Dairy Distillation Grant- Final Report 7/10/2019

Washington State University

Please explain the progress made on your project so far. *

Q: A clear explanation of the results of this grant contract and how the results could be expanded to improve water quality, soil health and how the environmental benefit(s) focused could be expanded.

Results

The former P recovery approach has been to use sulfuric acid and sodium hydroxide as pH modifiers for formation of struvite. Neither of these chemicals as acquired would allow the resultant struvite to be considered an organic source of nutrients. This project focused on demonstrating the production of struvite with oxalic acid and ammonia (ammonium water), two pH modifier sources that have potential for struvite to be considered organic.

Batches of 16,000 liters of manure are pre-treated with an acid pH modifier (oxalic acid or sulfuric) and subsequently pumped into the mobile struvite system with addition of a base pH modifier (NaoH or ammonia water). Data from each run are collected on: initial and final chemistry of liquid manure, volume of manure treated, volume of chemical used, mass of struvite produced, and purity of struvite.

Results Using Alternative pH Modifiers:

The team evaluated oxalic acid and aqueous ammonia as organic alternatives to sodium hydroxide in the mobile nutrient reduction treatment process. Calcium (Ca) has proven to be an initial barrier in the production of struvite from dairy manure. Calcium in typical dairy manure is bound tightly to phosphorus in the form of calcium phosphate. Oxalic acid is well known for its calcium-binding ability. Oxalic acid sequesters the calcium (to keep it from binding the phosphorus (P)) and precipitates the calcium as a nearly insoluble salt; calcium oxalate. Laboratory results previously exhibited that trapping calcium with oxalic acid can successfully render the phosphate available for removal of P in struvite.

In the laboratory, the WSU livestock nutrient management program has shown the ability to trap the Ca with oxalic acid and remove phosphorus as struvite. In the field, the mobile system was operated at a flow rate of approximately 32 liters per minute, and pH modifiers used were sulfuric acid or oxalic acid-sulfuric acid to decrease the pH, and sodium hydroxide to raise the pH. Oxalic acid was chosen for evaluation due to its dual ability to decrease pH and bind calcium. Results of the concentration of total P (TP) and ortho-P (OP) after manure treatment through the fluidized bed suggested no advantage of the combination of oxalic with sulfuric to decrease the concentration of P. Detailed analyses of centrifuged post-bed samples of manure effluent indicated that the oxalic was binding the free calcium, but remained suspended in the effluent. With raw manure, oxalate does not appear to be beneficial, unless there is a more effective step to drop ca-oxalate out of suspension, such as centrifuging.

Aqueous ammonia is currently being used as a pH modifier and as an alternative to caustic soda/sodium hydroxide and oxalic acid in the farm scale demonstration use of the mobile demonstration unit. The aqueous ammonia would be advantageous in farm management situations where additional nitrogen would be valued for its use as an agricultural crop nutrient. Also, aqueous ammonia would be considered organic if it was produced as a byproduct of another nutrient removal technology using manure as a substrate (with organic added or utilized components). If this aqueous ammonia byproduct from an organic processing method resembled the chemical commercial aqua ammonia (25-30 % NH_3), then the resulting struvite would be an organic product. The livestock nutrient management program is using commercial aqua ammonia as a pH modifier in this demonstration.

The aqueous ammonia as a pH modifier has outperformed using sodium hydroxide and oxalic acid with slightly higher OP reduction levels. The overall average OP% reduction was 74% and the overall average TP% reduction was 62% in the 15 collective batch runs using the aqueous ammonia. The highest nutrient reductions with aqueous ammonia as the pH modifier were observed with using anaerobically digested (AD) manure due to the fact that the digestion process uses the carbon to create methane for energy production, leaving the effluent to contain the majority of P in the inorganic form (ortho P). The highest OP% reduction using the digested manure was 94% compared to that of non-digested manure at 75%. The highest TP% reduction using AD manure was 87% compared to the non-AD dairy manure at 60%. The overall average OP% reduction in the batch runs using oxalic acid was 68% and the overall range of the average TP% reduction was 55%. The highest OP% reduction observed using oxalic acid was 76% and the highest TP% reduction observed was 63%. The struvite product positive yields that were harvested and collected at the end of the process runs averaged 10 lbs/tank (1 tank = approximately 3,000 gallons treated) using the aqueous ammonia and 0 lbs/run using the oxalic acid. The highest amount of struvite produced was 19.8 lbs/tank using the aqueous ammonia as a pH modifier with treatment of the AD manure.

Hourly consecutive samples (n= 9-23 hours, run consecutively) were taken during the oxalic and aqueous ammonia batch runs to determine if there is a certain point at which nutrient reduction is higher or lower and if improvements or modifications can be made to adjust for optimal nutrient removal. It appears that in the first hour of the process in the cone, some of the struvite bed that is used to grow the struvite crystals is dissolving into the treatment liquid which is creating a higher concentration (5% increase) of OP in the cone. This issue is mostly rectified in the second hour and a 13% average decrease in OP content than the original pretreated material is observed as the struvite is in the formation process.

Time Series Sampling

The time series sampling every hour during the fluidized bed process showed a wide variation of nutrient removal, as discussed previously. The occurrence of the first event/hour sampling point has an elevated value of OP and TP because the bed is suspected of being dissolved early in the process (figure below). Hours 6 and 7 of the process typically have the highest nutrient removal considering the variation. The variation is based on many different factors (TSS, Ca, Fe, etc. explained in previous reports throughout the duration of the grant contracting period).

