TAL-YA AGRICULTURE SOLUTIONS

Farmers in Israel have started using plastic irrigation trays to collect dew and funnel it to the plant.

WATER

The flow of technology

Farmers must develop new approaches if they are to keep producing crops as water supplies dwindle.

BY KATHERINE BOURZAC

On a still, warm evening in mid-June, leaves are reflected in the cool water that fills the irrigation channels of a pecan orchard in Clovis, California. This placid scene seems to have barely changed in the past 40 years.

Underground, however, the water table tells a different story. Satellite data show that in California's Central Valley, the most productive agricultural region in the United States, water levels in the aquifers have fallen by more than 20 millimetres a year between 2003 and 2012. The total volume of water lost in that period was about 30 billion cubic metres — almost the same as the capacity of the largest reservoir in the United States, Lake Mead in Nevada. The river basins that feed the aquifers are themselves shrinking, owing to a reduction in snowmelt from the surrounding Sierra Nevada mountains.

"California is facing a water crisis of epic proportions," warns James Famiglietti, director of the University of California Center for Hydrologic Modeling in Irvine. If present trends continue, he says, the Central Valley will run dry in 60 to 100 years.

This region is far from unique. Since 2002, when the first water-monitoring satellites were launched, Famiglietti has mapped diminishing groundwater reserves around the world (see 'Diminishing reserves'). His studies show, for example, that in the Indian states of Rajasthan, Punjab and Haryana, 109 billion cubic metres of water were lost from 2002 to 2008 (ref. 1), and in the Tigris and Euphrates river basins, shared by Turkey, Syria, Iraq and western Iran, 144 billion cubic metres of water were lost from 2003 to 2009 (ref. 2).

Agriculture accounts for about 70% of the world's freshwater use. Much of the irrigation water comes from underground reserves. But water is becoming an increasingly scarce resource — in many areas, climate change will result in more frequent droughts (see 'The dry facts', page S2). Less rain will create an even greater need for irrigation. Farmers around the world will need to find ways to increase their water supply or reduce their water use if the world is to achieve its aim of greater food security.

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DRIP FEEDING

Parts of the world with long histories of water shortages could serve as models. In Israel, for example, innovative use of water in agriculture is a matter of survival, says Alon Ben-Gal, an environmental scientist at the Gilat Centre, part of Israel's Agricultural Research Organization. Most of the country's farmed land is semi-arid with an annual rainfall of about 500 millimetres. "We hardly have enough water to drink," Ben-Gal says. "If we want to have agriculture, we don't have much of a choice but to embrace new technologies." This virtuosity is widely acknowledged. “Israel is off the charts in making every drop count,” says Famiglietti.

Not all irrigation is equal. Furrow irrigation, like that found in the orchards of California, is 64% efficient at getting water into plants for transpiration and growth, as opposed to being lost through evaporation or percolation deep into the soil. Sprinklers are a bit better, at about 75%. The best way, with an efficiency of 90%, is micro-irrigation, which uses plastic tubing to drip water at the base of plants in a regulated way.

Most of the water taken up by plants simply passes through them without being used. In order to decrease the amount of water the plant loses, scientists including Ben-Gal are trying to time the application of micro-irrigation drops to match up with the crop’s actual water use. The same crop may require 3–4 times more water in a hot, dry place than it would in a cool, humid one. Ben-Gal has shown that near-continuous trickle irrigation improves the efficiency of water uptake by the roots of sunflowers, one of Israel’s primary crops, compared with applying the same total amount of water once every 8 days, once every 2 days, or even 8 times a day[3].

SOLAR SYSTEMS

In Israel, 70% of agriculture relies on irrigation. At the other end of the spectrum, subsistence farmers in developing countries lack even the most basic water management technologies. In sub-Saharan Africa, for example, only 4% of agricultural land is irrigated, and most of that is concentrated in four countries: Madagascar, Nigeria, South Africa and Sudan. The Sudano-Sahel region of sub-Saharan Africa has significant groundwater reserves, but subsistence farmers lack the infrastructure and resources to pump it out.

Rural farmers in Benin, a small country in the Sudano-Sahel, typically grow one or two hectares of staple crops such as maize (corn), millet or tubers, relying on the rain that falls during a three- to six-month wet season. This dependence imposes a pattern of seasonal poverty and malnutrition. All the farmers are on the same schedule, so if the rains come they find themselves selling the same crops at the same time, creating gluts that depress prices. If the rains fail, none of them have crops to sell and they all go hungry.

A pilot project to bring solar-powered drip-irrigation systems to rural farmers in the Kalalé district in the north of Benin shows how these problems might be overcome[4]. In 2007, the Solar Electric Light Fund, a non-governmental organization based in Washington, DC, gave photovoltaic water pumps to farmers in the region, at a cost of about US$400 per farmer. The systems pump water from the ground at a rate determined by the sun. On sunnier days, when plants use more water, the photovoltaics produce more power, and more water drips onto the crops.

