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Growing for the future:

Collective action, land stewardship and soilborne pathogens in California strawberry production

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California accounts for more than 80% of U.S. strawberry production, a harvest worth \$2.5 billion in 2014. Fertile soils and the prevailing climate on the Central Coast support per acre yields twice that of Florida, the second largest producer, and 10 times more than most other states.

Yet California strawberry growers face significant challenges. Among the most important is the declining availability of suitable land. The potential for a given field to produce an acceptable yield depends not only on physical and chemical characteristics of the soil but also, critically, on the presence or absence of soil dwelling pathogens that can infect strawberry roots and cause diseases that limit fruit production. As described below, effective control of soilborne pathogens of strawberries was once readily achieved by means that are no longer available to strawberry growers.

It now seems likely that no single measure will suffice to meet the challenge of soilborne pathogens. Rather, a multi-faceted approach will be

required, one that integrates advances in disease resistance through breeding with closer attention to the factors that influence the survival, activity and spread of pathogen populations in soil. Many of the latter, such as rotating crops and cleaning equipment, frequently involve multiple operators. As a result, there is a need to recognize that pathogen-free soil is effectively a common-pool resource and that protecting it will require collective action.

The end of methyl bromide

Since the early 1950s, diseases caused by soilborne pathogens have been managed primarily through the use of preplant soil fumigation. Before that time, Verticillium wilt, caused by *Verticillium dahliae*, imposed a major limitation on strawberry production. Recognition of the fungicidal properties of chloropicrin and the enhanced efficacy achieved by addition of methyl bromide lifted this

Sustaining high strawberry yields will require an integrated approach that includes collaborative management of fields to limit the spread of soilborne pathogens.



limitation and allowed for a dramatic expansion in the production of fresh strawberries in California. However, because methyl bromide was identified as a contributor to ozone depletion, the United States and most other nations agreed to phase out its use as a soil fumigant, in line with the Montreal Protocol approved by the United Nations in 1987. This phaseout was to be completed by 2005 in developed countries and 2015 in developing countries, though critical use permits have extended use in California strawberry production, with incremental allocation reductions each year. Today, phaseout is nearly complete.

Consequently, chloropicrin is now typically the sole fungicidal fumigant in mixtures applied to soil prior to planting strawberries. Whereas control of Verticillium wilt was routinely achieved with a 2:1 blend of methyl bromide and chloropicrin applied at 350 pounds per acre, chloropicrin alone is not fully effective even at 400 pounds per acre, which is well above usual application rates. The efficacy of soil fumigation has been further constrained by the shift, for economic reasons, to drip application of fumigants to beds, rather than flat fumigation of an entire field. Bed fumigation fails to fully treat the soil, which allows for a progressive increase in soil inoculum levels over time.

Emerging problems

The adoption of altered fumigation practices has been closely associated with the emergence of diseases not previously known to affect strawberries in California. These diseases include Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *fragariae*, and dieback caused by *Macrophomina phaseolina*. A similar pattern has been

observed elsewhere in the United States and in other countries where methyl bromide is no longer used, such as Spain, Israel and South Korea, strengthening the causal relationship between diminished efficacy of fumigation and increased prevalence of disease caused by soilborne pathogens.

Because decades of study have failed to identify an environmentally acceptable and cost-effective substitute for methyl bromide, it seems unlikely that preplant fumigation will ever again provide complete control of soilborne diseases.

Multiple strategies

Sustaining high yields will require an integrated approach that employs more disease-resistant cultivars and cultural practices that can suppress pathogen activity in soil.

Higher levels of genetic resistance to disease in strawberry cultivars can be achieved through breeding. However, this disease resistance will never be complete and it will always be subject to compromise as resident pathogen populations evolve and new strains are introduced.

Accordingly, while genetic resistance will be a central strategy in disease management, it must be coupled with measures that minimize inoculum levels of strawberry pathogens in soil.

Such measures can include rotation of strawberries with non-susceptible crops, which provides an interval during which pathogen populations can decline by attrition. The rate of attrition is quite variable and dependent on many factors, but in general, a pathogen population may be expected to decline by approximately 50% each year when no host plant is available. Growers who do not rely on soil fumigation aim for a 3- to 4-year rotation to maintain economically viable production levels.

