrie Brown, "Agro-Terrorism: A Cause for Alarm," *Monitor*, Vol. 5, No. 1-2 (Winter-Spring 1999), p. 6.

part to the efficiency and the high health and quality standards that U.S. agriculture maintains, which keep production yields high and disease control costs low. The deliberate introduction of a pathogen—fungus, bacterium, virus, or insect pest—into U.S. livestock, poultry, or crops could cause a disease outbreak that would drive food prices up, halt valuable exports, and ultimately costs taxpayers billions of dollars in lost revenue and industry renewal costs.

For fiscal year (FY) 2000 more than $8 billion has been allocated to U.S. federal agencies for combating terrorism. The U.S. Department of Agriculture (USDA) will receive only 0.15% of that amount, about $12 million. The president's proposed budget for FY2001 more than triples the USDA's allocation to $41 million, which, if enacted, could significantly improve the agency's ability to defend against a terrorist attack on agriculture.[4] This paper suggests several ways that the USDA can to respond to this threat of "agroterrorism." The recommendations put forth are specifically intended to counter this threat, but they will also improve overall disease control capabilities, whether or not an attack occurs.

Figure 2: The four levels on which to counter the agroterrorist threat



The threat of an agroterrorist attack can be countered on four levels: (1) at the **organism** level, through animal or plant disease resistance; (2) at the **farm** level, through facility management techniques designed to prevent disease introduction or transmission; (3) at the agricultural **sector** level, through USDA disease detection and response procedures; and (4) at the **national** level, through policies designed to minimize the social and economic costs of a catastrophic disease outbreak.

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[4] *Annual Report to Congress on Combating Terrorism: Including Defense against Weapons of Mass Destruction/ Domestic Preparedness and Critical Infrastructure Protection* (Washington, D.C.: Office of Management and Budget, 2000), p. 47.

The four levels presented here are not independent of one another. If crops themselves are resistant to disease, or if diseases or pests can be excluded at the farm level, there will be less chance that the USDA will have to respond to an outbreak. If disease/pest control is successful at the organism, farm, and sector levels, national recovery policies will not be necessary. The threat of agroterrorism cannot be fully countered on any one level. The four levels presented in this paper correspond to four prongs of a comprehensive strategy to counter agroterrorism.

This paper begins with a short background on past agricultural catastrophes, past BW programs targeting agriculture, and the feasibility of an agroterrorist attack. It then examines each of the four levels listed above, explaining the central concerns of each and making relevant recommendations for USDA action.

BACKGROUND

A disease that is introduced deliberately may be indistinguishable from one that is introduced inadvertently, or from one that arises naturally. An examination of past outbreaks gives some indication of the level of damage to expect from an agroterrorist attack. Beyond the damage lies the question of who would carry out such an attack and for what reasons. To address this broad topic, this section gives an overview of who has developed antiagriculture BW in the past, who has actually used BW against agriculture, the technical requirements for an agroterrorist attack, and some potential motivations.

Past Incidents of Large-Scale Disease Outbreaks

Natural outbreaks of diseases among plants and animals demonstrate the destructive potential of an agroterrorist attack. Historic examples show that the financial impact of an outbreak includes not only the cost of the lost agricultural products, but also the cost of the disrupted trade.

Foreign Animal Disease Incidents

The cost of recovering from serious disease outbreaks is much higher than just the cost of disposing of the infected animals. To effectively control the spread of disease, animals that might have been exposed must also be destroyed. In some cases this includes all of the animals within a geographic radius, as well as those that have been exposed through common transportation routes. Even so, the cost of slaughtering and disposing of this increased number of animals is only a fraction of the total cost of disease eradication, the greater part being that of disrupted production and trade. The following incidents are examples of this effect.

