Science Societies

Managing for resiliency in the face of drought

By Megan Sever

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Photo by Bob Nichols/USDA.

Farmers are facing more frequent and severe droughts than they have in generations, including over this last year. By late summer 2022, nearly 40% of farmers in the U.S. had already plowed under or killed their crops. That's because those crops stood no chance of reaching maturity and harvest due to ongoing drought. Yields in Texas, for example, were proving almost 70% below normal as severe drought gripped the region. Some 60% of the West, South, and Central Plains were experiencing severe or worse drought. It's now the offseason for some crops and early season for others. It's a good time to advise farmers what changes they might undertake to make their farms more resilient.

The long range looks rough." That's a good summary of the last year. By late summer 2022, nearly 40% of farmers in the U.S. had already plowed under or killed their crops. That's because those crops stood no chance of reaching maturity and harvest due to ongoing drought. Yields in Texas, for example, were proving almost 70% below normal as severe drought gripped the region. Many fields were also baled rather than harvested, says Brian Arnall, a precision nutrient management extension specialist at Oklahoma State University. Some 60% of the West, South, and Central Plains were experiencing severe or worse drought. Hundreds of millions of acres of crops, from almonds to cotton to wheat, were experiencing drought. Cattle farmers from Texas through Oregon, meanwhile, were forced to sell off their herds early, losing money on the transactions as water sources and grazing grounds dried up.

July was the third hottest on record across the U.S. More than 7,000 temperature records fell over the summer. And September started off with the most extreme heat wave ever experienced across the western U.S. Farmers in Oklahoma, hoping for a reprieve from 100-degree temperatures to plant their winter wheat had to wait longer than usual for fall cooldowns to start. Some are still waiting on rain.

> *"Dispatches from the field, Stillwater, OK, Sept. 13: Had a few showers so large acres were planted for graze-out wheat. But not enough rain to build a profile, so combined with the heat—we will be near 100 this week—the wheat that was sown germed but is running out of moisture fast. Those who didn't plant are looking at dusting in or waiting. Grain-only wheat plants in October. But the long range looks rough."*

—Brian Arnall, Oklahoma State University

“Nobody’s really loving life right now,” Arnall says. “Everybody is just moving through with the hopes to get through 2022 to 2023.”

Dealing with drought isn’t new. As long as humans have been farming, we’ve worried about water. “There’s a drought somewhere every year,” says CCA Fred Vocasek, a senior lab agronomist at ServiTech Laboratories in Kansas. Soil conditions can easily slip into the too-dry realm even in humid climates. In more arid climates, though, like much of the High Plains, Southern Plains, and the West, a drought may be just a day away.

What is new, however, is how climate change is affecting the hydrologic cycle, causing longer, hotter and more frequent heat waves, longer and more frequent droughts with rapid intensification, and, simultaneously, more extreme rainfall events. What’s also new are our abilities to track some of these effects via satellite, to model and forecast them, and to efficiently manage nutrients and employ other conservation measures to help mitigate these changes.

It’s now the offseason for some crops and early season for others. It’s a good time to advise farmers what changes they might undertake to make their farms more resilient.

Defining Drought Conditions

The most severe droughts in recent memory in the U.S., beyond the current one and the 2011–2012 drought, were the droughts of the 1950s and the 1930s Dust Bowl. Photo by Irving Rusinow and courtesy of Shutterstock.

Droughts are periods of unusually dry weather. The first classification used by the U.S. Drought Monitor is D0, abnormally dry. Then it goes from moderate (D1) to severe (D2) to extreme (D3) to exceptional (D4). A location in the abnormally dry category can go to normal within 24 hours with one good slow, soaking rain that fills 50 to 60% of pore space in the soil, says Katie Lewis, a professor of soil chemistry and fertility at Texas A&M AgriLife Research and Texas Tech University. (Fifty to sixty percent of pore space filled with water is ideal. Much below 50 can lean into deficit conditions; much above can cause root diseases or even flooding.)