Soil amendments such as compost can also be beneficial by encouraging the growth of microbes (bacteria and fungi) that will inhibit plant pathogens and limit their ability to initiate infections.

It will also be important to limit opportunities for introduction of inoculum with soil or transplants. In the past, with fully effective fumigation practices, any pathogens that may have been present by the end of one season would likely be eliminated before the next crop was planted. Now, however, growers need to be mindful of the risks that attend movement of soil into their fields, as can occur with farming equipment and hand-held implements. Once a pathogen is established in a field, soil from that field can serve as a source of inoculum for other fields when equipment moves between them. It should be noted that because a pathogen population must increase to a certain threshold before it causes disease, the absence of symptoms offers no assurance that a field is free

A cross section of the crown of a strawberry plant with Fusarium wilt. The reddish-brown coloration is due to damage caused by growth of *Fusarium oxysporum* f. sp. *fragariae*.



of plant pathogens. Consequently, it is always advisable to limit movement of soil between fields. This can be accomplished to a considerable degree simply by using high-pressure water to remove soil from equipment.

Collective action

The withdrawal of methyl bromide increases the mutual dependence of growers: to the extent that individual growers do not take steps to manage the spread of soil pathogens, the entire community will suffer. Although land suitable for strawberry production is privately held, it may be seen as a common-pool resource. And to avoid a tragedy of the commons, it must be managed with a degree of collective action.

There are a number of obstacles to collective action. Using soil amendments, rotating crops and thoroughly cleaning equipment between fields all add costs. But the associated benefits are not fully realized immediately — rather, these actions must be justified as longer-term investments in the productivity of the broader land resource. In addition, while growers working their own land stand to eventually realize a direct return from such investments, growers on leased land may not. Furthermore, implementing these practices often involves other operators — such as vegetable growers, specialty equipment operators and harvesting crews — who may have little stake in helping to control the pathogens that affect strawberries.

Incentivizing collective action requires a means of incorporating the production risk posed by soilborne pathogens into the valuation of land, providing a financial basis for engaging growers and landowners in protecting fields against infestation. Making this type of valuation work demands more efficient — faster and less costly — quantitative measures of pathogen populations in soil. In addition, to properly gauge the risk posed by a given inoculum level, it will be necessary to better understand how physical, chemical and biological soil characteristics influence the activity of plant pathogens. This knowledge could then be used to establish metrics that characterize the inherent capacity of soil to suppress pathogen activity. These are areas of active research that involve collaboration among the University of California, the U.S. Department of Agriculture and the strawberry industry. Much progress has been made but many challenges remain.

Along with development of more effective soil-borne pathogen assessment tools, it will be necessary to demonstrate to landowners and growers that measures of disease risk influence the value of the land in a manner that can be reliably quantified. If these efforts are successful, it should be possible to justify investments that reduce risk.



For such investments to become an industry standard will require a degree of communication and collaboration on a regional scale that has not been common in California agriculture. However, history shows that such collaboration is possible and can be highly effective. In the 1960s, lettuce growers in Monterey County agreed to adopt a “lettuce free” period from December 7–21 each year when no lettuce can be grown, to help manage the disease known as lettuce mosaic. This agreement, which remains in force today, has been an essential element in the effective management of a devastating disease. While this example offers a hopeful indication of what can be achieved, the challenge facing strawberry growers is more complex and the cooperation needed will be more extensive. Work toward this goal benefits from a strong social network, and a research and extension system in California, which lay a good foundation for developing local and public cooperative governing mechanisms for soil to sustain a productive strawberry industry into the future. At a pivotal time when land is still productive but pathogens are becoming more widespread, a regional plan for maintaining uninfested, pathogen-free soil has an opportunity to emerge as the foundation for a sustainable industry in the absence of fumigation. [CA](http://calag.ucanr.edu)

Breeding can be used to achieve higher levels of resistance to disease. The San Andreas cultivar (left) is resistant to Fusarium wilt, while the Albion cultivar (right) is susceptible.