Because of its high level of virulence, foot-and-mouth disease (FMD) is particularly expensive to eradicate, and it triggers immediate export restrictions. One example is the Canadian outbreak of FMD between 1951 and 1953. By most accounts this was not an overwhelmingly large outbreak. Only about 2,000 animals had to be destroyed, at a cost of about $2 million. Trade restrictions, however, decreased the value of Canadian livestock by $650 million, and the total economic impact due to international embargoes was about $2 billion.[5] Similarly, an outbreak of FMD in Italy in 1993 cost $11.5 million to eradicate, but the marketing disruption was more than ten times this amount, about $120 million.[6] In 1996 FMD broke out among swine in Taiwan. Nearly 4 million hogs had to be destroyed, and the long-term losses to swine-related industries are projected to reach $7 billion.[7]

Another foreign animal disease (FAD), highly pathogenic avian influenza (HPAI), struck Pennsylvania in 1983. About 17 million chickens had to be disposed of, and the cost of disease eradication reached $86 million.[8] The price of poultry increased as a result, which cost consumers another $548 million. The incident cost an additional $7 million in lost wages.[9]

To date there have been 180,729 reported cases of bovine spongiform encephalopathy (BSE),[10] also known as "mad cow disease", though the actual number of infected animals is estimated at about one million.[11] A total of 1.35 million head of cattle have been destroyed, at a cost to date of about $4.2 billion.[12]

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[5] Ty Vannieuwenhoven, "Animal Health Emergency Management System," presentation at the American College of Veterinarian Preventative Medicine (ACVPM) Board Review, April 28, 2000. These figures are in 1987 dollars.
[6] Ibid.
[7] Terrance M. Wilson and Carol Tuszynski, "Foot-and-Mouth Disease in Taiwan—1997 Overview" U.S. Animal Health Association, 1997 Committee Report—Committee on Epizootic Attack. Available at http://www.usaha.org/reports/taiwanfmd.html; and Corrie Brown, "Economic Considerations of Agricultural Diseases," in *Food and Agricultural Security,* Frazier and Richardson, p. 93.
[8] Bernice Wuethrich, "Playing Chicken with an Epidemic," *Science*, March 17, 1995, and Vannieuwenhoven, "Animal Health Emergency Management System"
[9] Vannieuwenhoven, "Animal Health Emergency Management System". These figures are in 1996 dollars.
[10] "Bovine Spongiform Encephalopathy," statistics web site maintained by the Office International des Epizooties, last updated October 17, 2000. Of these, 179,257 of the cases are from Britain, and the remaining 1,472 were reported from Belgium, Denmark, France, Ireland, Liechtenstein, Luxembourg, the Netherlands, Portugal, and Switzerland. Available at http://www.oie.int/eng/info/en_esbru.htm and http://www.oie.int/eng/info/en_esbmonde.htm.
[11] Frederick Murphy, "The Threat Posed by the Global Emergence of Livestock, Food-borne, and Zoonotic Pathogens," in *Food and Agricultural Security*, Frazier and Drew Richardson, p. 22.
[12] Brown, "Agro-Terrorism: A Cause for Alarm," p. 7.

Crop Disease Incidents

Throughout history, outbreaks of crop diseases have been associated with famine. Late blight of potatoes swept through Ireland in 1845, ruining the country's staple crop and helping to bring about the famine of 1845-46. Brown spot disease of rice contributed to the Bengal famine in India in 1942-43, in which nearly 2 million people died.[13] Developing countries, many of which depend on a single crop for food and have little money for food imports, are particularly vulnerable to widespread starvation when crop diseases break out. Given its wealth and diversity of food production, the U.S. does not face this risk, but it remains vulnerable to substantial financial losses.

For example, in 1970 leaf blight destroyed about $1 billion worth of corn in the United States.[14] More recently, fusarium head blight, also called scab of wheat and barley, has affected several successive harvests in the Dakotas, Minnesota, and Manitoba especially between 1993 and 1998. Abnormally wet weather probably contributed to this disease's spread over 10 million acres, which has cost an estimated $1 billion in lost production.[15]