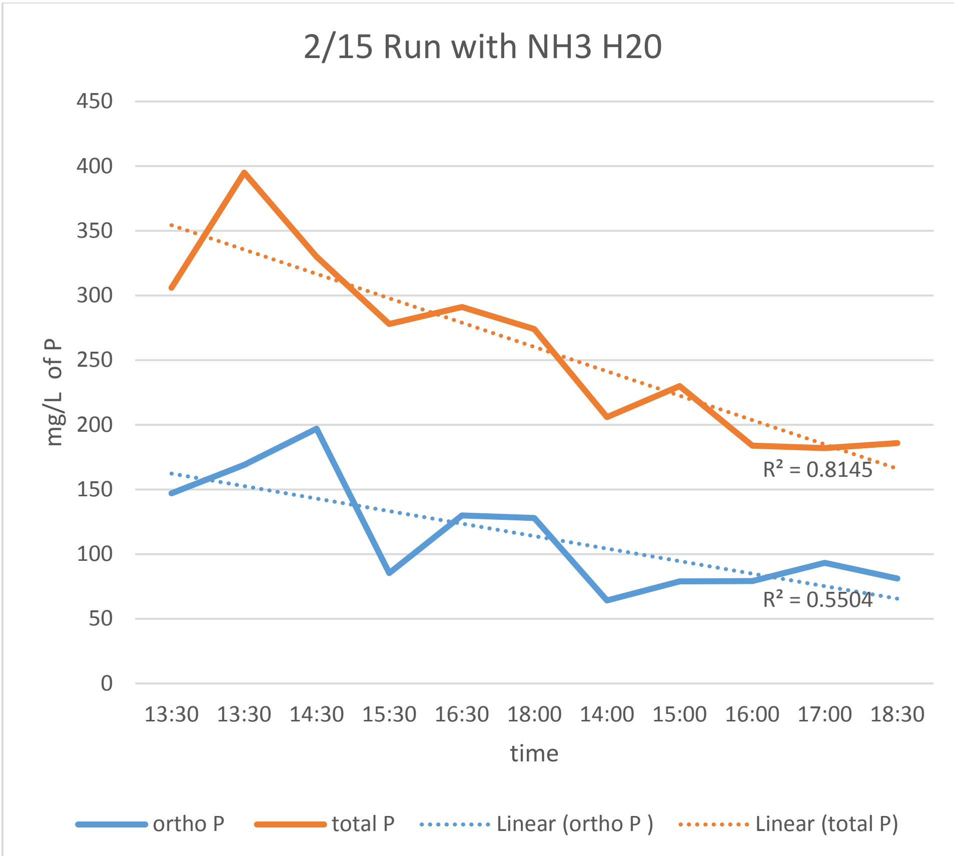
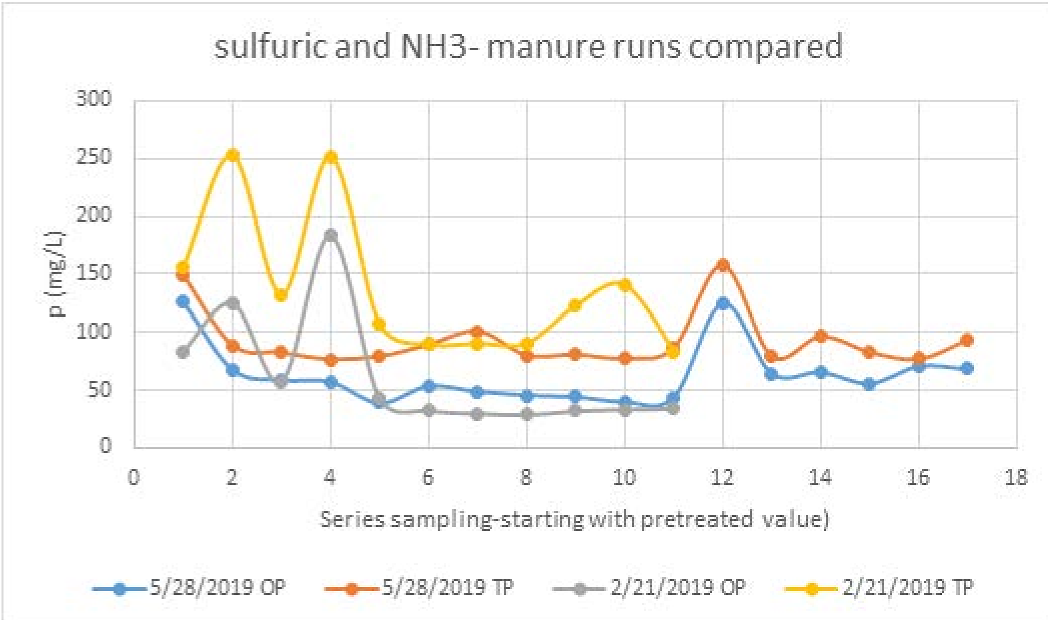


Figure 3. Hourly samples taken during the fluidized bed process using aqueous ammonia as a pH modifier. The decrease in OP is demonstrated at hour 6 with a 56% reduction in OP.

Sources of Struvite Bed in the Cone Crystallizer

The bed or source of substrate used in the cone crystallizer were compared using municipal waste derived struvite in the sand form vs a further processed form of struvite in a 0.9 mm pelletized ball used for land fertilizer application. The two sources of bed material were evaluated to further examine if the initial rise in OP (after the cone process initially starts) was from the small particle size of the bed substrate used and its contribution of P in the manure treated. As shown in the sources of bed figure below, the second data point for the May 2019 samples using the 0.9 mm pelletized ball is a decreased value showing P removal is occurring during the treatment run. However, the February 2019 data points show the second and fourth values to increase and then decrease as the nutrient removal process is forming struvite. One can conclude from this analysis that the slight increase in size in weight from a granular form (resembling sand) to a 0.9 mm pelletized ball helps keep the struvite bed from flowing over the cone, and also prevents it from contributing to elevated P concentrations in the treated manure.

