

California Lettuce Industry Threatened by Imported Pathogen

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The fungus *Verticillium dahliae*, which causes the disease Verticillium wilt, is an increasing problem for the California lettuce industry in Monterey and Santa Cruz counties. This paper discusses the introduction of the fungal pathogen to lettuce, policy options to prevent the disease, and ongoing research.

California growers planted 209,500 acres of lettuce in 2010. The value of California's lettuce crop, which represents the majority of United States' lettuce production, was over \$1.6 billion. A large portion of California lettuce comes from Santa Cruz and Monterey counties.

In 1995, Verticillium wilt, a disease caused by the fungus *Verticillium dahliae*, appeared suddenly and unexpectedly in lettuce in Watsonville, Santa Cruz County. Lettuce was previously thought to be immune to the disease, which affects hundreds of other plant species. In the past fifteen years, the number of lettuce fields affected has increased dramatically, reaching more than 175 by 2010, and amounting to 3,952 acres. More than 50% of the newly contaminated fields were reported in 2009 or 2010, indicating that the problem has spread more rapidly in recent years. Lettuce growers and handlers in Monterey and Santa Cruz counties are extremely concerned about Verticillium wilt.

Due to the agronomics of crop rotation, lettuce production is closely associated with the production of strawberries, spinach, and broccoli, all of which ranked in the top ten

in value of production in Monterey County in 2010. Spinach, in particular, is important because it is believed that the pathway for the introduction of *V. dahliae* into lettuce is spinach seeds. As shown in figure 1, approximately 30% of spinach seeds are grown domestically in the Pacific Northwest; the remainder are imported, primarily from Denmark and the Netherlands

Figure 2 shows the quantity of spinach seed imported by the United States. The recent increase in spinach production in California and the increase in *V. dahliae* in lettuce follow similar trends. Growers harvest spinach long before symptoms associated with the disease appear, but the Verticillium pathogen introduced from spinach seed remains in the soil. The fungus survives in the soil for up to ten years by producing black survival structures called microsclerotia.

During subsequent crop rotations, lettuce can be infected. Beyond a certain threshold of *V. dahliae* pathogen levels in the field (>150 microsclerotia per gram of soil), lettuce crops can be completely destroyed. Strawberries are also susceptible to this type of wilt. Broccoli, however, is immune

and planting it can actually reduce the levels of *V. dahliae* in the soil.

The purpose of this paper is to discuss the economic causes of Verticillium wilt, evaluate the policy options to control the disease, and outline future research necessary to solve this problem. Because spinach seed is imported, international trade is a cause of this disease. Treatment options for Verticillium wilt include: early harvest, broadcast or bed fumigation, crop rotation to broccoli, resistant varieties of lettuce, and seed testing and quarantine. Consideration of the economic and

Figure 1. Origin of Spinach Seeds Planted in the United States in 2010

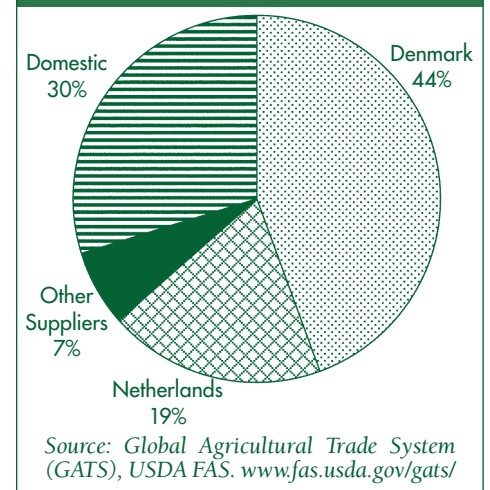
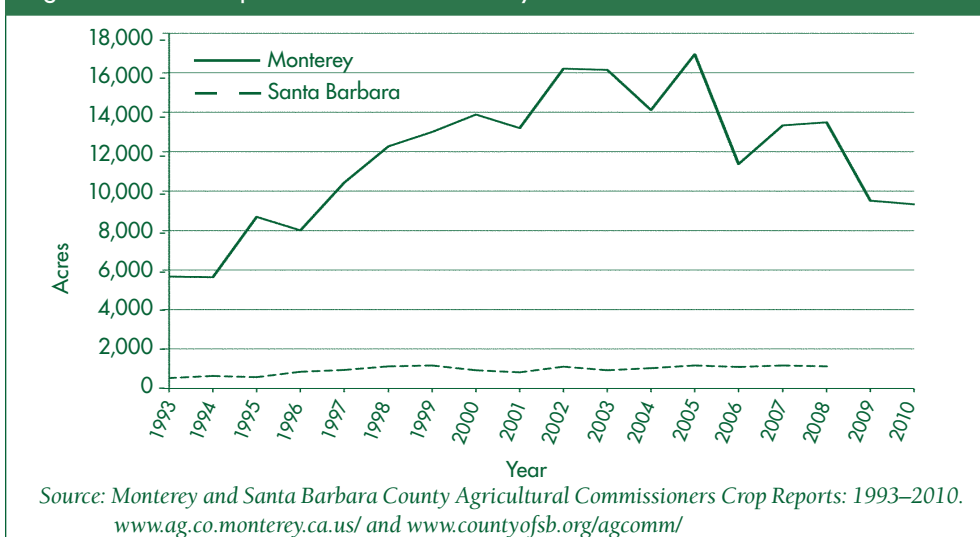


