Phosphorus and Pathogens

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I realize several things, one of which is that I'm the last thing on the agenda between your drive home and my three and a half hour drive home, so we'll try to get through this pretty quickly. I always liked show and tell in school and so we'll start this out with a little show and tell and then get Chad to help me here. What I want to do is talk about two things. One is initially an opportunity and then secondly we'll finish up with what I'll call a concern.

Let's start off with the phosphorus issue. This is a cartoon I picked up a few years ago and I thought it might fit in well when we started dealing with phosphorus in the environment. As most of you know, in 2003 EPA passed some new rules for large animal operations and those that are in the 700-cow and more size are going to have to deal with managing their operations from a nutrient management standpoint for phosphorus. As you can see here in the slide, there is quite a buildup in phosphorus in this soil. We may only see this much of it, but in fact we are seeing quite a bit of buildup of phosphorus in our soils on both sides of the mountains.

To give you some perspective of that, if we look at phosphorus utilization by the cow, she uses about 13% of it for maintenance, she puts about 27% of it in milk, and about 60% of it then goes into the initial manure, both feces and urine. We're only exporting somewhere in the neighborhood of maybe a quarter of the phosphorus off the farm. The rest of it stays there because it's not getting volatilized. It's left on the farm for you to manage or consider exporting. If we take the Whatcom County view of reality as it relates to phosphorus—in 2002 statistics would show that milk production was somewhere approaching 23,000 pounds of milk, about 62,000 milk cows, about this much phosphorus in milk, dry matter intake about this, this level of phosphorus in the feed. There were about 44,000 acres of crop land. This number comes from all the nutrient management plans, so it is not a guess. That equates to about 2,362 tons of phosphorus that was eaten by the cows, and because we export about 27%, that means we had close to 640 tons of phosphorus that was exported in milk. When we did the calculations, that left us with about 1,724 tons of positive P balance above what could be uptaken with crops in the county. If we then calculate that down, it shows an excess of something like 77 pounds per acre of excess P, above what would be taken up by, say, a grass silage type crop, and we know not all the land is in grass silage. To create a balance in Whatcom County and use up the rest of the 77 pounds, we would need another 44,000 acres. It's simple math, but I think it gets the point across that we're going to have to figure out some things.

I'm the kind of person who doesn't like problems without trying to come up with some solutions. We've been looking at a project to explore extracting the P and exporting it. We realize there's a minimal that can be done in terms of lowering the phosphorus below a certain level in the diet, so if it's only 25% going off farm, and 75% is staying on farm in those initial excretions, we have to figure out some methodology to capture that phosphorus and move it off farm. A sample of the extracted P is what's in the glass jar.

I'm going to draw on a talk that Keith Bowers gave last fall at the Dairy Federation meeting. I took a few of the more technical slides out. He talked about this phosphorus crystallizer system for treating waste water and it was a system that he developed when he did his Ph.D. work at North Carolina State University with swine manure. He has since moved here to Washington State and we've developed a pretty good collaborative relationship. He's originally trained as a chemical engineer, he knows his stuff, and I think we're making some pretty good progress.

Our objectives are to remove most of the phosphorus from the waste water and to develop a system that is simple to operate, compact, minimizes additional costs, avoids creating new environmental worries and so forth. Keith also wants to look at the ease of handing of the waste product. The material we passed around, called struvite, is as it comes out of the system that I'll show you in a slide. We did nothing more than lay it out on a table and let it dry, so it would be pretty easy to bag it up and ship it off the farm. We also need to see how it works on dairy waste versus swine waste.

This is actually a system. You pump liquid manure into the bottom of this cone and from about this point here on the cone to about this point here is a bed of this struvite. We run manure up through that and then, to make that bed of struvite form more struvite, which is pulling the phosphorus out, we inject at this point something to change the pH of the manure. In our initial studies we used ammonia. We've used buffers as well and they seem to work pretty well, which would minimize bringing in more nitrogen on the farm in terms of ammonia. The material then overflows here and comes out. As it builds more bed in here, then every few days the concept would be that you'd open a valve, drain some of the struvite out, leave enough bed there so you continue to have material to make more. Essentially what you'd be doing is periodically pulling some material out like this and then drying it.

