Mathematicians help California drought-weary berry growers address water issues

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It's not the way we're accustomed to thinking of farmers, but John Eiskamp uses an iPad routinely to ensure his blackberries and raspberries don't get more water than they need during these excessively dry times. The iPad connects to tensiometers that measure soil tension and help determine when to water the plants. Credit: National Science Foundation

It's just not summer without a piece of strawberry shortcake. Pinches of sugar release a flood of fragrant juices that pinken clouds of whipped cream and salty sweet cake on a sweltering day for a refreshing dessert that says, "Yes, summer has arrived."

Just as representative of this season's delights are those joys we associate with water: sparkling swimming pools, cooling mists of summer hoses and the scent of warm pavement suddenly accosted by raindrops.

As much as these two images fit snugly in sentimental minds, they do not coexist in California's berry farmlands, which reportedly produce 80 percent of the nation's strawberries.

According to the U.S. Geological Survey, "In 119 years of recorded history, 2013 was the driest calendar year for the state of California." To be sure, California, and specifically coastal Central California, is never overflowing with water in any year, but recent, yearly water-supply needs caused serious concern.

In January 2014, California's snowpack, which normally provides about one-third of the water used by California's cities and farms, was measured at 12 percent, the lowest for January in more than a half-century of record keeping. Governor Jerry Brown declared a drought emergency for the state, long before the "dry season," which usually occurs during the summer months.

Then, on April 1, the California Department of Water Resources measured water content of statewide snowpack at 32 percent of normal expectations for that time of year. California's water managers saw the result as truly foreboding since April typically is considered the snowpack's peak when snow and ice begin to melt into streams and reservoirs, and conditions were only expected to worsen.

Drought conditions like these, occurring annually, prompted policymakers, conservationists, geologists, hydrologists, farmers and business owners to creatively address the state's water problems. And, in an interesting turn, mathematicians factored into this mix with one of the most unique perspectives of all.

The berry business

John Eiskamp, owner and president of JE Farms describes the Pajaro Valley in Central Coastal California as the "berry capital of the world." Strawberries reign supreme, followed by raspberries and then blackberries, but ultimately, it's a berry world in his Santa Cruz County.

"This is an agricultural area," he said. "It's the driver of the economy. It provides the majority of the jobs. It provides the majority of the support industries that are here for agriculture—the companies that sell the product, the supplies, and the inputs that we growers use to produce the crops."

So, water shortage issues—even for berries that aren't the thirstiest crops by a long shot—still need water to produce saleable, harvestable fruit. According to Eiskamp, agriculture represents 85 percent of the valley's water usage, but because of that the growers know they must be good stewards of the limited water supply. Not surprisingly, they already have explored various crop rotation and water conservation strategies. However, this problem only worsens as each year passes. So, in 2011, a National Science Foundation-funded math institute, the American Institute of Mathematics (AIM) in Palo Alto, Calif., got involved in what they describe as an "optimization problem."

Math: It's not just for spreadsheets and bottomlines

Dried-up strawberry leaves are the norm in Central California's persistent drought conditions. According to the U.S. Geological Survey (USGS), "in 119 years of recorded history, 2013 was the driest calendar year for the state of California." Credit: National Science Foundation

One of eight NSF-funded math institutes, AIM brings 800 mathematicians from around the world to Palo Alto each year to study a "whole variety of programs," according to its deputy director Estelle Basor. Small research groups with "applied" objectives come for weeklong stints, modeling neural effects related to migraine headaches, more efficient medical imaging or, in this case, improved water use in drought-stricken areas. Additionally, the institute spends even more time on its initial focus of "pure math" research.

"I grew up in California. My father was an apple grower, and my mother's family was also involved in farming," mathematician Basor said. "So many aspects to farming are difficult. There are so many unknowns—weather, what other people are doing in other countries, pests, and supply and demand. I'm not sure that a lot of the public actually realize the risks involved. So, if we [mathematicians] can just help smooth out some of the decision-making process and help solve a few of the problems that growers might have, I think it's a really good step forward."