Figure 2. Spinach Seed Imported by the United States



Figure 3. Acres of Spinach Grown in Monterey and Santa Barbara Counties from 1993



practical feasibility of these different options should guide policy decisions.

Cause

Verticillium wilt is a disease caused by an invasive species. Agriculture has long been subject to significant damage from invasive species. As international trade has increased, the rate of pathogen introductions has also increased. Emerging infectious diseases (EIDs) caused by fungi threaten food security. Some estimates suggest the cost of lost crops due to non-indigenous plant pathogens in the United States is \$21 billion per year.

Economics is an important tool for invasive species research because human behavior and economic activities affect invasions. Purposefully or inadvertently, economic activity, such as transport of fungal-infected tradable goods and food, transfers alien species to new locations.

In the case of Verticillium wilt, spinach seeds entering the lettuce production regions of California contain seed-borne *V. dahliae*. Currently, the negative economic impacts of Verticillium wilt on lettuce are mostly felt in the local region, but attempts to limit new introductions may have international trade implications for the seed industry.

Genetic evidence shows that spinach seed is the primary mode of

introducing the *V. dahliae* pathogen into lettuce production fields. Analyses of the fungus from both lettuce and spinach have demonstrated that there is little differentiation between them. Additional tests have also shown that the fungus from spinach causes Verticillium wilt on lettuce.

The disease is appearing increasingly in the southern end of the Salinas Valley, where most of the current spinach production occurs, providing further circumstantial evidence that the fungus introduced from spinach is the cause of the disease in lettuce. Figure 3 shows the increase in spinach production in Monterey County, where Verticillium wilt is a problem, compared to the relatively stable level of spinach production in Santa Barbara County, where the disease has not appeared. Although historically the increase in spinach is linked to the increase in Verticillium wilt on lettuce, spinach production has declined in Monterey county since the E. coli outbreak in 2006.

Possible Solutions

Lettuce growers may not suspect that their crops are going to be affected by this disease until just weeks before the harvest when symptoms appear—at which point most inputs have already been applied. Growers may recoup some of their costs by harvesting

early, but if Verticillium wilt is too widespread in the field, handlers may refuse to accept the lettuce. Even if it can be harvested and sold, the weight of the crop will be diminished. There are no treatments for Verticillium wilt after the plants have become contaminated. Early harvest is more of a stopgap measure than a true solution.

The profit margin on lettuce is sufficiently small so soil fumigation of the lettuce fields is not economically feasible. In addition, due to restrictions on methyl bromide use, the most common and effective fumigant for *V. dahliae*, land planted to lettuce is typically not directly fumigated.

Instead, some growers fumigate with methyl bromide, plant to strawberries, and rely on the residual effect to protect two to three subsequent crops of lettuce. This method does not eliminate the pathogen, but temporarily suppresses it.

