Current Affairs

Managing water and pollutants in soil with electric currents

By JANET RALOFF

During World War II, the German Navy sought to garage some U-boats along a stretch of French coastline. But first it had to drain small portions of the wetlands long enough to sink the concrete footings needed to support the submarine pens.

According to intelligence reports acquired later by the U.S. Navy, the Germans did this by sinking metal rods into the soil and applying small electric currents to them. The currents effectively drove water out of the area where footings were to be laid, explains electrical engineer Stuart A. Hoenig of the University of Arizona in Tucson.

Hoenig, who served in the U.S. Navy during the war, later met a number of German engineers who told him that this use of electroosmosis was fairly common. Indeed, he recalls their telling him that Hitler's army applied currents to the tracks of tanks in its Eastern campaign so that the vehicles could maneuver through the normally untraversable muck that characterizes Russia's spring thaw.

"Isn't it used in the United States?" they asked him.

At the time, it certainly wasn't. Since then, however, the phenomenon has become the basis of efforts to "dewater" soils at construction sites, to desalinate water, and, most recently, to extract solvents and other toxic organic chemicals from groundwater (SN: 11/20/93, p.333).

But Hoenig and his colleagues in the university's agricultural engineering department would like to extend that technology even further, creating an arsenal of related programs to battle friction and pollution on the farm.

Photos: ARS/USDA

Irrigation furrows separate rows of lettuce in Arizona. Slack envisions burying cathodes in furrows and placing anodes near the crop to control fertilizer runoff.

Agricultural interest in electroosmosis dates back more than 70 years.

Soil can hold a lot of moisture, and minerals tend to impart a positive electric charge to each droplet of interred water. Early in this century, a team of British agricultural engineers reasoned that by applying a voltage, they could turn a plow blade into a negatively charged electrode (cathode) that would attract such positively charged water molecules.

Edward M. Crowther and William B. Haines of the Rothamsted Experimental Station in Harpenden, England, eventually confirmed that this electroendosmose, as they referred to the phenomenon, indeed delivered "striking reductions in friction"—at least in a laboratory setting. In contrast to the German war applications, the currents delivered by a 4-volt battery drove lubricating soil water toward the blade of a "plow"—a weighted metal spatula inserted into a tray of moist soil.

Without the current, it took a 600-gram weight on a pulley to draw the plow steadily across the soil; with the current, it required 300 g. And after "some minutes" more, it took only 50 g, the pair reported in the 1924 Journal of Agricultural Science. Reversing the flow, they converted the blade into a positively charged electrode (anode). At once, the water began to move away from the blade, increasing to 1,500 g the weight needed to pull their plow.

Although Crowther and Haines concluded that the technology showed tremendous promise, the necessary power supplies proved clumsy and unreliable—especially for use in an era that predated rural electrification, powerful tractors, and heavy-duty batteries.

Curiosity lay dormant until the 1950s and 1960s, when several Soviet, Chinese, and American investigators took another look. But just a look. While each team confirmed the technique's promise, none developed it into a product.

Dennis Larson, who now shepherds research on a host of related programs at Arizona, attributes that waning interest to "the limited auxiliary power available on [farm] vehicles up until the last decade."

Howard E. Clyma launched Arizona's involvement with a series of laboratory studies that resulted in a master's thesis 3 years ago. He found that electroosmosis could reduce draft energy—the energy needed to pull a tiller through soil—by almost 40 percent in loam.

But moisture content proved critical. When it dropped from 17 to 12 percent, that energy savings also dropped—to 24 percent. When he halved the tiller's speed, to 3.3 kilometers per hour, energy savings again fell to just 24 percent. (Such slow test speeds reflect the small scale of the laboratory "field." In fact, Hoenig says, electroosmosis would facilitate tilling at up to roughly 16 kilometers per hour, "which is a typical plowing speed.")

Electric power proved similarly important. When Clyma dropped the applied potential from 40 volts to 15, the draft force dropped by more than half (to 15.4 percent). Even the number of anodes used to push the water toward the tiller blade significantly affected friction. Reasoning that two might be better than one, he added a second anode behind the blade, but this change actually dropped the energy savings by almost a quarter—to 30.4 percent.

The makeup of the dirt itself emerged as the most important variable. For instance, whereas one anode proved optimal in loam, a friable mix of clay, silt, and sand, the best performance in clay was obtained from two anodes. Moreover, the greatest savings of draft energy in a clay soil, as opposed to loam, occurred with lower water content and slower tillage speed.

Even under the best conditions, however, energy savings from electroosmo-

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sis averaged a mere 11 percent in clay.

But Larson cautions against being misled by comparisons between reductions in draft energy and actual energy savings. Because of its inherently crumbly nature, Larson explains, loam presents less resistance to the plow than clay does. So a small reduction in the large energy expenditure required to cut through clay fields may actually save the farmer more money than a bigger reduction in the power needed to till loam.