Sources of Struvite Bed Figure:



*May 2019 data is from using the 0.9 mm ball form of struvite

*February 2019 is from using the granular sand form of struvite

Agronomic Application of Struvite Results

The WSU livestock nutrient management team applied struvite as a fertilizer on two commercial alfalfa fields in Eastern WA on August 11 (Farm 1) and September 6 (Farm 2) of 2017. The 2018, the struvite fertilizer applications occurred on August 17th (Farm 2) and October 10th (Farm 1).

Farm 1: The second application of struvite (1st in 2018) was be applied to an existing stand of alfalfa after the fourth cutting on a commercial alfalfa operation in Moses Lake WA on October 10, 2018. The treatment was 87 lbs. of P_2O_5 as Mono Ammonium Phosphate (MAP) and 311lbs of P_2O_5 as Struvite applied per acre. The demonstration area has had 4 cuttings to date in 2018 (1st on May 23rd, 2018; 2nd on July 2, 2018; 3rd on August 7, 2018; and 4th cutting on September 19, 2018) on 30 acres of land. The control field or grower managed field also had 4 cuttings (same as above), fertilized with MAP, added (259 lbs/acre), on 33 acres. The struvite fertilizer plus MAP field performed well in comparison to the MAP only/control field in 2018. The struvite field yielded 2.2 tons/acre compared to the MAP only field (2.39 tons/acre) on the first cutting on May 23rd, 2018. The second cutting also proved comparable between the fertilizers at 2.39 and 2.45 tons/acre for the struvite plus MAP and the MAP only fields, respectively. The struvite plus MAP and the MAP only fertilizer treatments were also similar for the third cutting (1.63 vs 1.57 tons/acre, respectively). The fourth cutting yielded 0.9 tons/acre for the Struvite plus MAP field and 1.1 tons/acre for the MAP only field.

Farm 2: The struvite treatment was originally applied to a new alfalfa seeding on a commercial hay operation in Kittitas, WA on September 6, 2017. The field was reseeded in April 2018, as many of the alfalfa plants experienced die off and were affected by freezing winter temperatures. The August 2018 application used 123 lbs. of P_2O_5 as Mono Ammonium Phosphate (MAP)/acre on the control field and 221 lbs of P_2O_5 as Struvite/acre on the treatment field. The first cutting of 2018 on 6/27/2018 yielded 2.3 tons/acre of alfalfa/acre for the treated struvite field and 2.0 tons/acre for the control field. The second cutting was on 8/7/2018 and the yields were estimated because due to a lack of communication when counting the bales. The third cutting occurred on 9/21/18 and yielded 0.78 tons of alfalfa hay/acre for the treated struvite field vs. the control field which yielded 0.95 tons/acre.

Soil samples, and plant tissue samples were collected and evaluated for nutrient content and forage quality for both Farm 1 and 2. Soil information is characterized using the data below for both farms. Forage quality data is in current evaluation for 2018 cuttings.

Farm 1 *existing stand*	Olsen P (mg/kg)		K (mg/kg)		Mg (mg/kg)		OM (mg/kg)	
	Control	*Treatment*	*Control*	*Treatment*	*Control*	*Treatment*	*Control*	*Treatment*
6/27/2017	18	13	57	49	1	0.8	1.9	2.1
8/9/2017	17	12	84	63	2	2	1	1
9/28/2017	20	20	133	118	2.1	2	2.1	2.7
5/31/2018	18	10	127	93	2.1	2.2	2.2	1.7
7/11/2018	14.0	9.3	136.5	100.0	2.1	2.2	2.4	2.4
8/14/2018	12.8	10.0	96.3	76.3	1.9	2.1	2.1	1.9
9/28/2018	11.3	9.8	118	97	2.1	2.2	1.9	2

Farm 2 *New Seeding*	Olsen P (mg/kg)		K (mg/kg)		Mg (mg/kg)		OM (mg/kg)	
	Control	*Treatment*	*Control*	*Treatment*	*Control*	*Treatment*	*Control*	*Treatment*
8/8/2017	18	18	112	86	3.5	3.4	3	3.5
5/16/2018	16	17	133	142	3.2	4	1.1	1.1
7/13/2018	20	18	137	109.3	3.5	4.2	2.5	2.4
8/15/2018	13.8	7.0	101.5	70.3	3.3	4.0	2.3	2.2
10/2/2018	18.25	16	115	101.5	3.1	3.9	2.2	2.2

In summary, results showed Struvite produced similar alfalfa yields, phosphorus uptake, and quality as MAP (Table 1).

		Yield (tons/acre)		Average Tissue P (%)		
Farm	**Fertilizer**	**Total**	**1st Cut**	**Season**	**1st Cut**	**Avg. RFV***
1	MAP	7.3	2.0	0.28	0.25	181
	Struvite	7.3	2.3	0.28	0.24	168
2	MAP	7.5	2.4	0.27	0.26	155
	Struvite + MAP	7.1	2.2	0.27	0.28	165

*The Relative Feed Value reflects the digestibility and intake potential of feeds, where greater numbers mean better quality.