Furthermore, the decrease in Critical Use Exemptions for methyl bromide under the Montreal Protocol makes this an unlikely long-term solution. Critical Use Exemptions are granted when “there are no other technically or economically feasible alternatives or substitutes available” to treat crops and the lack of availability would result in significant market disruption.

Other fungicides to treat lettuce fields directly to control other diseases are usually applied through irrigation drip tape. However, with this method, the entire field is not thoroughly treated and, thus, is less effective on diseases for which they are used but have little or no effect on Verticillium wilt. Organic producers are especially vulnerable because they cannot use any of these chemical treatment methods.

Because such a wide variety of crops, and even weeds, can be hosts to *V. dahliae*, crop rotation is not a complete solution. However, planting to broccoli reduces the incidence of Verticillium wilt on a subsequent lettuce crop on the same field.

Table 1. Value per Acre for California Crops

	Lettuce	Broccoli	Spinach	Strawberries
Value (\$ per Acre)	7,908	5,809	6,974	43,955

Note: Average value for years 2008-2010.
Source: California Agricultural Statistics: 2010 Crop Year. USDA NASS. www.cdfa.ca.gov/Statistics/

Table 1 shows the value per acre for the relevant crops in California. Broccoli is a low-margin crop and in the prime production areas of Monterey and Santa Cruz counties, it is not economically feasible to grow, unless one accounts for the side benefits of reducing the incidence of Verticillium wilt. Most broccoli is grown in the Central Valley and Imperial County where land costs are lower. Unfortunately, if all fields affected by the pathogen were planted to broccoli with enough frequency to reduce the disease, the broccoli market would be flooded, making an already marginally profitable crop even less so.

Resistant varieties of lettuce may be part of a policy to treat Verticillium wilt, but due to the evolution of the pathogen, this is unlikely to solve the problem completely. The USDA, along with the UC Davis breeding program, does the preliminary work to develop resistant varieties and then releases the work to private companies who further develop them into commercial cultivars.

There are two races, or types, of *V. dahliae* that affect lettuce. A variety resistant to race one should be available in the next year or two. However, growers will likely face increased costs to purchase these seeds. More problematic is the evolution of the pathogen. As more growers plant the variety resistant to race one, this selects for race two, i.e., encourages the spread of race two relative to race one. New varieties resistant to race two have not been identified at this time.

Although the actions described above may play a role in reducing the impact of *V. dahliae*, the most promising policy is seed testing, treatment and, perhaps, quarantine. A similar policy exists in Monterey County for Lettuce Mosaic

Virus (LMV), which is also a seed-borne disease. No lettuce seed may be planted in the county without having first been “indexed,” or tested, to have no more than zero infected seeds in a batch of 30,000. Implementing a similar policy for *V. dahliae* would require testing spinach seeds, rather than only lettuce seeds.

The indirect nature of the *V. dahliae* contamination complicates measuring the costs and benefits of a quarantine policy. A major issue is who pays for the seed testing—seed companies, lettuce growers, or spinach growers. Another part of this policy could require seed treatment for seeds which do not pass inspection.

Researchers are developing seed treatment protocols to reduce the introduction of the pathogen. If approved for organic growers, seed cleaning would be one of the few treatment options available to them. However, the issue remains—spinach growers, lettuce growers, and seed companies disagree on who should be responsible for the cost of these measures.

Current and Future Research

Verticillium wilt is likely to become increasingly important if current trends continue. Spinach production is likely to remain important to Monterey and Santa Cruz counties, so the number of infected fields is likely to continue increasing. The tightening of restrictions on methyl bromide use reduces the current and most direct solution. Given these facts, it is a critical time to study the impacts of the disease on the production of lettuce and related crops to recommend appropriate policy responses for the Verticillium wilt problem.

Goals of ongoing work include: characterizing populations of the fungus *V. dahliae*, determining the impact of the seed trade on Verticillium wilt, and studying sources of resistance and seed treatments for both conventional and organic growers. Learning more about each of these areas will allow for more effective and thorough economic analysis of Verticillium wilt, such as its cost on the leafy greens industry, the policy options available to mitigate these costs, and the international trade implications.

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For additional information, the authors recommend:

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