On the flip side, a site can go from normal to drought conditions virtually overnight as well, especially as lower-than-normal precipitation meets a heat wave with high winds and/or high solar radiation, causing high evapotranspiration rates. That's known as a flash drought. Flash droughts happen frequently, especially in the central and western U.S. "If not predicted and discovered early enough, changes in soil moisture that accompany flash drought can cause extensive damage to agriculture," according to the National Integrated Drought Information System (**Drought.gov**). Flash droughts may be shorter lived than prolonged droughts, but they can still cause massive crop losses.

In early September, prolonged drought conditions were affecting 80% of the High Plains (North and South Dakota, Nebraska, Kansas, Colorado, and Wyoming), according to the Drought Monitor. That's up from three months and a year prior but down from the start of the calendar year. Just over 60% of the South (Oklahoma, Texas, Arkansas, Louisiana, Mississippi, and Tennessee) was in drought conditions, up significantly from

2021. And 88% of the West was under drought conditions, which is actually less than it was three months ago, at the start of the calendar year, and one year ago.

When we think about droughts, we tend to think back to the last bad season, says Jim Schepers, a retired soil scientist with the USDA-ARS and emeritus professor at the University of Nebraska. “Farmers will always remember a bad event, whether it’s grandpa telling the young bucks how damn bad it got” or they themselves lived through it, he says. This year has reminded farmers of a really bad drought in 2011 and 2012.

Between 1998 and 2014, much of the U.S. was in drought. In the Southern Plains, the worst period started in fall 2010, but were followed by one of the hottest, driest summers in history for the region, according to **NOAA**. In Texas, 2011 marked the driest year on record. Grain production was half of normal levels and **cost more than $7 billion in crop and livestock losses**. In other parts of the Plains and West, the drought peaked in 2012. Since then, droughts have popped up all across the region, worse in some places than others at a given time.

Aerial views of drought affected Colorado farmlands in 2012 in Colorado. Green areas are irrigated, and the yellow areas are dryland wheat crops. USDA photo by Lance Cheung.

In 2020, a reconstruction of past droughts showed that the droughts of the 21st century—especially if you count the exceptionally dry period from 2000 through 2018 as one large drought—may rival past severe droughts, like those of the 1950s and 1930s, the latter of which includes the infamous Dust Bowl. That study found that despite the severity, duration, and spatial coverage of those severe droughts, they pale in comparison to the megadroughts that struck the High Plains between AD 850 and 1500, some of which lasted more than 100 years (see sidebar). Now, though, a follow-up **study** in March 2022 in *Nature Climate Change* has shown that the current drought period from 2000 through 2021 (not even including 2022) is the driest 22-year period since at least AD 800.

Droughts in the future could surpass megadroughts of the past due to rising global temperatures. Rising temperatures intensify the hydrologic cycle. Higher temperatures can lead to both more drought and more extreme rainfall events. Higher temperatures lead to droughts by drying out the soils and plants, which causes the plants to release less moisture into the air, leading to less rain. Similarly, higher temperatures can lead to extreme rainfall events because warmer air leads to more evaporation and warmer air can hold more water vapor, leading to more intense rains. These are complicated feedback loops. Intensification of the El Niño–Southern Oscillation meteorological pattern is also leading to more hydrologic changes. This winter, for example, we're likely to see a rare third consecutive year of La Niña conditions, which leads to the southwestern U.S.—which is already in the midst of a severe drought—being drier than normal. The prevailing wisdom is that projected increases in temperatures are likely to lead to more frequent and more extreme droughts, so we better figure out how to adapt.

Megadroughts Over the Millennia

This year's drought is pretty bad in the West—in fact, after a couple decades of dry weather, it is the driest, 22-year period in 1,200 years and possibly longer.

The length and severity of this dry spell has tipped the scales: We are now in a megadrought—defined as a period of severe dryness lasting several decades. There can be periods of wetter weather within the dry period, but the overall trend is excessive dryness.

Tree-ring analyses have found severe droughts and megadroughts over the last 1,200 years in the West and the Plains, an area known over geologic time for hydrologic and climatic swings. Until now, the worst-known megadroughts occurred between about AD 850 and 1600, **wrote** A. Park Williams and colleagues in *Nature Climate Change* in March 2022. Other **studies** have found extreme megadroughts in the region as far back as the second century AD with a marked period of "unusual dryness" between AD 1 and 400.