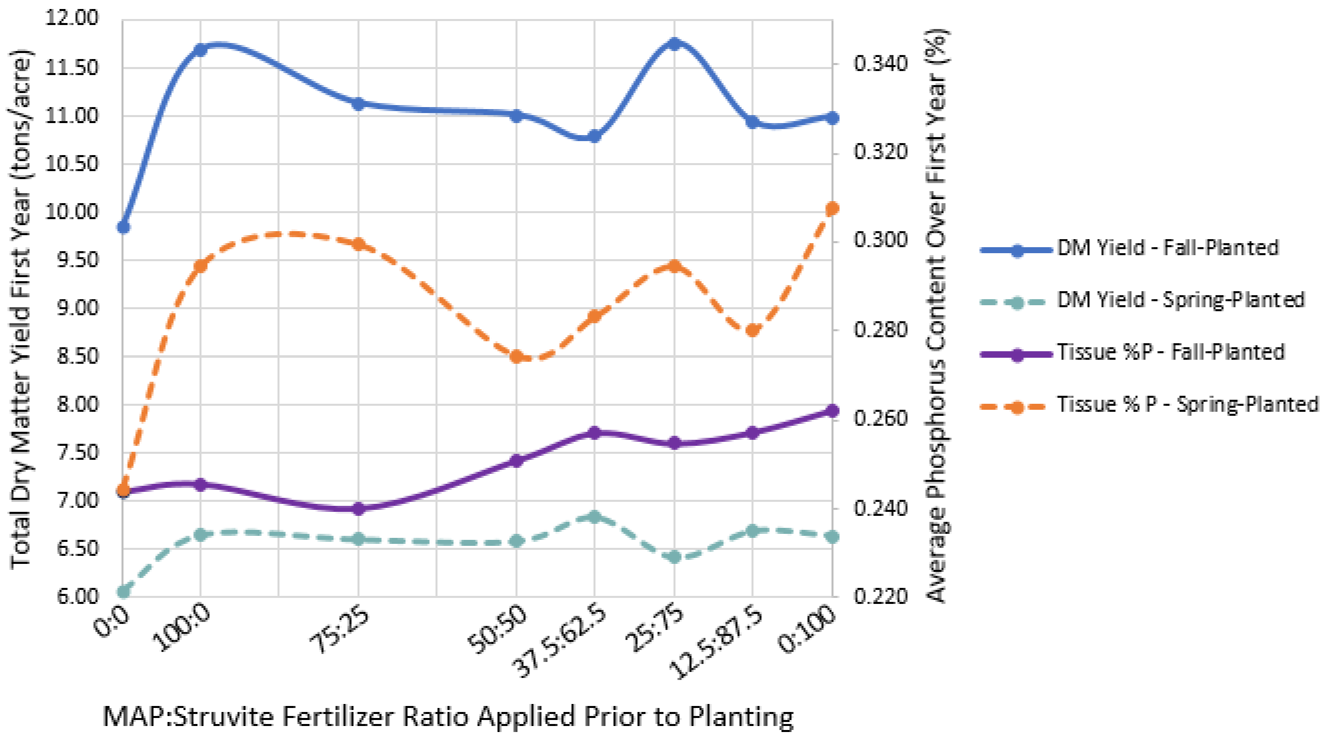
Table 1. Alfalfa hay yields, P uptake, and relative feed value (RFV) from 2018

a. Two simultaneous plot studies (< 1 acre each) were conducted by Dr. Norberg in Prosser to compare agronomic performance of different combinations of Struvite and MAP mixtures on fall and spring planted alfalfa.

Plots were randomly fertilized at a constant rate with one of 7 different mixtures of MAP: Struvite (100:0, 75:25, 50:50, 37.5:62.5, 25:75, 12.5: 87.5, 0:100) just before planting, or left as an unfertilized check. The fall-planted alfalfa was cut 5 times in 2018, while spring-planted was only cut 3 times. The source of P, whether MAP or Struvite, did not have a significant effect on yield or P uptake in the first cutting and season-wide, regardless of planting time (Figures 1 and 2).

In short, what we've learned so far from the field demonstrations with the supporting data of the plot work is that Struvite can provide enough P in the first year after fertilization to reach comparable yields and P uptake as MAP. Furthermore, the similarity in the first cutting after a new seeding in both studies has shown Struvite is available to meet the immediate needs for early establishment of alfalfa. This ongoing research will continue for a second harvest season this summer to compare the long-term performance of the two fertilizers.

Figure 1. 2018 Accumulative Dry Matter Yield and Average Phosphorus Content in 2018 of Fall† and Spring Planted‡ Alfalfa Fertilized with MAP and Struvite-MAP mixtures



† Fall planted data shown above is across 5 cuttings for dry matter yield, and 4 cuttings for P concentration

‡ Spring planted data shown above is across 3 cuttings for both DM yield and P concentration.

Figure 1. 2018 Accumulative Dry Matter Yield and Average Phosphorus Content in 2018 of Fall* and Spring** Planted Alfalfa Fertilized with MAP and Struvite-MAP mixtures [*Fall planted data shown above is across 5 cuttings for dry matter yield, and 4 cuttings for P concentration.] [**Spring planted data shown above is across 3 cuttings for both DM yield and P concentration]

Figure 2. Dry Matter Yield and Average Phosphorus Content at First Cutting in 2018 of Fall and Spring Planted Alfalfa Fertilized with MAP and Struvite-MAP mixtures