Even a minor disease outbreak can have severe economic effects due to export restrictions. In 1996 a fungus disease called Karnal bunt was discovered in wheat seeds that had been grown in Arizona and shipped to other southwestern states. Following this discovery, more than fifty countries—including China, the largest importer of U.S. wheat—adopted phytosanitary trade restrictions against the U.S., which are regulations intended to keep foreign plant diseases or pests outside one's borders.[16] Because of the "highly credible, rapid, and effective control and clean-up of the states concerned," however, the importers accepted a quarantine area that included just the affected areas, which allowed international trade of wheat from other regions to continue.[17] Control and clean-up by the USDA's Animal and Plant Health Inspection Service (APHIS) cost an estimated $45 million, and the impact on exports was reduced to about $250 million, compared to the $6 billion total value of U.S. wheat exports.[18]

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[13] Paul Rogers, Simon Whitby, and Malcolm Dando, "Biological Warfare against Crops," *Scientific American*, (June 1999), p. 73.
[14] Ibid., p. 73.
[15] Edward Lotterman, "Scab: The Ninth District's Agricultural Plague of the '90s," *Fedgazette*, (November, 1998), p. 1.
[16] Bruce R. Beattie and Dan R. Biggerstaff, "Karnal Bunt: A Wimp of a Disease, but an Irresistible Political Opportunity," *Choices: The Magazine of Food, Farm, and Resource Issues*, (Second Quarter, 1999). Available online at http://www.aphis.usda.gov/karnalbunt/forum/forum-arizona.html.
[17] Horn and Breeze, "Agriculture and Food Security," p. 13.
[18] Ibid.

Antianimal and Anticrop Biological Weapons Programs

The deliberate introduction of disease is not a new idea. Militaries have targeted agriculture throughout history as a means of depriving the enemy of their food supply. Over the past century, several nations developed BW for use against agriculture, as described below.

Anti-Animal and Anti-Crop BW Research during World War II

During World War II several countries, including Germany, the United Kingdom, the United States, Canada, and Japan, had biological weapons programs that conducted research on antianimal and anticrop agents. Germany's program included defensive BW research on FMD, rinderpest, and potato beetles. Despite Adolf Hitler's prohibition of offensive BW research, German scientists investigated FMD as a potential offensive weapon.[19]

Meanwhile the British developed a retaliatory capability to be used if the Germans attacked with BW. They manufactured and stockpiled 5 million "cattle-cakes" laced with lethal doses of anthrax spores. These cakes were to be dropped on German grazing lands where they would be eaten by cattle. The destruction of German herds by anthrax infection was intended to be a serious economic blow to Germany's overstrained agriculture sector.[20]

The United States, in cooperation with Canada and Great Britain, investigated many animal and plant diseases during World War II. Anthrax, brucellosis, and glanders, which are both antipersonnel and antianimal agents, were all evaluated for mass production. Other primarily defensive work was done on rinderpest, Newcastle disease, and fowl plague.[21] In addition, several plant diseases were studied for their offensive potential, including late blight of potato, rice blast, brown spot of rice, rubber leaf blight, Southern blight, and wheat rusts.[22]

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[19] *Biological and Toxin Weapons: Research, Development, and Use from the Middle Ages to 1945*, Erhard Geissler and John Ellis van Courtland Moon, eds. (Oxford: Oxford University Press, Stockholm International Peace Research Institute [SIPRI], 1999), pp. 114-116.
[20] Ibid., p. 181.
[21] Ibid., p. 240.
[22] Ibid., p. 241.

The vulnerabilities that were targeted by the U.S. anticrop program were the Soviet wheat crop in the Ukraine and the rice crop in Asia.[23] The rice fungus diseases and Southern blight were pursued as a means of destroying Japan's rice and staple cereals crops, while the potato disease research was aimed at Germany's crops.[24]

Although Japan's massive World War II BW program was concerned primarily with human diseases, considerable research on crop diseases was done as well. The Japanese investigated fungi, bacteria, and nematodes—agents that affect grains and vegetables, particularly those found in Manchuria and Siberia.[25]

BW Programs since World War II

The United States, the Soviet Union, Great Britain, and Canada continued their BW programs after the war.[26] Between 1951 and 1969, the U.S. maintained stockpiles of three anticrop pathogens: stem rust of wheat (36,000 kg), stem rust of rye, and rice blast (900 kg).[27] Then in 1969 the U.S. renounced its BW program, though it continued defensive research. All four countries signed and ratified the Biological Weapons Convention (BWC) of 1972, which prohibits the acquisition and use of biological weapons. By 1975 the U.S. had destroyed its remaining BW stockpiles.[28]

