by-products

Reusing by-products in agricultural fields

by Caroline Schneider

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Left: Flue gas desulfurization gypsum is a by-product of scrubbing sulfur dioxide gases from coal-fired power plant emissions. Researchers are using this by-product and others to remove dissolved phosphorus from agricultural runoff. Photo to the left courtesy of iStock. Opposite page: USDA-ARS soil scientist Ray Bryant (left) and UMES associate professor Arthur Allen collect samples of groundwater before and after it is filtered through an underground “curtain” of gypsum. The gypsum curtains remove phosphorus from the groundwater before it flows into a drainage ditch, preventing the phosphorus from reaching the Chesapeake Bay. Photo by Stephen Ausmus (USDA-ARS).
Darrell Norton’s history with gypsum is long. Throughout decades of research, he has seen the popular soil amendment deliver many benefits to farmers’ fields.

He has also helped find alternative sources for gypsum, advancing it from a mined fertilizer to a by-product of industry and a waste that can be reused for its agricultural value. But despite the benefits, gypsum—along with Norton’s research—has faced its share of obstacles.

Throughout their use, gypsum products created from industry waste have been targeted by the USEPA as possible sources of contaminants. In the early 1990s, the USEPA began to regulate phosphogypsum, a waste product from the phosphorus fertilizer industry, due to concerns about radon emissions. Norton, professor emeritus at Purdue University and retired research soil scientist for the USDA-ARS, says that although radon levels were below those found in natural soils, the use of phosphogypsum was stalled. Large piles of it still sit in states along the Gulf of Mexico.

Likewise, the most widely used gypsum by-product today, flue gas desulfurization (FGD) gypsum, is at risk of being classified as a hazardous waste. The USEPA is testing it for trace elements, such as mercury and arsenic. While research has shown that levels of those elements are extremely low, the agency could halt use of this latest gypsum by-product.

In addition to USEPA regulations, FGD gypsum faces another challenge. This form of gypsum is a by-product of scrubbing sulfur dioxide gases from coal-fired power plant emissions. But the low costs of natural gas could undercut coal-fired power plants and, therefore, the production of FGD gypsum.

“The future of FGD gypsum production looks bleak for two reasons,” Norton says. “One is possible [USEPA] regulations, and two is the high price of scrubbing compared with the low cost of natural gas to produce electricity.”

While the future of gypsum by-products may be uncertain, the reuse of wastes is a necessary goal as the world population and the amounts of waste created continue to increase. While individual citizens do what they can to reduce their impact on the earth, similar efforts are being made by farmers, agronomists, and scientists as sustainability and environmental care become increasingly important to those who work on and with the land. Reuse of by-products and waste through established practices and new techniques is both benefiting agricultural fields and providing the products with a second life. But the reuse of wastes can be tricky. Concerns about contamination and risks set forth the need to balance waste reduction, the agricultural benefit, and environmental safety.

Gypsum is an interesting case study. Also known as calcium sulfate dihydrate, it has been used as a fertilizer and soil amendment for many years to reduce erosion, limit runoff, and increase water quality in nearby surface waters. New sources of gypsum have caused a resurgence of interest in the benefits of...
gypsum for agricultural soils and crop yields in recent years.

With the cost of mined gypsum going up and supply going down, it makes sense to use FGD gypsum instead. A by-product of power plant emission scrubbing, 25 million tons of it were produced in 2010. But USEPA concerns and the increased price of emission scrubbing compared with natural gas could soon limit the accessibility of FGD gypsum and the amounts produced.

Removing Dissolved P from Runoff

As farmers and researchers, including Norton, wait to hear about the fate of FGD gypsum, Chad Penn and Josh McGrath are looking into another way to help farmers and reuse wastes. They are using by-products, including gypsum, to answer a specific and important question—how can we best remove dissolved phosphorus from agricultural runoff?

There are two forms of phosphorus (P) in urban and agricultural runoff—dissolved and particulate. Particulate P is attached to sediment or soil particles, and its transport can be limited by controlling erosion. Dissolved P, however, cannot be stopped by erosion control, and it can lead to algal blooms and decreased water quality once it reaches surface waters.

“As long as soil P levels are high, more P will be transported out of the system every time you get a runoff event,” says Penn, associate professor at Oklahoma State University and member of ASA, CSSA, and SSSA.