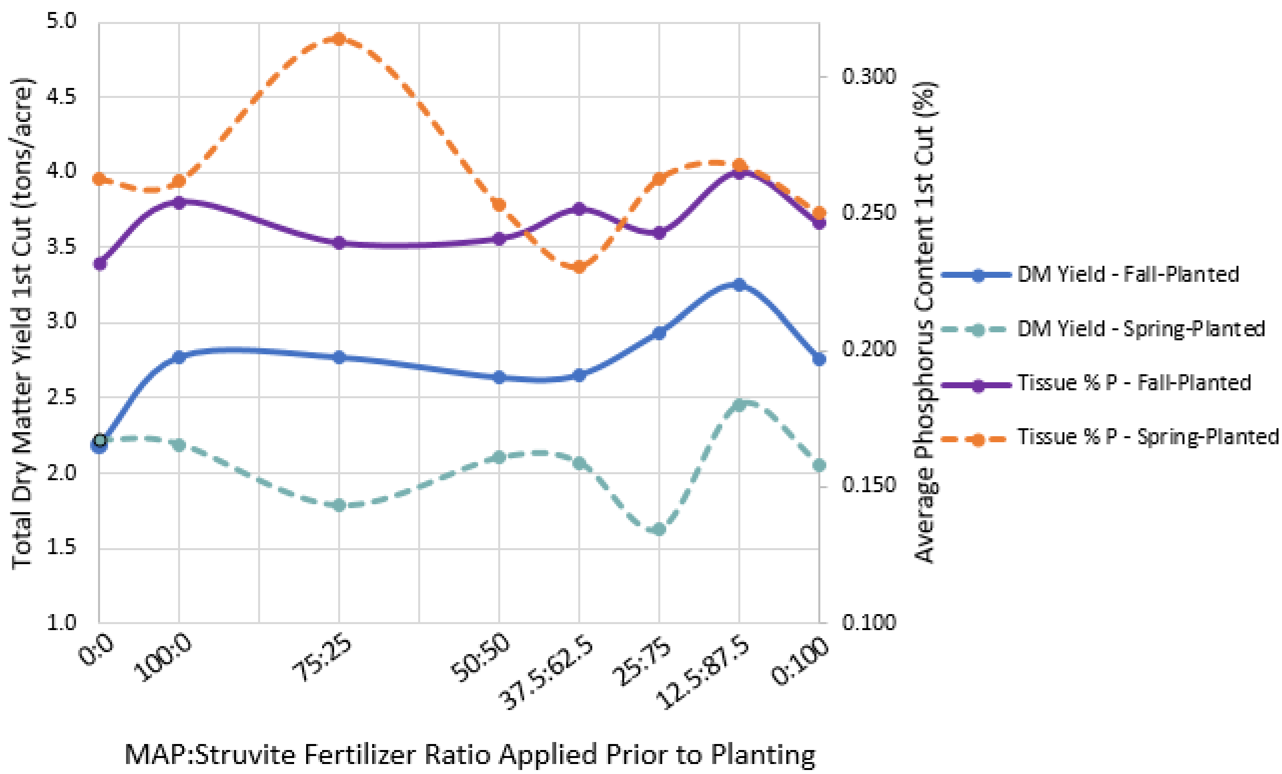


Figure 2. Dry Matter Yield and Average Phosphorus Content at First Cutting in 2018 of Fall and Spring Planted Alfalfa Fertilized with MAP and Struvite-MAP mixtures.

b. Also, the rate of release of P into the soil from variable rates of MAP to struvite is currently underway.

The objectives in this laboratory project are to develop a phosphorus release curve for different ratios of MAP:struvite through a soil incubation study, complementary to Dr. Steve Norberg's ongoing studies on P uptake in alfalfa. Also, to determine effect of spring's lower soil temperatures on release of phosphorus compared to a fall application to better equip farmers with the information needed to efficiently use struvite. The data from the extractions has not yet been analyzed as the extractions will be finished the first week of May 2019.

Next Steps

This grant could be expanded to create a regional P recycling relationship between the dairy and alfalfa industries by a few key concepts. Each concept has the primary goal of maximizing the formation and capture of P as struvite, and improving the efficiency of the run procedure. This nutrient recovery technology would be more accessible by further investigating the economics, the ease of procedure and higher yields of struvite. The adoption of this nutrient recovery technology by WA dairy producers would limit the amount of excess P applied to crops would lessen the soil P build up resulting in improved water quality and significantly improved environmental benefits for the local ag and tribal communities, the aquatic industries, natural resources and the environment, and the public.

1. There is a significant cost associated with the addition of chemicals used to buffer the manure. The higher the solids content, the higher the addition of chemical required to buffer the manure in order for the formation of struvite to occur. This issue of high chemical costs could be further examined by:
   - Use the fluidized bed system in coordination with a centrifugation system or dissolved air flotation (DAF) system to decrease the total suspended solids (TSS) content to no more than 1% (10,000 mg/L or ppm) and preferably below 5%. Considering the suspended solids (SS) that make it through the centrifuge system would be the slowest-settling SS, values above 1% could make it difficult to get low-enough TSS liquid in the typical acidify-and-settle pretreatment. When using the centrifuge as an alternative to, or additive with, the settling step in the typical pre-treatment step. In this case, one would want the TSS to get as low as that which we achieve in the settling, that is, whatever TSS levels is in the feed to the cone crystallizer in instances with good results. However, if one uses oxalic acid in the pretreatment to form calcium oxalate, then the TSS removal has to be very good, yielding a near-clear liquid (may still be deeply colored though), with something less than 0.1%, maybe 0.2% at maximum, of TSS. This could be achieved using a DAF system because the DAF system is effective at removing even fine suspended calcium phosphate, which van be even more difficult than removing calcium oxalate.
   - Develop relationship between TSS, viscosity and struvite retention in cone reactor to determine a predictive relationship for efficient retention of struvite in the reactor cone.
2. Efforts to increase struvite yields. This would be accomplished by:
   - Considering multiple options to decrease the struvite formed into the reduced nutrient effluent (material coming out of the cone, most likely into a storage lagoon on a typical farm operation). Procedure modifications will be performed to keep the formed struvite in the cone by adjusting the flow rates and/or volume processed, versus floating over into the reduced nutrient effluent.
   - Collect samples of low (< 5,000 mg/L TSS) TSS manure (i.e.: as a product stream from a dissolved air flotation (DAF) system and also, from a post centrifugation system) to demonstrate if the TSS and the resulting massive buffering capacity of high dairy TSS in manure is the largest obstacle in producing struvite using the fluidized bed cone treatment. The cone process would be run with serial sampling under these low TSS conditions from processed manure using the previously demonstrated pH modifiers.
   - Refine the method for dosing of low-pH modifier (acid) into the bottom of the reactor (dilute vs concentrated).
   - Additional analysis from repeated runs to compare batch system vs continuous mode of operation for efficiency of struvite recovery.