The most severe droughts in recent memory in the U.S., beyond the current one and the 2011–2012 drought—which by September 2012 encompassed more than 65% of the lower 48 states—were the droughts of the 1950s and the 1930s Dust Bowl. A **comparison** of Palmer Drought Severity Index values by meteorologist Richard R. Heim Jr. in the *Bulletin of the American Meteorological Society* in 2017 found that 1954 was the closest historical analog to 2012 in terms of severity and spatial pattern with 1936 being the second closest.

This winter, NOAA says we're experiencing our third straight year of La Niña conditions. Many previous severe droughts also coincided with La Niña, including the 2010–2012 drought and the 1954–1956 drought. With intensification of the El Niño–Southern Oscillation climate pattern (La Niña is the "cold" part of the ENSO cycle) expected as the global climate warms, we can probably expect even worse ahead.

Today's dry spell, Williams and colleagues **wrote** in a previous paper in *Science*, "appears to be just the beginning of a more extreme trend toward megadrought as global warming continues."

Water's Role

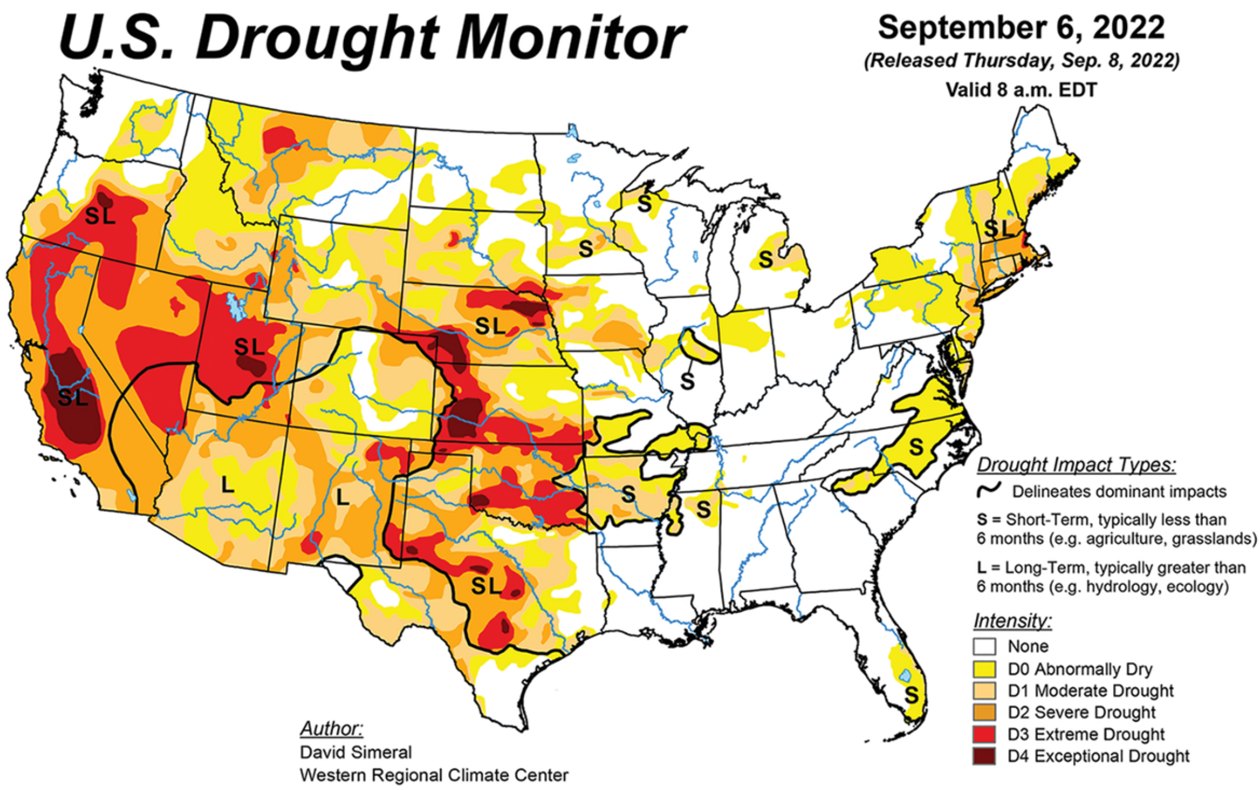
"Water is the all-encompassing, greatest limiting factor that we have in our soil," Lewis says. It influences nutrient cycling, including plant uptake of nutrients; microbial activity both positive and negative; and can even change pH.