Unlike the Western programs, the Soviet BW program did not end with BWC ratification. It grew during the 1970s and 1980s to include more than 30,000 scientists and workers, as well as seven production and two storage facilities.[29] The extensive program had an antiagriculture weapons branch, run by the ministry of agriculture. This agency developed anticrop agents including wheat rust, rice blast, and rye blast, and anti-animal agents including African swine fever, rinderpest, and foot-and-mouth disease.[30]

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[23] Simon Whitby and Paul Rogers, "Anti-crop Biological Warfare—Implications of the Iraqi and U.S. Programs", *Defense Analysis*, Vol. 13, No. 3, (1997), p. 312-313.
[24] Geissler and van Courtland Moon, p. 241.
[25] Ibid., p. 139.
[26] Richard A. Falkenrath, Robert D. Newman, and Bradley A. Thayer, *America's Achilles' Heel: Nuclear, Biological, and Chemical Terrorism and Covert Attack* (Cambridge, Mass.: MIT Press, 1998), p. 67. Also Tom Mangold and Jeff Goldberg, *Plague Wars* (New York: St. Martin's Press, 1999), p. 41.
[27] Whitby and Rogers, "Anti-crop Biological Warfare—Implications of the Iraqi and U.S. Programs," p. 310.
[28] Falkenrath, Newman, and Thayer, *America's Achilles' Heel*, p. 67.
[29] Mangold and Goldberg, *Plague Wars,* p. 65; and Ken Alibek, *Biohazard* (New York: Random House, 1999), pp. xii-xiii.
[30] Ken Alibek, "The Soviet Union's Anti-Agricultural Biological Weapons," in *Food and Agricultural Security*, Frazier and Richardson, p. 18.

Ken Alibek, a former high-level administrator of the Soviet BW program, claims that by 1990, however, the Soviet Union had abandoned its antiagricultural weapons program.[31]

Iraq is also known to have developed BW recently, including anticrop agents. Its research was primarily occupied with fungi that cause damaging diseases to cereal crops: rusts, blasts, and smuts. Iran's wheat crop is thought to be the target of these pathogens.[32] In 1985 and 1988 Iraq infected test wheat fields with wheat cover smut, demonstrating the efficacy of this fungus as a biological agent. Iraq claims to have destroyed the infected wheat in 1990.[33] Wheat cover smut results in a significant crop yield loss, and it produces the highly volatile trimethylamine gas, which can cause explosions in harvesters.[34]

Actual Use and Allegations of Use of BW against Agriculture

Despite the large amount of past research devoted to anticrop and antianimal agents, BW have rarely been used against agricultural targets. During World War I the Germans clandestinely inoculated horses and mules, being shipped from U.S. ports to the Allies, with anthrax and glanders, by swabbing the animals' muzzles with the infectious agents.[35] While these pathogens carried risks to humans as well as to the animals, no instances of human illness were recorded.[36] This was part of Germany's larger biological sabotage program in which they attempted to infect draft, cavalry, and military livestock between 1915 and 1918 in Romania, Spain, Norway, Argentina, and the U.S.[37]

Japan is alleged to have used animal and plant pathogens, including rinderpest and anthrax, against Russia and Mongolia in 1940.[38] This, however, seems to be the only actual use of BW against agriculture during World War II, despite the extensive research effort in several countries at that time.[39]

Nevertheless, there were numerous accusations of BW use. The potato beetle was a serious natural concern in Western Europe during World War II. Britain accused Germany of dropping small, cardboard bombs filled with Colorado beetles onto potato fields in southern England, including the Isle of Wight, in