There is a need for creating regionally sustainable feed and dairy industries, and this is driven by: 1) diminishing supply of non-renewable P supplies, 2) the need for limiting the build-up and subsequent loss of P from soil, and 3) the high cost of fertilizers.

Phosphorus continues to accumulate in soils associated with the use of dairy manure. Once the soil P reaches a critical level, the soil's ability to hold that P is diminished and P is at risk of loss to the environment. The US EPA reports that nutrient pollution is the leading cause of water quality impairment in lakes and estuaries and is second behind sediments as a leading cause in rivers. In addition, the price of commercial P based fertilizers recently soared to record high prices, and are likely to do so again as diminishing reserves struggle to accommodate increasing demand. A viable solution is the adoption of technology to capture P from liquid manure in the form of struvite, a slow release form of P based fertilizer. The struvite that is formed is easy to handle and transport, and is low in moisture (looks much like sand – see picture below). Each farm has a unique need for P removal to reach a whole farm nutrient balance.

Q: Detailed description of the innovative and emerging technology(s) evaluated.

There is an apparent need for creating regionally sustainable feed and dairy industries, and this is driven by: 1) diminishing supply of non-renewable P supplies, 2) the need for limiting the build-up and subsequent loss of P from soil, and 3) the high cost of fertilizers. Phosphorus continues to accumulate in soils associated with the use of dairy manure. Once the soil P reaches a critical level, the soil's ability to hold that P is diminished and P is at risk of loss to the environment. The US EPA reports that nutrient pollution is the leading cause of water quality impairment in lakes and estuaries and is second behind sediments as a leading cause in rivers. In addition, the price of commercial P based fertilizers recently soared to record high prices, and are likely to do so again as diminishing reserves struggle to accommodate increasing demand. A viable solution is the adoption of technology to capture P from liquid manure in the form of struvite, a slow release form of P based fertilizer. The struvite that is formed is easy to handle and transport, and is low in moisture (looks much like sand). Each farm has a unique need for P removal to reach a whole farm nutrient balance. This project demonstrates the farm-scale deployment of a mobile system for economical and efficient means of capture and subsequent transport of nutrients from a region or P density to an area of forage production that needs supplemental P. In addition, the of a nutrient recovery system (struvite technology), is already used in large wastewater plants.

Struvite technology, already in use in large municipal wastewater plants, has been limited in its adoption in liquid livestock manure due to two factors: (1) the relatively small and numerous units that would need to be installed and operated at dairy farms; and (2) the need to transport the small quantities of raw struvite from the numerous locations to a product center for drying and preparation for distribution to the areas that need additional P. The purpose of this project is to break these two barriers by assembling a mobile, trailer-mounted unit and demonstrating it at separate farm locations. The unit removes P from liquid manure, converting it to raw struvite. The raw struvite, being very rich in P (29% P2O5 equivalent), will be sufficiently compact that it can be easily transported by the mobile unit to the product center, and shipped from there to the grower industry (crops and horticulture) in the region.

Struvite presents an advantage versus the other methods of nutrient removal in that the removed phosphorus is captured in a more useful form—a small volume of sand-like mineral fertilizer that is relatively low in water content (10 to 40 percent, typically). Other methods produce a semi-solid that is low in phosphorus content--typically less than 5% P_2O_5, and also has larger amounts of water, with water often present in greater amounts than the solids, which are already low in phosphorus content. Thus the struvite product typically offers a positive value, as its fertilizer value is greater than the labor and freight cost of transporting it to areas where phosphorus is needed. However, the economics can be improved by further reducing the labor and freight costs by capitalizing on economies of scale offered by a mobile system. In addition, labor costs, and potentially capital costs, can also be reduced through use of a single experienced operator and a single struvite system for several locations in place of having a separate operator and system for each individual farm.

The mobile struvite system is designed to capture phosphorus from liquid manure in a material much like sand for export as a fertilizer off-farm. This is accomplished by reacting free inorganic phosphorus with magnesium and ammonia-nitrogen to form a compound called magnesium-mon-ammonium phosphate, or commonly called, struvite.

Manure from farms (approx. 2,800- 4,000 gallons) was processed with the mobile struvite system as shown in the attached graphic illustration.

The struvite process is described in the consecutive steps below:

Step 1: manure is acidified with sulfuric acid to break the bond between inorganic phosphorus and Ca

Step 2: magnesium chloride is added to insure that sufficient Mg is available

Step 3: 50 pounds of struvite bed is placed into the bottom of the cone to serve as a seed bed

Step 4: the acid-treated manure is pumped into the bottom of the cone and a base (sodium hydroxide) is pumped into the bottom of the cone to raise the pH and create the formation of new struvite crystals.

During the processing of the manure through the cone, samples were obtained at (least) 2 different time points as the treated manure left the cone to assess the reduction of phosphorus, at approximately 2-3 hours and 4-6 hours. Samples at both time points were used to make estimates of the system's performance.