The problem of dissolved P transport to surface waters is one that is particularly relevant for McGrath, associate professor at the University of Maryland and ASA and SSSA member. On the Delmarva Peninsula, a concentrated poultry industry and years of manure application have led to soil P concentrations well above the optimal levels for crop production.

“These fields are typically located on the coastal plain where there is extensive ditching to drain the fields,” McGrath explains. “This provides a very direct connection between the field and surface water. Over 90% of the P that we find in the water traveling through those ditches gets there through shallow subsurface pathways.”

Because dissolved P travels in that subsurface flow, typical management practices that can stop the transport of particulate P, such as erosion control, are not effective for dissolved P. So Penn and McGrath, along with ASA Fellow Ray Bryant of the USDA-ARS, developed a different approach—ditch filters.

“We decided to try to treat the water leaving the fields,” McGrath explains. “The ditch filters provide an intervention point where this can occur.”

The ditch filters are large structures that intercept surface and subsurface flow, forcing the water to travel through one of several by-products including gypsum, mining residuals, drinking water treatment residuals, or steel slag (a by-product of steel mills). The chosen material traps dissolved P while allowing the water to continue on its way. The by-product, with the P attached, can then be removed from the structure and replenished as needed. The ability to remove the by-product once it is full of P was an important design feature for Penn.

“By amending a material to soils, you’re only tying up P—you’re not removing it from the system,” he explains. “So I asked: Can I build a giant filter in the landscape to remove the P from the runoff in such a way that I can then remove the material after it’s become saturated to actually take it out of the system?”

The answer to that question turned out to be yes. Once the by-product in the filters is saturated, it can be...
shoveled or dumped out of the filter, and the filter can then be refilled with fresh material.

Several other features of the ditch filters make them customizable structures ideal for various environments—the size and shape, the by-product used, and the placement. The filters can be constructed as canisters, boxes, or confined beds depending on the site, and users can choose a by-product that works best for them, taking into consideration the proximity of the source, the cost, and the properties of the material.

Targeting the Hot Spots

Additionally, the site and placement for the filter is an important decision. “It’s best to be very careful on where to place these … to target hot spots where you know you have high concentrations of P leaving the site and it’s likely to make it to a surface water body,” Penn says. “The idea of just putting the filters randomly wherever there’s concentrated water flow is a waste of time and money. You have to do your homework first.”

Penn’s team is currently working on a filter for one such hot spot on a poultry farm. The runoff at that site flows in front of the barns where some of the poultry litter, which contains P, spills out. The water then heads toward a creek about 200 yards away. With high concentrations of P in that runoff, it was an ideal target for a ditch filter.
Another hot spot that the researchers are looking at is a golf course near a large casino owned by the Chickasaw nation. After conducting tests and finding that they had high concentrations of P leaving the golf course, they asked Penn if a filter could be built to stop nutrients from entering a neighbor’s lake.

To find the best design and setup for each site, Penn, McGrath, and their colleagues have created a model that takes into account several features such as characteristics of the by-products, how often the user wants to replenish the by-product, features of the field site (water flow rates and concentration of P in the runoff), and the amount of P to be removed. The researchers plan to make the model available on the internet soon.

“We want to increase agricultural productivity and sustainability while reducing effects on the environment and creating something that’s economically viable.”

Studies that characterized the by-product materials and helped users understand their properties in the context of filtering out P were published in the May–June 2012 issue of the Journal of Environmental Quality.1 As part of the larger model, those properties will ultimately determine the amount of material needed for their filter and the cost of such a project.

Penn hopes that the costs associated with the structures are eventually offset by nutrient trading, which would work much like carbon trading. He foresees that like wastewater treatment plants, each farm could be assessed for a total maximum daily load of P that is allowed to leave the site. In this way, if a farmer does not use the full allowance, he or she could sell the unused credits to a neighboring farm or wastewater treatment plant that has exceeded its total.

"Nutrient trading could pay for these structures," Penn says. "That’s the bottom line.’’

In addition to reduced P levels and the financial benefits that farmers could see from the ditch filters, other advantages may be possible depending on the by-product that is chosen. Many of the by-products that Penn has tested also remove heavy metals or organic compounds, such as pesticides, from runoff. Also, compost or peat material could be mixed in with the by-product to further trap contaminants.

What Happens to the Reused Waste?