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[31] Ibid., p. 19.
[32] Whitby and Rogers, "Anti-crop Biological Warfare—Implications of the Iraqi and U.S. Programs," p. 305.
[33] Raymond Zilinskas, "Iraq's Biological Warfare Program: The Past as Future?" in *Biological Weapons: Limiting the Threat*, Joshua Lederberg, ed., (Cambridge, Mass.: MIT Press, 1999), p. 139.
[34] Whitby and Rogers, "Anti-crop Biological Warfare—Implications of the Iraqi and U.S. Programs," p. 305.
[35] Stockholm International Peace Research Institute, *The Problem of Chemical and Biological Warfare,* Vol. 1*, The Rise of CB Weapons* (Stockholm: Almqvist and Wiksell, 1971), pp. 216-217.
[36] Geissler and van Courtland Moon, p. 35.
[37] Ibid., p. 59.
[38] SIPRI, *The Problem of Chemical and Biological Warfare,* p. 223.
[39] Geissler and van Courtland Moon, p. 121.

1943.[40] Germany itself was worried about the possibility of an enemy introducing the beetles into its fields. In 1944 there were reports of potato beetle outbreaks in northern Bavaria and Thuringia, and the Germans were quick to confirm these along with earlier outbreaks as enemy activity. Neither Britain nor the U.S., however, considered using potato beetles for BW purposes during World War II.[41]

Allegations of BW use continued during the Cold War. For example, Cuba has accused the U.S. of attacking the Cuban people, animals, and crops with biological agents twelve times during the period 1964-97. A recent report offers explanations for each episode, and concludes that each probably occurred naturally or was the result of human activity such as trade or travel.[42] Despite the various accusations, "biological weapons use by states since World War II [agricultural or otherwise] appears to be confined to a handful of state-directed assassinations employing biological agents and toxins."[43]

Likewise, agroterrorist attacks by nonstate actors have been rare; only one case of use and one case of threatened use have been documented. The first event was in 1952, when a group called the Mau Mau, a nationalist liberation movement originating with the Kikuyu tribe, used a plant toxin (African bush milk) to poison thirty-three steers at a Kenyan mission station, located in areas reserved for the tribe. This was believed to be part of a larger sabotage campaign against the British colonists and their livestock throughout Kenya.[44] The other case took place in the early 1980s when a group of Tamil militants threatened to spread foreign plant diseases among rubber and tea plantations in Sri Lanka, intending to cripple the Sinhalese-dominated government.[45] It is not clear which Tamil group initiated the threat, but because many such groups were supported in part by the Indian government, it is possible that the perpetrator was actually a state actor. (Until the evidence is confirmed, however, the incident will remain classified as a having been perpetrated by a nonstate actor.) These are the only well-documented instances of actual or threatened BW use against agriculture by nonstate actors during the 20th century.[46]

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[40] SIPRI, *The Problem of Chemical and Biological Warfare,* p. 223.
[41] Geissler and van Courtland Moon, p. 117.
[42] Raymond Zilinskas, "Cuban Allegations of Biological Warfare by the United States: Assessing the Evidence," *Critical Reviews in Microbiology*, Vol. 25, No. 5 (1999).
[43] Falkenrath, Newman, and Thayer, *America's Achilles' Heel*, p. 79.
[44] W. Seth Carus, "Bioterrorism and Biocrimes: the Illicit Use of Biological Agents in the 20th Century," working paper, (Washington, D.C.: Center for Counterproliferation Research, National Defense University, April 2000 revision), pp. 75-76.
[45] Carus, "Bioterrorism and Biocrimes: the Illicit Use of Biological Agents in the 20th Century," pp. 161-162.
[46] However, BW have been used by nonstate actors *in defense of* agriculture. When the New Zealand government ended its rabbit control program, sheep farmers were forced to shoulder the cost themselves. In 1997 several sheep farmers illegally released a rabbit pathogen onto their farms as a cheap and decisive way to control the rabbit population, which had been eating the grass designated for sheep. Rabbit calicivirus disease (RCD) killed many thousands of rabbits before it mutated into a nonlethal strain. The farmers' improper handling of the pathogen is

NOTE: The second section of the reading, pages 17-20, starts with this page.