After evaluating manure from approximately 30 farms, the following factors were determined to affect performance of the system and formation of struvite: total suspended solids (TSS), calcium (Ca), iron (Fe), ratio of ortho-phosphate-P (OP): total P (TP), viscosity, and ammonia concentration. These factors contributed to the variation in P reductions (%) during the struvite production process.

Q: Estimate of acquisition, maintenance and operating costs for a dairy operator to implement the technology.

For a scenario with a 2,500 cow dairy, the capital cost to fabricate a cone crystallizer at the dairy would be approximately $200,000. This would assume a 10-year life, and this equates to a cost per cow day at $200,000/ (10x365x2500) = 2.2 cents per cow day. For maintenance, assume yearly maintenance at 5% of capital cost (a rough rule of thumb). Then maintenance is $10,000 per year, or $10,000/(365x2500) = 1.1 cents per cow day. Also, add two hours of labor at $25/hour, which is $50/day, or $50/2500 = 2 cents per cow day. Chemical costs at a commercial scale operation from the data obtained during this grant contract would amount to approximately $0.39 per cow per day. These rough estimates would be approximately $0.44-$0.45 per cow per day given the scenario parameters.

Q: How costs for implementation of the technology could be mitigated by any marketable byproducts created by the technology.

The costs for marketing and selling struvite to mitigate nutrient recovery (NR) technology costs would be minimal because it would affect a dairy farmer's business plan. Generally speaking, most dairy farmers are interested in feeding cows, making milk, hay and/or corn. Marketing and selling struvite would be another business plan all together. However, it would be a least cost solution for a farmer to export P on the farm.

Any technology or solution that a dairy farmer could use to remove excess P from their farm would cost more than to export P as struvite. No other NR technology removing P from a dairy wastewater stream to date, produces a dry product, which is much less expensive to export than a liquid slurry, or even a dewatered solids product. The dairy industry would perceive this technology as most costly. The fluidized bed technology can export P less expensively than other NR technologies.

Q: Assessment of potential markets and demand for byproducts created by the technology being evaluated.

The potential market for dairy based recycled P in the form of struvite is immense. Struvite would be highly valued in the horticulture and greenhouse applications as well as in the regional alfalfa and hay industry because of its highly desired fertilizer properties. The struvite is virtually water insoluble, and in the ortho-P form which means it is in a plant available form to be used by the plant. Struvite used as a fertilizer is also a slow to medium release form through releasing nutrients (N, P, Mg) in response to a plants production of organic acid called citrate soluble mode of action. This allows struvite to gradually be released into the soil solution when the plant needs it the most. This mode of continuous release provides plant available N, P and Mg while minimizing the runoff, leaching and bind up of nutrients. Not to mention, the value-added component of being a non-mined, renewable source of fertilizer and originating from recycled dairy manure.

Q: If relevant an assessment of potential federal and state tax credits available for implementation on dairy farms of the new technology or associated byproducts created by the technology.

There is no awareness of nutrient tax credit opportunities available for implementation on dairy farms of the NR technology or the struvite created by the technology.

Q: If relevant an assessment of potential federal, state and private cost-share funds to support implementation and operation of the technology on dairy farms.

There is a potential opportunity for supportive funding via NRCS cost share programs.

Q: Assessment of potential positive and negative impacts to soil, water (surface and ground) and/or air created by the technology being evaluated.

There is a need for creating regionally sustainable feed and dairy industries, and this is driven by: 1) diminishing supply of non-renewable P supplies, 2) the need for limiting the build-up and subsequent loss of P from soil, and 3) the high cost of fertilizers. Phosphorus continues to accumulate in soils associated with the use of dairy manure. In addition, the price of commercial P based fertilizers recently soared to record high prices, and are likely to do so again as diminishing reserves struggle to accommodate increasing demand. Struvite as a recycled source of P can be used as comparable, and even higher valued than mined P from phosphate rock reserves.

There are great environmental benefits to water, soil and natural resource conservation associated with producing struvite using a fluidized bed cone crystallizer, and also using struvite as a recycled form of P as fertilizer. Implementation of the cone crystallizer on a dairy farm would create a reduced nutrient effluent and hence avoid over application of P to fields. Farmers would meet the crop nutrient requirements and therefore protect water quality preventing associated risks of runoff and leaching. Less soil P accumulation significantly reduces runoff and leaching and also the common association of eutrophication of surface waters near manure applied fields.

Q: Benefits and challenges to the scalability of the technology for various size dairy operations.

The scalability of the technology has less to do with the size of the dairy herd/the size of the dairy operation, as it is the crop land available per cow that is the major factor. The amount of land available to spread the manure without over applying P is the challenge that most dairy farmers face, especially in increasingly populated areas in Western WA. The farms that have limited acres per cow are going to be in need of adopting NR technology to export P.

Q: Recommendations for future "next steps" in the possible broader implementation of the technology being evaluated.

Please refer to the previous "Next Steps" section above on identifying clarified waste streams (low TSS that contain appropriate concentrated amounts of P for extraction/ capture).

Is the project currently on schedule to be completed on time? If not please explain. *

N/A

Have you experienced difficulties with any permits required for your project? If so, please explain. *

N/A

Aside from permitting has the project experienced any challenges or difficulties? *

Many challenges have previously been discussed in this report and also mentioned in the next steps section above.

As previously discussed, a large quantity of chemicals is required to overcome the buffering capacity of the manure resulting in high operation costs. These costs could significantly be decreased with using the cone crystallizer after a flush dairy based centrifugation system or dissolved air flotation (DAF) system to decrease the total suspended solids (TSS) content. The project has faced challenges with finding a concentrated low TSS waste stream of concentrated P. Many dairies with centrifuges in the state use the manures from their dry lots to run through them so the resulting effluent is still high in TSS from being a concentrated material that will not work well with the crystallizer. In addition, the DAF system at a couple of dairies have been shut down due to the current dire economic situation that many US dairy farmers are currently facing. Improvements in nutrient management come well after feeding cows, paying labor and bills to keep their operations in business.