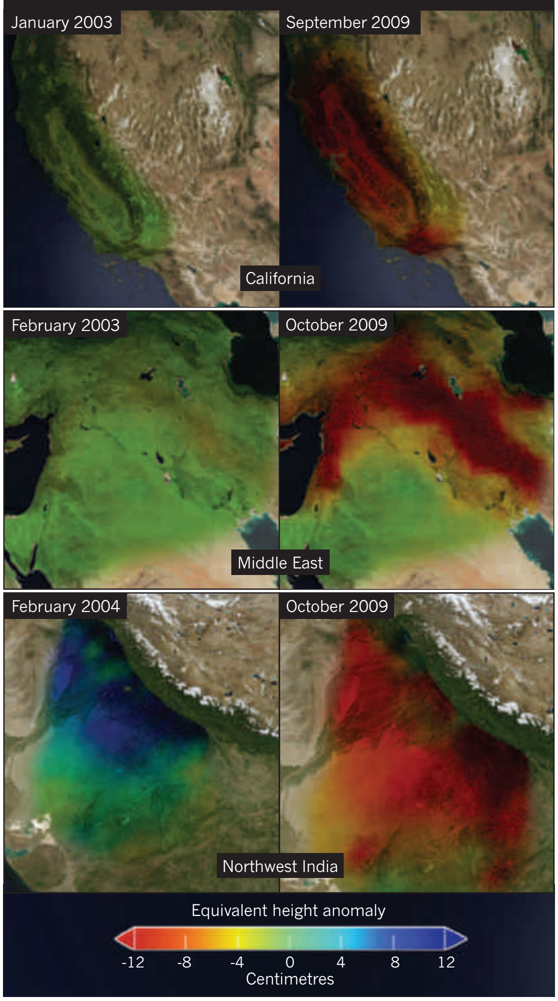
Stabilizing farmers’ access to water, and minimizing their vulnerability to drought, has a positive domino effect, says Jennifer Burney, an environmental scientist at the University of California, San Diego, who has been studying the Benin programme. Burney says that the irrigation pumps enable farmers to grow crops at times of year when there is no rain. This removes the problem of all the farmers trying to sell the same crops at the same time. What’s more, farmers with pumps are growing a greater diversity of crops, including green vegetables, improving their nutrition and financial situation as well.

So far, Burney’s team has published results from only the first two years of the project. In her initial study, households with pumps increased their vegetable consumption by 3–5 servings per person per day (where one serving is approximately 150 g). These families were also less likely to feel chronically food insecure[4]. In the long term, she says, “families with the pumps are using increased income to buy more food, and to invest in assets like livestock and school fees.” The programme has been expanded to 10 villages in Benin.

Alternatives to solar-powered pumps include hand pumps and diesel-powered pumps, which provide similar benefits at a lower cost. However, both have their drawbacks: hand-pumps are extremely labour intensive, and the diesel ones require continued access to, and spending on, fuel, says Burney. But no matter how these systems are powered, rural farmers who live on less than $1 a day cannot afford to pay the upfront costs of irrigation systems, and need access to the financial system in the form of microloans to support these investments.

DIMINISHING RESERVES

Over the years, the GRACE satellites have recorded massive water loss from aquifers around the world, as great as 4 cm per year (equivalent water depth) in some regions[1,2,7].



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REDUCING USE

More complex technologies may help in parts of the world where water use faces a rather different problem. In the midwestern United States, climate change is regarded less as a scientific issue than a political one. The region suffered a drought in 2012 that some climatologists saw as a preview of what might be coming with climate change. The Ogallala Aquifer, which underlies eight states in the region, is heavily used. Unless demands on the aquifer change, its southern extension, under northern Texas, may dry up in just 30 years, says Famiglietti. Here, economic pressures promote the overuse of water, and irrigation engineers hope to make a difference by arming farmers with data.

It can be difficult for farmers to decide how much to irrigate. Pumping is not expensive, and this can lead to over-watering, says Freddie Lamm, an irrigation engineer at Kansas State University in Colby. It costs $10 to pump each additional centimetre of water onto a hectare of corn, says Lamm. Additional irrigation can improve yields and boost profits, and there’s little disincentive to putting down a bit too much water. So farmers often do, just to make sure there’s enough.