So, Basor talked to Driscoll Associates, familiar to many as purveyors of of Driscoll's berries, and invited them to participate in an institute workshop that brought together 30 mathematicians from around the world to discuss sustainability problems. Nine of the participants worked on the berry problem, and along with three industry representatives, got the ball rolling. These collaborators then formed a smaller group to focus on the water supply's confined aquifer and its chronic overdraft of water that had persisted over many years.

"We were given a list of possible changes that could happen in terms of crop rotation, fallowing land, looking at developing recharge areas to capture rainfall to reduce the amount of water that's being taken out of the aquifer or the ground water region," said Katie Fowler, an associate professor of mathematics at Clarkson University in Potsdam, N.Y., and member of this math team.

She explained how they could look at the problem simplistically by just considering crops' water consumption and different planting strategies. But, more sophisticated, elegant modeling included soil properties, precipitation data, topography and run-off measurements. With essentially two tiers of data, they could create a model that minimized aquifer impact and found ways to recharge it naturally.

"The approach is an example of 'multi-objective optimization,'" she said. "We've developed three performance metrics. A person is going to want to try to make as much profit as possible using the least amount of water while meeting market demands. And those [goals] are naturally competing. So our most recent work has been towards offering a set of possible solutions with a clear description of those trade-offs."

In fact, another researcher, Lea Jenkins, an associate professor in mathematical sciences at Clemson University, describes the model as "stochastic," which means values of variables are random, versus "deterministic," when a problem has parameters with fixed values.

"This problem is about math," said Dan Balbas, vice president of operations for Reiter Affiliated Companies, a grower for Driscoll's, and who attended the 2011 workshop. "You've got a given resource, so how do you maximize it to maintain sustainability and do the right thing from an economic and environmental standpoint, marrying the two. It's math. It really is math. I think the hard thing is getting the input numbers right because it's a tricky thing to quantify, but it's absolutely a mathematical situation. It's how much water do we have, and how do we best use it. It's numbers."

And it's involvement from growers that make this process work.

"Part of the reason we like to come out here is to get farmers to help us—to make sure that the models we use are reasonable or are somewhat accurate and represent a reality that they're living in," Jenkins said. "And the best we can do is give them possible solutions to a very complicated problem and then ask them how they can help us improve those solutions."

Pajaro Valley has long been known for its perfect conditions for strawberry growing. Credit: National Science Foundation

Interestingly enough, as the mathematicians talk about their process thus far, they admit that while they have collaborated with a variety of players in this issue, they still need to bring in sociologists and environmental economists to improve their model.

A better future for berries

So, this team of mathematicians has now created models that help identify which crops to plant where and when. With iPad in hand, growers like Eiskamp and Balbas can go to the fields connecting to wireless tensiometers in real time to essentially tell them when plants have been watered sufficiently, minimizing waste and ensuring fertilizers stay in the root zone where plants can most efficiently access them and keep from contaminating the water aquifer.

"The thing the math institute best did was shed light on per-unit of water—what is the best crop to grow?" Balbas said. "We found that raspberries—from a per-unit-of-water standpoint—were a better crop, so we've grown the raspberry program a little bit. Of course, that changed the economics. In fact we have so many more raspberries now, it would be good to do the analysis again. It's a moving target. There are a lot more raspberries in the valley, partly because of water, but partly because it was just good business."

Ultimately, this mathematical perspective to addressing irrigation, crop rotation and drought mitigation is something that can be applied elsewhere.

"You have a set of crops that you're planting where you are realizing a profit," Jenkins said. "The crops need certain resources to survive. It might be a berry farm here, but it might be a wheat farm in the Midwest. And it might be a soy bean or a corn farm in the Southeast."

The nuances that customize the models come with specific local or state government regulations or water management requirements.

"Water is a resource that needs to be conserved, and there are competing interests," Jenkins added. "There are environmental and ecological interests associated with keeping certain wetlands that might go dry if an underlying aquifer is overused. And the economy of a local region may depend on the economies of the farmers, so if the farmers aren't realizing the profit they need, then that impacts the economy of the whole region.

"There are not only ag users, but also urban users and recreational users. To get a unified perspective, ultimately everybody needs to get involved."

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