Have you provided any tours, presentations or press releases in relation to the project? *

- The presentation titled, 'Performance of a Mobile System for Recovery of Phosphorus as Struvite from Liquid Dairy Manure' was given by Dr. Joe Harrison on January 9, 2019 to approximately 40 people at the Soil Science Society of America (SSSA) International Soils Meeting in San Diego, CA. The poster presentation titled 'Effect of Struvite and Mono Ammonium Phosphate on Yield and Nutrient Uptake of Alfalfa' was presented during the poster presentation session on January 7, 2019 to the attendees of the SSSA meeting.
- The mobile struvite project was featured at the NW Hay Expo by the Washington State Hay Growers Association. Approximately 15 people were at the presentation titled, 'Struvite Fertility Work' given by Erin Mackey, WSU graduate student.
- The presentation 'The Mobile Struvite Project: Phosphorus cycling between the dairy and alfalfa industries' was given by Dr. Joe Harrison to approximately 110 viewers through the Livestock, Poultry Environmental Learning Center's *'Separation Technologies for Capturing Nutrients from Manure'* national webcast series on January 18, 2019.
- **The presentation '**Comparison of Sulfuric vs Oxalic Sulfuric When Forming Struvite from Liquid Dairy Manure' and 'Comparison of Struvite to Mono-ammonium-Phosphate as a Phosphorus Source on Commercial Alfalfa Fields' will be given by Dr. Harrison in April 2019 at the Livestock and Poultry Environmental Learning Center's 'Waste to Worth' conference in Minneapolis, MN.
- The article 'Alfalfa hay sample plant tissue analysis and struvite use' by Dr. Steve Norberg (the agronomist on this demonstration project) was published in the March 2019 issue of 'Hay and Forage Grower' magazine. https://www.hayandforage.com/article-2405-alfalfa-hay-sample-plant-tissue-analysis-and-struvite-use.html
- The article Progressive Hay Grower Article/ June 2019 : *Developing Practical Phosphorus and Potassium Tissue Test Recommendations and Utilizing Struvite in Modern Alfalfa Systems* Norberg, S., E. Mackey, S. Fransen, J. Harrison, D. Llewellyn, and L. Whitefield (attached)
- Three project videos:

1. The Mobile Struvite Project: Capturing Phosphorus from Dairy Liquid Manure and Cost Efficient Nutrient Transport: https://puyallup.wsu.edu/lnm/mobile-struvite-project/
   Washington State University (WSU) is using a farm scale mobile struvite crystallizer unit at 30 dairies in the State of Washington to demonstrate this technology's ability to protect the environment by removing excess phosphorus from dairy wastewater. Phosphorus continues to accumulate in soils associated with the use of dairy manure. In addition, the price of commercial P based fertilizers recently soared to record high prices, and are likely to do so again as diminishing reserves struggle to accommodate increasing demand. A viable solution is the adoption of technology to capture P from liquid manure in the form of struvite, a slow release form of P based fertilizer. The struvite that is formed is easy to handle and transport, and is low in moisture (looks much like sand). Each farm has a unique need for P removal to reach a whole farm nutrient balance. The Mobile Struvite Project demonstrates the farm-scale deployment of a mobile system for economical and efficient

means of capture and subsequent transport of nutrients from a region or P density to an area of forage production that needs supplemental P.

2. Capturing Phosphorus from Dairy Manure in the Form of Struvite on 30 Dairy Farms in WA State: https://puyallup.wsu.edu/lnm/mobile-struvite-project-removing-capturing-p-liquid-dairy-manure/ Approximately 27 % of the phosphorus that the cow eats is captured in milk and exported off farm, the remainder not used by the cows is excreted in manure. As a result, there has been an increased build-up of P in soils on farms without sufficient land base to use all the P in manure for crop production. To address these issues, a nutrient recovery system has been developed (a fluidized bed) for extraction of P from manure in the form of struvite (magnesium-ammonium-phosphate), a slow release, easy to handle, P based fertilizer, for off-farm export as a fertilizer source. Each farm has a unique need for P removal to reach a whole farm nutrient balance. The Mobile Struvite Project demonstrates the farm-scale deployment of a mobile struvite system for economical and efficient means of P capture and subsequent transport of nutrients from a region or P density to an area of forage production that needs supplemental P.
3. Struvite, a Recycled Form of Phosphorus from Dairy Manure, used as Fertilizer for Alfalfa Production: https://puyallup.wsu.edu/lnm/struvite-used-p-based-fertilizer-alfalfa-production/ Approximately 27 % of the phosphorus that the cow eats is captured in milk and exported off farm, the remainder not used by the cows is excreted in manure. As a result, there has been an increased build-up of P in soils on farms without sufficient land base to use all the P in manure for crop production. To address these issues, a nutrient recovery system has been developed (a fluidized bed) for extraction of P from manure in the form of struvite (magnesium-ammonium-phosphate) for off-farm export as a fertilizer source. Struvite, a recycled form of phosphorus from dairy manure, and Mono Ammonium Phosphate (MAP) were applied to 30 acre and 60 acre sections of alfalfa fields at two commercial forage operations in Eastern WA. Results indicate that struvite is equivalent to MAP as a P source for commercial production of alfalfa.

General comments:

Thank you for the supportive investment of furthering the scientific exploration of P capture in efforts to ensure farmers can operate in both an environmentally sustainable and financially efficient manner.