Crop Diseases and Pests

Most crop diseases do not kill plants outright. Instead they produce failed harvests by drastically reducing the quality and quantity of a plant's output. Unlike animals, plants do not have immune systems that actively seek out and destroy pathogens. They have different kinds of protective mechanisms, one of which is their cell walls, which are made primarily of cellulose and lignin. These rigid barriers are impervious to many pathogens, particularly viruses.[63] Whereas viruses present the greatest agroterrorist threat to animals, fungi present the biggest threat to crops. The three anticrop agents developed by the United States in the 1960s were all fungi: wheat rust, corn smut, and rice blast.

If a fungus were introduced under the right conditions, "the spores…[could be] spread for great distances by the wind and establish centers for further spread once they infect a plant. Because of infection, subsequent spread normally occurs in a series of waves, the frequency of which depends on the incubation period of the particular fungus."[64]

Just as the WTO looks to the OIE for animal export guidelines, it recognizes the International Plant Protection Convention (IPPC) as the source of international standards for the phytosanitary measures affecting trade.[65] The IPCC has 111 member countries, each of which submits its own phytosanitary restrictions—the pathogens to which imported plants and plant products must not have been exposed—according to the standards set by the IPPC and the country's specific vulnerabilities. There is no analog of List A for crop diseases, given that every country sets its own import requirements. There are,

[61] Telephone conversation with Dr. Bruce Carter, USDA Center for Veterinary Biologics (Ames, Iowa), March 28, 2000.
[62] Ibid. Dr. Carter, however, is working on the task of finding manufacturers of List A disease vaccines.
[63] Telephone conversation with Dr. Paul Kohnen, USDA ARS plant pathologist.
[64] J. H.Rothschild, *Tomorrow's Weapons: Chemical and Biological* (New York: McGraw-Hill, 1964), p. 24.
[65] "International Plant Protection Convention," available at http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGP/AGPP/PQ/En/IPPCe.htm.

however, diseases that are particularly worrisome due to their ease of transmission, high level of impact on harvests, ability to infect staple cereals, and historical consideration for offensive weapons use. Table 2 shows some of these pathogens.

Table 2: Crop Diseases of Particular Agroterrorist Concern

Crop Affected	Pathogen Type	Pathogen	Disease	Primary Mode of Transmission
Cereals (wheat, barley, rye)	Fungus	*Puccinia graminis**	Stem rust of wheat	Airborne spores
	Fungus	*Puccinia glumarum**	Stripe rust of cereals	Airborne spores
	Fungus	*Erysiphe graminis*	Powdery mildew of cereals	Airborne spores
Corn	Bacteria	*Pseudomonas alboprecipitans*	Corn blight	Waterborne cells
Rice	Fungus	*Pyricularia oryzae**	Rice blast	Airborne spores
	Bacteria	*Xanthomonas oryzae*	Rice blight	Waterborne cells
	Fungus	*Helminthosporium oryzae*	Rice brown-spot disease	Airborne spores
Potato	Fungus	*Phytophthora infestans*	Late blight of potato	Airborne spores

*Recommended for export control by the Australia Group, an international consortium that recommends items and pathogens for export control to limit chemical and biological weapons proliferation.

Source: Charles Piller and Keith Yamamoto, *Gene Wars* (New York: Beech Tree, 1988), pp.246-247.

Transmission of Crop Diseases

Plant pathogens are transmitted by wind, water, or vectors such as insects. They are also heavily dependent on environmental factors such as temperature, humidity, rainfall, and sunlight. Due to this heavy dependence on external factors, the introduction of a pathogen does not necessarily result in widespread infection. *Phytophthora infestans*, the fungus responsible for late blight of potatoes, existed in Ireland long before the 1845 blight that destroyed the Irish potato crop. It was the unique weather conditions that year, however, that allowed the fungus to reproduce and spread so quickly. There are three primary transmission modes of crop diseases.