When Keith worked with this on swine manure, they were getting as much as 87% of the orthophosphate removal, about 82% of the total phosphorus. Our success so far with liquid dairy cow manure has not been quite as great. We're getting somewhere between 10 and 50% with some of our initial conditions, and we've learned some recent things we think are going to help improve that a bit more.

In this particular initial study, we're working with raw manure, but one of the grants that Shulin mentioned, the Conservation Innovation Grant, we have just in the last week begun to work with the anaerobic digested manure as well. And we have a 3-year project to look at this system on the back end of a digester.

Product characteristics—struvite is magnesium ammonia phosphate; pure struvite would be about 10% magnesium, 5.7% ammonia nitrogen, and about 12.6% phosphorus. Typical analysis from a system that Keith had formerly run with swine manure would indicate that it comes close to that. As we did some of the work at Workhoven's Dairy, we actually found that we don't need to add the magnesium. We have plenty of that, so that's one less thing we've had to add.

We can consider this product as a fertilizer because of the phosphorus content, but also this has some nitrogen content. As collected, it would have an NPK content of about 6-31-0.3, if you heated it, which is going to be an energy cost there, but if you did, this would be the formula.

An idea brought up in previous work was whether or not it could be used as a feed supplement. You could take this and actually use it as a phosphorus and magnesium source and feed it back to animals. We did that as part of our pilot study and fed it in a chick growth study on the main campus in Pullman. The chicks did not like it real well so they didn't eat it. It turned out that, because they did not eat it, they grew less. But when we did bone ashes on those and then looked at the phosphorus content, the phosphorus content of the bones seemed to be okay. We think there is some other factor there that may even be involved in their not liking the material and it may be that the phosphorus is actually available. Anyhow, we have looked at that and there may be opportunities there.

Question—

Yes, what you do is you're kicking off the water molecules. This struvite has six water molecules attached to it, so if you heat it you're going to drive off some of those waters and you change the nutrient concentration. I wouldn't think it would be something you'd really want to be doing because you're going to have some extra costs there.

Adapting it to dairy waste water—we found out that magnesium addition is not required, at least at the Workhoven Dairy where we've been working since last September. All the different titration studies that we've looked at show that there's plenty of magnesium there. Recently we've looked at some acidification and what we're doing is dropping the pH on the manure a bit for a while and then raising it back up, and that seemingly is improving the phosphorus removal. That's the track we're currently on.

The other important thing is that we've found that using buffers rather than ammonia, buffers like sesquicarbonate type buffers that you might normally feed, seems to work well in raising the pH the amount we need. That may get us away from bringing an anhydrous tank onto the farm.

That's the opportunity—that's the phosphorus story.

Now we're going to move into the area of concern, that of pathogens. If you can't read that in the back, it says, "The good news is the bacteria count in our water supply is down to one per gallon," but there is a pretty large critter in that jar.

I collected this one years ago, back when I used to do silage fermentation work. You use bacteria for that, so I'm moving into a different arena and the slide still works. This is a wheel and it represents the concept. We've done a lot of work with a number of dairies up in the Snohomish area, the Workhoven Dairy being one of them. Over the last few years they've built a relationship with the Tulalip Indian Tribe to look at putting in a community digester. I've been on the periphery of that discussion and occasionally they ask me for some information about manure production and various issues.

I drive around the state quite a lot, so I'm going down I-5 one day and I'm thinking about all the different things they have going on with the proposed community anaerobic digester project there for the Tulalips. I know they've done a feasibility study and that was a really detailed study. They looked at the whole area of all the other waste streams they could get, resource streams they could get into the system. For instance, food waste from the Monroe prison, local food industry, the Tulalips have fish carcasses, just a number of different things they looked at as feedstocks to come to a digester. So I wonder, have you guys thought about biosecurity? And so I called Andy Workhoven on the phone and I say, "Andy, you guys have looked at all these different feedstocks, have you ever talked about biosecurity?" There was silence on the other end of the phone. I said, "Andy, we've got to look for some money to investigate this."