The key element is soil moisture—the percent of pore space in soil that's filled with water versus air. Soil moisture controls evapotranspiration, or how much water evaporates into the atmosphere via plants, says Noemi Vergopolan, a computational hydrologist at Princeton University and NOAA Geophysical Fluid Dynamics Laboratory. Soil moisture levels are essential indicators of drought and arguably the most important element of how drought impacts agriculture. Soil moisture controls the exchanges of water, energy, and carbon at the land surface, Vergopolan says. Both extreme low moisture and excess moisture can lead to floods. Super dry, hydrophobic soils can cause an intense rainfall to run off, rather than infiltrate and soak in; super wet soils are too saturated to accept any more water, causing rain to run off as well.

Low soil moisture can also lead to deep cracks, sometimes a meter deep (as was the case this year in central Kansas, Arnall says). When rain falls, it can flow down through the cracks, bypassing the soil and missing the soil pores rather than replenishing soil moisture, Schepers says.

Low soil moisture levels and their impacts on plants and trees can also lead to and aggravate wildfires by increasing dry vegetation fuel load, Vergopolan says. While droughts halt plants' and trees' carbon dioxide uptake from the atmosphere, wildfires lead to more carbon dioxide emissions, she says.

But one of the biggest issues is that without adequate soil moisture or with excessive heat, microbial activity can cease. Without microbial activity, nutrient cycling ceases "as you're not going to have conversion of nutrients from organic forms into inorganic forms," Lewis says. That often leads to excess nitrates in plants. "It's a perennial problem," Vocasek says. When soil moisture is too low, nitrogen doesn't move through the soil profile. Stressed plants can still take some nitrogen up though, and when they do, because there's less biomass produced, there's a greater concentration of nitrates in each plant, Lewis notes. Excess nitrates are toxic to animals feeding on the plants, leading to everything from sickness to abortion in pregnant livestock and death, Schepers notes (see sidebar). It's a huge problem, Arnall says, and one everyone is talking about this year.



In early September, drought conditions were affecting 80% of the High Plains, just over 60% of the South, and 88% of the West. Illustration courtesy of the U.S. Drought Monitor.

Tracking, Measuring, and Forecasting Soil Moisture

Soil moisture is highly variable in space and time, Vergopolan says. The Drought Monitor uses multiple inputs, including the Palmer Drought Severity Index as well as satellite-based assessments of vegetation health and hydrologic data like snowpack, plus ground-truthing, to assess the past week's drought conditions. But the Drought Monitor gives coarse spatial and temporal resolution tracking, on the county level, which makes it less useful for farmers on the ground dealing with differing soil moisture levels at the field level. It's also a "back-cast" rather than a forecast in that it details the conditions over the previous week. It's still a great tool for tracking widespread drought, but Vergopolan and others are hoping to be able to bring the resolution in tighter to help farmers even more.

Current satellite monitoring systems routinely measure soil moisture at 25- to 36-km resolution. But at even 1-km resolution, far superior to what's available now, up to 80% of soil moisture spatial information is lost, Vergopolan and her colleagues **wrote in Geophysical Research Letters** in August. Soil moisture spatial information is completely lost at current satellite monitoring resolutions. So she and her team came up with a way to measure soil moisture at 30-m resolution by combining satellites with models, in situ observations, and machine learning.

Earlier in the growing season, another option for managing nutrients under a changing climate is to time fertilizer application when conditions are optimal. Photo courtesy of Adobe Stock/eleonimages.