The idea behind the filters centers on the reuse of wastes. Once the waste has been reused, what happens next? Answering this question is the next step in the research. Penn and his colleagues have started the investigation by looking to see if used gypsum would release P back to the soils if spread on fields. It appears, however, that the P is locked tight to the by-product and therefore does not release the nutrient. The other impacts of gypsum on soil quality, however, mean that it could be spread on fields for those secondary benefits. As for other materials, researchers are currently investigating possible processes to strip the materials for reuse or incorporate them into non-agricultural uses.

“At this point, after we are done with the material and remove it from the filter, we return it to its original life cycle,” McGrath explains. “With gypsum that might mean land applying it or with slag, [sending it] to the aggregate industry for road construction.”

Both McGrath and Penn are careful to test all possible by-products for their safety both in the ditch filters and for secondary purposes after they have been saturated. That safety testing, Penn states, is absolutely necessary as research continues and the structures come closer to full implementation.

“I would never put anything out there, either in a structure or for land application, without looking at it closely for potential contaminants,” Penn says. “Each material needs to be screened for safety.”

As Penn and McGrath further characterize the ability of their ditch filters to intercept surface and subsurface flow, other scientists are looking at a different drainage system—pipe drains. A research team from The Netherlands recently published a paper in the January–February 2013 issue of the Journal of Environmental Quality assessing the benefit of enveloping pipe drains with iron-coated sand to eliminate P from runoff.2

Iron-coated sand is a by-product formed during the production of drinking water from groundwater. A sand filter is used to take out the iron

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1 See the articles here: https://dl.sciencesocieties.org/publications/jeq/tocs/41/3.
2 See the article here: https://dl.sciencesocieties.org/publications/jeq/abstracts/42/1/250
(and prevent unwanted colors and flavors in the water), and the iron coats the sand as it is removed. The high affinity of the iron-coated sand for P then makes it an ideal candidate for removal of P from agricultural runoff.

The research team, led by Jan Groenenberg of Alterra Wageningen UR, found that pipe drains enveloped by the iron-coated sand effectively removed an average of 94% of dissolved P from runoff. Looking for detrimental side effects, they also concluded that iron and P did not get released from the sand and end up back in the soil. The researchers estimated that an enveloped pipe drain would be able to lower P concentrations in water for about 14 years, making the use of this drinking water by-product a promising possibility.

Supplying P to Fields

While researchers use by-products to decrease P in runoff where it is overabundant, other groups are finding ways to supply P to fields that need it. Manufactured from mined rock phosphate, mineral P fertilizers are used extensively in agriculture, but they are a non-renewable resource. In addition to the limited availability, the fertilizer is often contaminated with cadmium (Cd), making it less than ideal for application to fields needing P for crop growth. Researchers at the University of Rostock in Germany, however, are looking to a by-product as both a source of P and a means to immobilize Cd in soil.

Bone char, made from animal bone chips left over from the meat-processing industry, contains P but almost no Cd. In a study published in the March-April 2013 issue of the Journal of Environmental Quality, researchers found that not only did bone char release P to the soil at levels and in a temporal pattern that would benefit plant growth, but it also immobilized Cd. This research, then, begins to establish a basis for the use of bone char as a clean P source with the ability to immobilize Cd and thus improve agricultural soil quality.

As both consumers and farmers become more concerned about the effects of human living on the environment, the need to reuse and recycle wastes is even more pronounced.3

Enhancing agricultural fields using by-products—from gypsum to bone char—is ideal as both the need for food and the impacts of humans rise.

“We want to increase agricultural productivity and sustainability while reducing effects on the environment and creating something that’s economically viable,” Penn explains.

Along with the benefits of by-products that researchers are finding, however, it is also important to understand the potential hazards such wastes may present to the environment and to humans. A thorough testing of by-products and their possible side effects will inevitably cross some off the list.

Norton hopes that FGD gypsum, facing regulation and supply obstacles, won’t be one of the by-products taken out of consideration. Instead, he anticipates that proper management and new technologies that could further “clean” FGD gypsum will convince others that it is a useful by-product with many benefits for agricultural fields. Says Norton, “We just want to help the farmers.”

C. Schneider, CSA News magazine science writer

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3 See https://dl.sciencesocieties.org/publications/jeq/abstracts/42/2/405

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Left: Pipe drain enveloped with iron-coated sand. After a material is removed from a filter, it is returned to its original life cycle. With gypsum that might mean land applying it (middle), or with slag, making it available for road construction (right). Photos from l to r courtesy of Wim Chardon and Gerwin Koopmans, GYPSOIL/ Ron Chamberlain, and Flickr/Dru Bloomfield.
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