Electric currents move water by dragging or repelling chemicals dissolved in or associated with it. But in some instances, those currents may have an independent effect on dissolved compounds. Indeed, that now appears to be the case with nitrate, observes University of Arizona irrigation engineer Donald C. Slack.

In agricultural areas of the United States that overlie fairly shallow aquifers, fertilizers—principally nitrates and phosphorus—have become a significant source of groundwater contamination. New data obtained by the Arizona team indicate that it might be possible to manipulate these dissolved nutrients with electric currents so they don't wash below the root zone before plants can use them.

Larson and Naglaa Eid report preliminary laboratory and field tests showing that although water will migrate toward a cathode, any nitrate in it will tend to move toward the anode—even when that means traveling against the flow of water.

Today, much of agriculture depends on irrigation. Drip systems, the most efficient type, consist of perforated pipes or hoses that slowly leak water into the area where it will be used: a plant's root zone. Slack envisions someday burying drip irrigation tubes that have a built-in metal strip. Hooked up to the positive terminal on a power source, each strip would serve as an anode. Midway between each row of drip tubes he would bury another metal rod—this one a cathode—in association with drainage pipes.

When a farmer applies a current, Slack notes, salt—which can poison plants—should move with the water toward the drains and away from delicate roots. At the same time, nutrients such as nitrates and phosphates would remain trapped where they can do plants the most good.

Some engineers have been working to extend related technologies well beyond the farm. In one such application, Hoenig has been studying the lubricating effects of electroosmosis on drill bits. Well drillers tend to exploit tiny fractures in stone that, under pressure, will create fissures and break apart the larger rock.

The minuscule initial cracks "are naturally charged by processes in the rock," Hoenig explains. Imparting a negative charge to a drill bit can speed the rate of rock fracturing, he says.

With a current of less than 1 amp and a negative potential of 5 to 10 volts, Hoenig doubled the speed with which his drill cut through granite. Moreover, he notes, imparting an electric current reduced wear on the drill bit by about 20 percent. That could prove important, he argues, because drillers spend a lot of time replacing dull bits. The resulting downtime, he notes, can "be very costly if, as in the oil industry, you're paying [drillers] $5,000 an hour."

Researchers at the University of Southampton, in England, had hoped a similar argument might whip up interest in electroosmosis among contractors.

Penned livestock produce copious quantities of nitrate-rich wastes, which often find their way into groundwater. Arizona's Peter Waller is heading up work on the design of an electrostatic filter to trap nitrates from such feedlots—and from septic tanks. This system would direct an electric current into tiny conducting fibers thinner than a human hair. When water is pumped through a fabric woven from such fibers, any nitrates present would cling to the anodic filter. When the filter is full, the current could be turned off and clean water shunted through the filter to flush the concentrated nitrates into a reservoir for disposal or recycling.

Builders typically use a drop hammer to pound metal piles into the soil. Their crews then pour concrete into the dirt holes left when the pile is withdrawn to create structural piers or footings.

In the lab, and later in field tests, Roy Butterfield and his graduate students demonstrated that by making a metal pile into a cathode, they could cut by two-thirds the effort needed to drive the pile into soil. "If it took 150 blows to knock it in without electroosmosis, we could knock it in with 50," Butterfield recalls.

But when his team demonstrated this at a field site, they encountered lukewarm interest at best.

The technology required them to electrically insulate the pile drivers and then supply the piles with large quantities of low-voltage electricity. Butterfield quickly found that civil engineers and their crews were "terrified" of having large currents floating around in the ground where people were working.

The time savings they gained by slipping piles in more easily wasn't sufficient to win over this fear of currents. "The whole cycle of knocking in a tube, making the pile, pulling out the tube, and moving on to the next site typically takes between 2 and 3 hours," Butterfield learned. "And we would have saved only about 10 minutes each cycle." So he shelved the idea.

But Butterfield, now retired, tries to remain optimistic—especially about his team's novel, self-driving piles. The prototypes, also shelved for more than a decade, worked beautifully, he claims. By harnessing electroosmosis, "these piles pulled themselves into the ground like a worm. You'd just set them into clay, turn them on, and they'd disappear."

Tractor manufacturers haven't beaten a path to the Arizona team's door either, despite the Electric Power Research Institute's publication 2 years ago of a report on the group's findings. But farmers from Canada to Texas have been telephoning for a source of the equipment. "I've had to tell them it's still experimental" and awaiting commercial interest, Slack says.

In March, the Arizona researchers were finally approached by a firm interested in collaborating with them—but on tests aimed at modifying the tillage application for a nonagricultural function.

Are the researchers disappointed? "Yes," Hoenig says, "but not surprised." Large companies "are often convinced they know all there is to know," he says. Which explains why so many of them politely showed the inventor behind today's ubiquitous photocopiers to the door, he contends. "I know some of the people he took [his demonstrations] to," Hoenig says, "and they asked, Who needs this?"

But the inventor's persistence paid off, as Xerox's name recognition today attests. The moral, as Hoenig sees it, "is not to give up." □