It's currently in the proof-of-concept stage, and there's more work to be done, Vergopolan says, but the results are exciting. Though this method can only track soil moisture levels in the top few centimeters and not the root zone, it's still useful for farmers because those top few centimeters are where the microbial activity is and where much of the fertilizers are applied. She's hoping in the future the team can partner with government or industry to provide farmers with near-real-time drought monitors to help farmers understand current soil moisture variability without having to go out in the fields and ground-truth everything. They envision a future where farmers could have access to this high-resolution information in the palm of their hands through an app on their phone that would tell them soil moisture conditions, she says, which they could then use to know when to apply fertilizers, for example, or how much or in what form (e.g., dry vs. wet), or when or how much to irrigate. The idea is to help farmers improve decision making, she says.

Another experimental drought-monitoring tool works more on the forecasting side. The **Evaporative Demand Drought Index** helps forecast both flash and prolonged droughts by looking at atmospheric evaporative demand—or "thirst of the atmosphere"—for a given location across a given time period. It can help offer early warnings for drought conditions.

The more tools farmers have in their toolboxes, the better, Schepers says. Many farmers are familiar with the Palmer index, which estimates relative soil moisture conditions based on "a simplified soil water balance," according to the Drought Monitor. Others may be more familiar with the Drought Monitor's weekly updates. Between weather reports, popular press articles, drought monitors, and other forms of communications, "there's a higher level of knowledge and understanding" about drought among farmers than ever before, he says. Farmers also have more options for dealing with a current or pending drought.

What Can I Do in the Middle of a Drought?

Depending on where a crop is in the growing season, in the middle of a drought, choices may be limited, Lewis says. For some farmers, irrigation is an option. But even in irrigation-heavy areas, like parts of Nebraska, there may be limitations, such as water district regulations that say a farmer has a certain amount of water they can use over a given three-year period, Schepers says. The farmer has to decide whether to irrigate now or later and how much. Irrigation also costs money. A farmer may have to calculate whether the amount of money (water/electricity) it takes to irrigate would pay off in being able to harvest the crop, he says.

The Nitrate Issue

Taking a stalk sample to test for nitrates. Photo by Kevin Lawson and courtesy of the University of Arkansas System Division of Agriculture.

When soils are abnormally dry, such as during a drought, fertilizers can actually cause more harm than good—in several different ways.

First, if fertilizers do what they're supposed to do—namely boosting plants' productivity and increasing their biomass—the larger plants will need more water to survive, depleting the soil of what little moisture there was. Adding nutrients to the system limits water even further, says Katie Lewis, a professor of soil chemistry and fertility at Texas A&M AgriLife Research and Texas Tech University. **Research in Global Change Biology** last year showed that "nutrient addition amplified detrimental drought effects" on grasses like wheat.

Second, when plants have to root deeper to find water during a drought, they can bring up extra nitrogen that was previously stored lower in the soil profile.

Anytime plants bring up water, they bring up nitrates, says Jim Schepers, a retired soil scientist with the USDA-ARS and emeritus professor at the University of Nebraska. That means plants would have a lot of excess nitrogen to potentially pull up, but also they wouldn't need all the nitrogen that is applied at the surface, so you'd end up with excess "stranded" nitrogen in the top soil layers.

When drought-stressed plants do pull up nitrogen, they often end up with high concentrations of nitrates in the lower stalks, Schepers says. "If you're running a livestock operation, you need to be careful of high nitrate in the silage," which could cause nitrate poisoning, he says. The majority of nitrate poisoning cases occur because of drought-stressed food sources. The two ways to prevent this problem, he says, are to test your soils and your plants for nitrates (take a portion of the stalk, for example, and send it to a soil-testing lab) or to chop your crop higher since nitrates accumulate at the base and concentrations decrease as you go up the plant.

Testing your soils is an important aspect of nitrogen management after a drought, says Brian Arnall, a precision nutrient management extension specialist at Oklahoma State University. When soils are excessively dry, the process of breaking down residue slows and essentially stops until moisture returns, he says. The movement of nitrate up the soil profile via evapotranspiration and lack of utilization of the previously applied nitrogen during a drought could leave a lot of nitrogen in the soil for the next year. “The challenge is that once moisture returns, the process will start, and microbes will consume a great deal of that nitrogen in order to break down carbon-heavy residue.” So you can’t just assume that there is—or isn’t—a lot of residual nitrogen. Testing is the only way to know.

