SCOTT BAUER/USDA

TEST PLOT U.S. Department of Agriculture researchers study biological pest control methods on strawberries.

STRAWBERRIES HANG IN THE BALANCE

With the loss of fumigants, growers face a daunting search for ways to **CONTROL SOIL-BORNE PESTS**

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THIS MONTH eager shoppers celebrate the arrival of fresh, sweet, juicy strawberries. The tasty but delicate fruit is beloved by humans—and also by dozens of insects and disease organisms ranging from aphids to verticillium fungi.

To give their plants a healthy head start, many strawberry growers rely on fumigants to control soil-borne fungal diseases, nematodes, and weeds. But these effective tools are on their way out. Environmental and health regulations, including the approaching phaseout of methyl bromide, have severely constrained the type and amount of fumigants that can be used.

Moreover, no new chemical soil treatments are in the pipeline, experts say. Growers face the scary prospect of raising strawberries with little fumigant or none at all.

Researchers and farmers hope to replace fumigants by scaling up nonchemical soil treatments and developing disease-resistant plant varieties and beneficial soil microbes. But none of the approaches have yet been proven at large scale. And it is unclear whether they will add up to yield the volumes that growers—and strawberry lovers—have come to expect.

More than 80% of U.S. production of fresh and frozen strawberries comes from coastal regions of California. According to the California Strawberry Commission, the crop is worth about $2.6 billion annually. The commission and its grower-members have sponsored research on methods to replace fumigants for more than a decade.

"The reason we had [fumigants] in the first place was the tremendous potential for crop losses," explains A. G. Kawamura, whose family business, Orange County Produce, grows strawberries in California. "Now we don't have methyl bromide, and the regulatory system is getting tougher and tougher. We're seeing significant diseases that had been suppressed for all these years come back."

Methyl bromide is the fumigant that growers will miss most. This "surefire" pesticide was introduced in the U.S. in 1961. It is applied as a gas to raised soil beds before strawberry plants are transplanted. Farmers place tarps or plastic film on treated fields to trap the gas, which helps it work better and protects workers and people who live nearby.

"The whole modern strawberry industry grew up around methyl bromide," says Carol Shennan, professor of environmental studies at the University of California, Santa Cruz. The economics of strawberry growing are based on farmers' ability to grow the fruit continuously on the same fields, or to rotate strawberry with vegetable crops that are also grown on fumigated soils. "Fumigants are the linchpin of the whole system," she says.

A colorless, odorless gas, methyl bromide is irritating to the eyes, skin, and mucous membranes of the upper respiratory tract. It can cause serious lung injuries if inhaled. In the 1980s and '90s, antipesticide activists in California campaigned against its use.

But it's the molecule's behavior in the atmosphere that sealed its fate: In the presence of light, methyl bromide degrades, releasing ozone-destroying elemental bromine. In 1990, an addition to the Montreal Protocol on Substances That Deplete the Ozone Layer mandated its phaseout in developed countries by 2005.

Every year since 2005, growers have petitioned for—and received—critical-use exemptions for methyl bromide on strawberry fields and for uses such as fumigating grains and other crops after harvest. But the exemptions have required growers to cut back use of the chemical drastically over the years. Environmental Protection Agency filings suggest that the exemptions will end completely after 2016.

A FEW OTHER fumigant molecules, notably chloropicrin and 1,3-dichloropropene, or 1,3-D, are still in use, but none have the broad pest-destroying capability of methyl bromide. In addition, chloropicrin, like methyl bromide, can cause respiratory health effects, and 1,3-D is listed as a known carcinogen in California. The state restricts both fumigants by requiring location-specific application limits and large buffer zones.

Strawberry growers would like new fumigant active ingredients or the ability to use existing ones every four or five years, but the industry as a whole is not pursuing those strategies. "There is lot of public sentiment against use of fumigants—especially for a nonstaple crop like strawberries," Shennan explains.

Instead, growers will have to speed up a transition that began years ago: enhancing soil—rather than merely sterilizing it—to grow stronger plants, according to Kawamura. "There was a realization that you needed to add back organic matter, to invest in the ground," he says.

The 20% of conventional strawberry farmers who also grow organic strawberries can turn to methods they use with their organic crops. For instance, organic growers rotate their strawberry fields and grow cover crops in the in-between years. Crops such as mustard and other members of the brassica family help break the pest cycle by interrupting the growth of disease microbes and nematodes. They also suppress weeds and build up the soil with organic matter.

BUT EVEN SUPPRESSED pests can explode in population depending on weather conditions, such as a long, cold, rainy stretch. To get problem fields in shape for planting, organic growers turn to nonchemical methods designed to kill the organisms, including blasting their plots with steam.