About a year ago we were fortunate to get some funding through the university to look at potential movement of pathogens through a community-type anaerobic digester. This wheel is supposed to represent that, with the middle here being a centralized anaerobic digester, and each one of these spokes out here would be a dairy. You might have a dairy that would move its manure to the anaerobic digester system and then move it back to the farm, whether it be the solids or the liquids. If you have this kind of movement, your microbes go to the digester, some 95 to 98% get killed, and maybe you bring 2% of those bugs back. But it's your bugs going and your bugs coming back. But now if you begin to look at a community-type system, you've got your neighbor's bugs and the neighbor's neighbor's bugs, and so forth. If they have different bugs than you do and they're not bugs you want, maybe you've created an opportunity to actually bring bugs onto your place that you didn't really want. So, it's this kind of movement that made me think maybe I've got something my neighbor doesn't want but it's not going to much matter because, if there's enough of them left in that, then they're going to end up with them.

I'm trained as a dairy nutritionist, but what I am really passionate about is doing applied research. This was one of those kind of applied challenges, so I got hold of my veterinary colleagues at the main campus. We hooked up with Mike Gamroth in Oregon, Dale Hancock with the Field Disease Investigative Unit in Pullman, Lindsay Oakes, Jim Everman—these are the folks who really know the microbe side of it. We set up a protocol for looking at the different microbes that would be of concern for transmitting some of the domestic disease agents in this context of anaerobic digesters.

Previous speakers today have shown this. We can get a very high level of pathogen kill, as much as 98%. One to two log unit reduction is common for mesophilic and the thermophilics may be up to as much as 4 log. Of course it depends where you start from as well. While there can be reductions in pathogens with digesters, what risks still might be there when we think about a community digester approach, particularly when liquid or solid manure fractions are returned back to the participating dairies? We're basically looking at the herd-to-herd transmission issue.

Risks? If they aren't closed herds, what about purchased animals? Custom raising heifers, moving them off and whatever kind of commingling of bugs might occur there as they come back. Use of manure solids as bedding. While some of the earlier talks today showed that fiber bedding was good from a mastitis standpoint, are there other risks? Use of liquid manure as a fertilizer, irrigation or actually maybe even flushing your alleyways—these are various avenues for introduction of bugs as well as reintroduction exposure of animals.

We didn't have any operating anaerobic digesters in Washington and we didn't have any community digesters. But they did in Oregon. We got hold of Mike Gamroth, Mike made contact with the Tillamook folks and one other AD system down there, and we set up the study. We took samples before they went through the anaerobic digester and we took samples afterwards. Sampling period was biweekly on two consecutive days for six sampling events. What this means is my technician went down to Oregon on Sunday night, she sampled at the first dairy in the morning, went to the next dairy in the afternoon, sampled, went to the shipping point, shipped samples Fed Ex overnight to Pullman, and then they had the samples. She stayed overnight in Tillamook, sampled there, went back to the other dairy the next afternoon, hit the next shipping point and shipped those to Pullman. So our samples were going overnight shipment to the laboratory at the WSU vet school.

Samples were obtained before and after digestion, so we'd get it as the liquid was going into the AD system and then we got it immediately coming out of the AD. We also got the liquid and solid stream at the point of solid separation. The design of the two digesters was different, one being plug-flow and the other is more of a continuous mix/continuous feed. Both of these were running at 100°F, there's actually a thermometer in one of those. The specific organisms that we selected for evaluation were salmonella, we also looked at generic *E. coli*, including O157:H7, Jack-in-the-Box bug, enterococci, enteroviruses, and then mycobacterium paratuberculosis or the Johne's bug.

Generic *E. coli* were selected because of high concentrations. They're consistently there in fecal waste and because they have a low thermal tolerance, an AD system ought to knock them off pretty quickly. The numbers show that. Enterococci were selected because they are consistently present but they have a little bit more thermal tolerance. They might not be as easily killed. Salmonella and mycobacterium were selected because they are themselves important biosecurity agents and because they occur frequently enough that we might have a chance of seeing them. Enteroviruses were selected because they occur uniformly in cattle populations at high prevalence and they have a level of environmental resistance similar to certain viruses that have biosecurity implications.

So, to the data. To orient you a little bit—what we'll have in these first couple of slides is a combination of data from the continuous mix and then the plug-flow. The solid blue bar being the samples collected before digestion and then afterwards. So here with generic *E. coli*, we're seeing this reduction from log 5.5 down to about log 3.5. We didn't see quite the reduction here in the continuous mix as we did here in the plug-flow. We have a pretty high kill in both, but there are some apparent differences between the two systems.