The best way to solve the nitrate–drought problem, Lewis, Schepers, and Arnall agree, is to only apply as much nitrogen as absolutely necessary to see benefits and apply it when the timing is optimal.

Where irrigation isn’t an option, farmers might choose to plow under or bale their crops rather than harvest them, like many did last summer. It’s a calculated decision, Arnall says. “If I have about $20 worth of nitrogen, $20 worth of potassium, and $10 worth of phosphorus, can I get back those inputs if I bale it?” he says. Baling the crop removes it, and its nutrients, offsite. If they do bale it, farmers might consider leaving more residue—like chopping crops higher—to take advantage of the nitrogen that is in the lower stalks for the next year.

Earlier in the growing season, another option for managing nutrients under a changing climate is to time fertilizer application when conditions are optimal, Vergopolan says. Such a nutrient management strategy can be a conservation measure since applying only what is needed at the right time and in the right amount can protect air and water quality, maintain or improve soil quality, and limit greenhouse gas emissions. To help determine when conditions are optimal, during the growing season, farmers can check soil moisture levels using gravimetric methods, soil probes, or dielectric sensors. “If conditions are too dry, nitrification is not going to happen. But plants also are not going to absorb the fertilizers if the soil is too wet,” she says.

An even easier way midseason to determine whether more fertilizer would be helpful is to employ “check strips,” Arnall says. Check strips are rows in the field that are enriched with nitrogen, whereas the rest of the field is not. The idea is that when the nitrogen-rich strip shows up during the growing season, you know the rest of the field is becoming deficient, he says. It’s an early warning system. Usually in drier years, for wheat, farmers don’t need as much nitrogen as wetter years. “We’ve been utilizing the enrich strips in wheat since the early 2000s in Oklahoma,” Arnall says. “We have a lot of sensors and other technologies, but the visual of seeing it as you drive by your field—or not seeing it—is highly valuable.” Such a simple tool can save tremendous amounts of fertilizer—and money.

Ways to Increase Resiliency

Even more ideal is making fields more resilient. “What we do now can potentially influence 5 to 10 years down the road,” Lewis says. Many different conservation practices can help, she says, such as crop rotations, reduced tillage, and potentially cover crops. “Any conservation-type practice that’s going to improve the soil from chemical, biological, physical perspectives, those are going to better help the soil withstand drought events in the future.”

Many farmers already rotate their crops. One potential way rotation can help in droughts, though, is in fertilizer management. For example, "if you have a drought one year, instead of planting soybeans, you might decide to plant corn again the second year because you have so much residual nitrogen, and nitrogen is expensive," Schepers says. That decision should be made in fall for spring crops, he says.

Check strips are rows in the field that are enriched with nitrogen, whereas the rest of the field is not. This allows farmers to tell when the crop starts to be nitrogen deficient because the test strip will suddenly become visible. Photo courtesy of University of Wisconsin Discovery Farms.

Cover crops are a hotly debated option for dealing with droughts, Arnall says. Cover crops reduce evapotranspiration, so they can be helpful over time, Lewis says. But they also remove water from the field (taking it up as they grow). So you risk removing moisture from the field as you grow cover crops and then not having enough for your cash crop, Arnall says. Whether cover crops will work basically depends on whether you're in a high-rainfall region, he says. It also depends on what you're growing, he adds. For example, cotton leaves a "bare scorched earth," so alternating with grazed wheat or using cover crops can be really helpful.

For those irrigating, Schepers says, another option is to install center-pivot irrigation. Research in Nebraska has shown that using center-pivot irrigation instead of furrow irrigation results in using half as much water and reducing nitrogen by up to one-third, he says.

Despite the weather and climate issues, these are "promising times" for farmers in that they have more tools at their disposal than ever before, Vergopolan says. If you think about where we were 5 or 10 years ago, and where we might be 5 or 10 years from now, she says, it’s exciting to have new prospects for monitoring and dealing with droughts.

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Back to issue

Back to home