1. Airborne Transmission of Plant Diseases: Fungi. The life cycle of fungi includes the production of dry spores, which are dispersed on the wind. "Spores…traveling on the wind can attain altitudes as high as 10 km and distances of over 1000 km down range of their origin."[66]

Once a fungus has infected an area, it is extremely difficult to eliminate all of the spores. Fungicides can help, but fungi can persist in other hosts, allowing the disease to continue infecting plants for long periods of time. Chestnut blight, caused by a fungus introduced originally from Asia, has virtually eliminated the American chestnut tree from the U.S. by this mechanism.[67]

2. Plant Disease Transmission via Insect Vectors: Viruses. As mentioned earlier, plant cell walls are impervious to viruses, which can develop and reproduce only by invading a host cell and taking over its metabolism. The only way a plant can be infected with a virus is if the virus is introduced through a broken cell wall. Insects such as aphids are often virus carriers. When an aphid feeds on a leaf, it pierces cell walls and inadvertently transmits the virus.

Although viruses can be extremely damaging to crops, their ability to spread is limited by insect movement. Generally, viruses do not have the ability to spread as far as fungi can. Virus control depends heavily upon insect control and the use of virus-resistant crop strains. Currently crop viruses are untreatable.

3. Waterborne Transmission of Plant Diseases: Bacteria. Bacteria require moisture for transmission. They cannot be transmitted on the wind, but they often travel via wind-driven rain. Splashing rainwater can transmit bacteria from plant to plant, and irrigation runoff can spread bacteria over entire fields. Insects can transmit bacteria as well. Like viruses, bacteria can cause serious plant diseases, but they cannot generally spread over vast areas as fungi can.

Pathogen Resistance in Crops

Crops can be made resistant to many diseases through genetic selection and mass production of resistant strains. Many commercial seed companies sell hybrids that are resistant to specific pathogens. Today

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[66] Eric Taylor, *Lethal Mists* (Commack, NY: Nova Science, 1999), p. 160.
[67] William Purves, Gordon Orians, and H. Craig Heller, *Life:The Science of Biology* (Sunderland, Mass.: Sinauer Associates, 1995), p. 1178.

wheat rust is controlled by the use of resistant wheat strains. Seed companies must find a new strain each year to keep up with the rapid evolution of the rust fungus.[68]

Other forms of pathogen resistance include herbicides, to eliminate weeds, and pesticides, to control insect pests. Virus-resistant plant varieties reduce the need for insect control as a means of stopping virus transmission. Insects, however, can do serious direct damage to crops, and infestations of particular insects can prompt export restrictions. The Mediterranean fruit fly, commonly known as the Medfly, lays its eggs on many types of fruit on which the larvae later feed. If the Medfly became established in the U.S., the USDA estimates that it would cost $1.5 billion per year in lost production and export restrictions.[69] The introduction of a foreign pest is another potential agroterrorist threat.

[68] Ibid., p. 536. Resistant strains of wheat are different from genetically modified strains of wheat. Resistant strains occur naturally. When a strain is found that resists a particular disease, it is selected and propagated. GMOs do not occur naturally. They are engineered to have advantageous properties, and they often incorporate genes from other species.
[69] "The Mediterranean Fruit Fly," USDA:APHIS:Plant Protection and Quarantine fact sheet, May 1999. Available at http://www.aphis.usda.gov:80/oa/pubs/fsmedfly.html
[70] Murphy et al., *Veterinary Virology*, p. 467.
[71] Murphy, "The Threat Posed by the Global Emergence of Livestock, Food-borne, and Zoonotic Pathogens," p. 23; and "CJD (New Variant) - UK: Update, June 2000," Pro-MED Mail post No. 20000707.1126, July 7, 2000. Available in Pro-MED Mail archives at http://www.promedmail.org.
[72] Improper rendering procedures are considered to be the cause of the widespread BSE outbreak. These have been changed, so no further infections are expected. For more information, see below.

Responding to the Threat of Agroterrorism:
Specific Recommendations for the
United States Department of Agriculture

Anne Kohnen

ESDP-2000-04
BCSIA-2000-29 **October 2000**

CITATION AND REPRODUCTION

This document appears as Discussion Paper 2000-29 of the Belfer Center for Science and International Affairs and as contribution ESDP-2000-04 of the Executive Session on Domestic Preparedness, a joint project of the Belfer Center and the Taubman Center for State and Local Government. Comments are welcome and may be directed to the author in care of the Executive Session on Domestic Session.

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