Organic tricks of this type are of interest to researchers seeking to help conventional strawberry farmers cope with the loss of fumigants. They have been studying how well, and how economically, organic methods can work on the scale required for conventional operations, explains Carolyn O'Donnell, communications director for the California Strawberry Commission.

"We've spent at least six years looking for alternatives, and we've been down a couple of paths that haven't penciled out," she says. The steam method can't be scaled up for an entire conventional field, she adds, but it is a tool that farmers can use on areas where pests have gained a strong foothold.

Another unsuccessful method was raising strawberries in nonsoil substrates, such as coir, a fiber that comes from coconut husks. Coir is popular with hydroponic growers because it provides a hospitable, airy zone for roots without hosting disease organisms. But substrates don't hold water or fertilizer well and thus require prohibitively large investments in specialty irrigation equipment to work at field scale.

Still in the running, O'Donnell says, is anaerobic soil disinfestation, or ASD. As the name implies, ASD works by creating anaerobic soil conditions, which are toxic for plant pathogens. Farmers spread a carbon-rich layer such as rice bran, saturate the ground with water, and then lay down a seal of plastic tarp. This allows anaerobic microbes to metabolize the carbon source, creating metabolites that kill pests.

Shennan's research group has been studying ASD. She says it works well to control verticillium wilt but is less effective in controlling some strains of fusarium, another common fungal disease. "Now, we're working on how to fine-tune the system based on location, climate, and pathogens of concern. It won't be the same recipe for everyone."

It's clear that farmers will need innovative production practices, but they will also need new strawberry varieties that are less susceptible to soil-borne diseases. And so they are closely watching a new effort at UC Davis led by plant breeder Steven J. Knapp.

The modern strawberry is a cross of two wild varieties, one from eastern North America and the other from Chile. An octoploid, it has eight sets of chromosomes and four genomes. Knapp says his team is mining these complicated genetics for resistance traits, which can be amplified through traditional breeding. They are also canvassing the planet's wild strawberry plants for new traits.

Today, the UC Davis greenhouse contains 1,600 unique varieties. "We are going to look very broadly at global diversity in strawberries for native genes we can introduce," Knapp says.

He is confident that varieties with some resistance to the key soil-borne diseases will be developed. About six years of development and testing will be needed before new varieties are broadly available to growers.

In the meantime, Kawamura, the strawberry grower, is learning how cover crops and beneficial organisms can help his strawberries fend off hungry soil pathogens. "I'm trying to learn these different relationships—what kind of populations lead to different results."

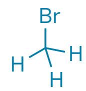
Still, Kawamura is worried about the lack of urgency to find solutions that he and other growers can trust. "We need the strawberry commission and the universities to make the investments in these new breeding efforts and new tools—to pursue new science as it emerges—and we don't see that happening," he says. ■

TIMELINE

Strawberry growers' ability to use fumigants is slowly evaporating

1987 Montreal protocol is signed, requiring the phaseout of substances that deplete the ozone layer.

1990 The London Amendment to the Montreal protocol adds methyl bromide, a common soil fumigant, to the list of ozone-depleting substances to be phased out by 2005 in developed regions.



Methyl bromide

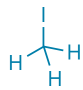
1990 California suspends use of the soil fumigant 1,3-dichloropropene, calling it a known carcinogen. Along with the fumigant chloropicrin, 1,3-D was considered a potential replacement for methyl bromide.

1,3–Dichloropropene

2005 California authorizes limited use of 1,3-D with strict control measures, including new labels, reduced application rates, and buffer zones.

2005 The Environmental Protection Agency starts seeking annual critical-use exemptions for methyl bromide from the Parties to the Montreal Protocol. Each year since, California strawberry growers have received an exemption, though usage amounts decreased.

2010 California approves the use of methyl iodide as a methyl bromide replacement. But a scientific review suggests methyl iodide could alter DNA and taint groundwater. A coalition of environmental and farmworker groups sues the state.



Methyl iodide

2012 Tokyo-based Arysta LifeScience decides to stop distributing methyl iodide in the U.S.

2013 EPA authorizes methyl bromide critical-use exemptions for 2014 and 2015 for California strawberries and cured pork.

2015 California places tough new restrictions on chloropicrin, including buffer zones and application limits.

Chloropicrin

2016 Likely for the final year, California strawberry growers will be allowed to use methyl bromide under a critical-use exemption.

SOURCES: C&EN, *Federal Register*, European Food Safety Authority, California Department of Pesticide Regulation