The main crops in this region are commodities such as maize and soybeans, irrigated by large sprinklers or elevated pipes fitted with water hoses that reach the ground. Drip irrigation, which uses less water and has less wastage from evaporation, would save water, but the systems cost twice as much and require more maintenance. Drip irrigation is appropriate for higher-value crops, such as the fruit and vegetables grown in Israel, but is too expensive to use for the commodity cereals that dominate farming in the Midwest, says Lamm. However, if a water-saving technology is priced right, is easy to install, maintain and use, and makes predictions so reliable that farmers trust it to ensure they are not underwatering, then Lamm believes farmers will take it up.

Susan O'Shaughnessy, an agricultural engineer at the US Department of Agriculture's research service in Bushland, Texas, is developing a monitoring technology she believes will have the right price point. She is studying the use of sensing networks to monitor plant stress and soil moisture locally in real time, so water can be delivered precisely when and where it is needed. Infrared temperature sensors mounted on irrigation equipment monitor plants' temperature throughout the day. If the plants are the same temperature as the air or cooler, they are fine. If they are hotter than the ambient air, especially early in the morning, they are stressed and need water. In studies by O'Shaughnessy's group, using temperature monitors saved 500 cubic metres of water per hectare over a year for both cotton[5] and sorghum[6] without affecting the yield.

The Bushland researchers are collaborating with equipment manufacturer Valmont Industries of Omaha, Nebraska, to integrate these sensors into centre-pivot sprinklers. The idea is that integrating them into something farmers already buy will be much less expensive than selling separate systems. In addition, the proliferation of devices such as mobile phones has driven down the price of wireless-sensor components. O'Shaughnessy expects these integrated systems to be cheap enough for use on commodity crops.

O'Shaughnessy says that in a decade or so, integrated sensors will be widespread on farms. Sensors on irrigation systems, tractors and other equipment will gather data about crop and livestock health, local rainfall, soil moisture and other factors. This local information will be integrated with data from weather services and water-monitoring satellites. Farmers will then be able to monitor the data in detail or receive warning signals when something's not right. "Some degree of automation could help producers optimize inputs — water, fertilization, livestock nutrition — and monitor health. Ultimately the information could be used in tracking for consumer information or marketing," she predicts. But the most vital outcome from all this technology would be simple: preserving water.


JENNIFER BURNEY

Solar-powered drip-irrigation systems allow farmers in Benin to pump water to crops during dry periods.

TAPPING THE SEAS

No matter how well existing water reserves are managed, it may not be enough to keep current agricultural systems from collapsing. Sustainable agriculture will therefore need new sources of water. Fortunately, we live on a planet whose surface is 71% covered with water, virtually none of it currently used for farming. "Tapping into the sea water is the only option available, particularly in the Gulf Region, northern Africa and Australia," says Nidal Hillal, who studies desalination at Swansea University, UK.

At the moment, desalination produces 75 million cubic metres of water a day, which is used primarily for drinking and for industrial use. Older desalination technologies, which essentially work by boiling water, use 20–25 kilowatt hours to produce 1,000 litres and are only practical in oil-rich, water-poor places such as Saudi Arabia. The latest technologies, which use filtration membranes, use just 3–4 kilowatt hours per 1,000 litres, and materials scientists such as Hillal are trying to lower the costs even further. The energy used to pump and pressurize the water during the process accounts for more than 40% of the cost of desalination.

"Tapping into the sea water is the only option in the Gulf Region, northern Africa and Australia."

As water becomes scarcer, desalination membranes get better, and engineers work out how to couple desalination to renewable energy sources, such as solar-thermal plants, desalination for agriculture may become more attractive and perhaps necessary, says John Lienhard, director of the Center for Clean Water and Clean Energy at the Massachusetts Institute of Technology (MIT) in Cambridge. He estimates that, depending on the initial salinity of the water, the minimum energy required for desalination is about 1 kilowatt hour per 1,000 litres.

Spain already uses about one-fifth of its desalinated water for agriculture. Israel has also been experimenting with using it for irrigation, although with mixed results. Desalination removes the sodium and chloride salts that can stunt plant growth, but these are not the only ions at work. Desalinated water also lacks magnesium, calcium and sulphates, and replacing these requires additional fertilization. The high levels of boron, which is naturally present in sea water and retained in desalinated water, have been found to reduce tomato and peanut yields in Israel's arid Negev region. Such unintended consequences are being uncovered as more desalinated water is used, says Ben-Gal.

Technology must be used, however, because groundwater supplies are finite and drought is becoming more common in agricultural areas. As farmers in places such as California's Central Valley pump water from ever deeper reserves to flood their fields and orchards, no one knows what they will find — this water may also have undesirable chemicals dissolved in it because it has been lying undisturbed for longer.

The options available are more efficient irrigation technology, better monitoring of water use, and seeking new sources of fresh water, says Lienhard. But which is the best solution? "All of the above," he says. ■

Katherine Bourzac *is a freelance science writer based in San Francisco, California.*

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