With the enterococci, as I mentioned earlier, these are a bit more thermal tolerant. We didn't see nearly the reduction in either system, but again saw a greater reduction in the plug-flow.

The next slide shows the enterovirus data. We actually had some samples where we picked it up on some composted solids that we were able to sample in the field afterwards. When we looked at the samples before digestion on continuous mix versus plug-flow (this is presented on percent of the samples that showed viable enterovirus here), about 30 to 40% were showing viable before digestion either on the continuous or the plug-flow where we're seeing only a 10 to 20% after. Obvious kill-off here, but even after composting on the plug-flow, we were picking up in a limited number of samples somewhere around 25%. We're still showing some bovine enterovirus.

These are the data on the mycobacterium or the Johne's, and I think it's the biggest concern. This is the one you probably ought to give some thought to.

What I'm going to do is focus on this second line, here, and the fourth line. If we look at samples before digestion with the continuous mix, we saw 80% of the samples (8 out of 10 samples) showed mycobacterium. When we look at post-digestion, 40% were positive. About half of the samples still had enough there that they were detectable. With the plug-flow, there were 90% (9 out of 10), and afterwards there were still 63% of samples showing mycobacterium.

This is just a percent presence or absence. I talked to Lindsay Oakes about the actual numbers of mycobacterium, and I said, "Is the amount that is left there enough to be a concern?"

He said, "Yes," that there were still enough left that you need to be consider whatever kind of strategies you can to minimize your exposure.

So I think the overall data that others have shown today plus what we have collected does show that we do have a high kill on a number of these organisms we'd like to get rid of, but when you get into some things like Johne's, we may have to be considering some other alternative technologies to either knock those bugs down or, once you're handling that manure back at the farm again, doing it in a way that's going to minimize exposure of your animals for subsequent infection.

Thanks for your attention.

Question—

How was it done? They used a very lengthy incubation and then, I believe, they used PCR following up on that. I'm not the lab person. This is pretty high tech stuff.

Question—

My understanding, through the incubation, if they were dead they wouldn't have grown. And then they were confirmed with PCR, so this is real stuff. These are the real bugs.

Question—

The question and comment is, wouldn't a system that does a more complete breakdown of the volatile solids also probably do a higher kill rate on the bugs, and that was our inference when we were in the study. Obviously we had two systems so we can't do statistics on it, but, yes, that's my interpretation of the data. In fact, the more breakdown, the longer you have in the residence time, the greater opportunity you have for kill.

Question—

Correct. The comment was about the work we've done since last September using a buffer rather than ammonia to create that struvite. What you're doing is you're not only pulling phosphorus out of the system, but you're also pulling nitrogen out. And that's correct. In terms of the struvite working as a fertilizer, we have three experiments going on. My daughter is in fifth grade, and she's growing triticale with it at three fertilization rates and comparing it to ammonium nitrate and there are treatment differences, so it's working in her science fair project. Bob Stevens of Prosser is looking at this, growing triticale on low-phosphorus western Washington soils and low-phosphorus eastern Washington soils and that experiment is currently underway. Then we also had some agriculture students at a local high school who are looking at this and using potting soils. I believe they are growing corn, triticale and soybeans. So we have several experiments going on, and what we have so far looks promising.

Question—(Phil Lusk) Just a comment, going back to the Danish experience, where they do have a lot of centralized digesters. Ben Dixon with the Danish Veterinary Services investigated this extensively and, of course, as you pointed out, a medium temperature digester operating at 100°F has a one or two log pathogen reduction. Ben Dixon's research found log 4. Of course it depends on the organism type, and I can't recall exactly what it was. But if you operate either post- or pre-digestion at 160°F for one hour for any number of pathogens you get very high kill. For a centralized digester, a thermophilic stage at some point is probably necessary.

So the comment is, as we get into adopting these digesters at the field level, when you look at the real world situations we have here, there may be some considerations, either pre- or post-digestion, to help do some additional pathogen kill as we know more. As we went through the literature, many of the studies were done at laboratory bench scale. Our two and a half month study generated real world cow data, and that's why I'm excited about the information here. If we want to minimize the risk, we have to do some additional things and that's really the take-home message. Thanks for that comment.

Thanks for listening.