CIG Report for Six Month Reporting Period: February 2018- August/September 2019
(with project continuation under an approved no cost 1 year extension through 12-28-2019).

Grantee name: Washington State University

Mobile System for Nutrient (Phosphorus) Recovery and Cost Efficient Nutrient Transport

Award identifying number: 69-3A75-17-51

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This project is divided into two main components:

1. *Mobile demonstration of nutrient recovery system*
2. *Agronomic land application of struvite to commercial alfalfa fields*

Summarize the work performed during the project period covered by this report:

Component 1: *Mobile demonstration of the nutrient recovery system*

a. During the period of September 2018 to December 2018, the mobile cone unit has completed the project objective of evaluating manure sourced from 30 dairy farms. The demonstrations have allowed us to gain a better understanding of how a mobile nutrient removal technology could function under a diverse set of field and weather conditions and with manure of variable composition.

The mobile system was used to evaluate manure from 30 different dairies. Samples were taken to evaluate the nutrient removal process at various stages of the process.

The pre-treated concentrations in manure before entering the nutrient removal technology were: ortho-phosphorus (P) range, 53 to 445 mg/L; total P range, 98 to 566 mg/L; Ca range, 256 to 1519 mg/L; Mg range, 252 to 1238 mg/L; Fe, range 9 to 117 mg/L;, and total suspended solids, range 840 to 22,000 mg/L. A reduction in ortho-P or total-P in samples leaving the cone compared to samples entering the cone, was used to estimate efficiency of P removal. In 27 runs when reduction in ortho-P was positive, the average reduction in ortho- P was 32 % with a range of 1 to 76%. In 28 runs when total-P reduction was positive, the average reduction in total-P was 29.5 % with a range of 2 to 71.8 %. The struvite crystals formed resemble the true characteristics of struvite. Using the data from 25 struvite samples produced from the mobile cone- the struvite average concentration of elements of interest were: 45392 mg/kg of total N, 9.3 mg/kg of total nitrate/nitrite, 664 mg/kg of Ortho P, 6617 mg/kg of Ca, 680 mg/kg of Fe, 74,159 mg/kg of Mg, 105,547 mg/kg of total P, 45,820 and mg/kg of TKN. In addition, citrate soluble phosphoric acid is used as a method to quantify the amount of phosphorus that is readily available to the plant. Data from 18 struvite samples indicated that 25.17 % of P was citrate soluble (as is basis) and available to the plant. The quantity of struvite bed produced in each of the 30 runs was variable and seems to be related to the viscosity of the manure.

b. The production of struvite and the differences in nutrient removal may be attributed to the following challenges from the variability in the manure characteristics, and how the project team has dealt with them:

- *Challenge*: Wide ranges of calcium (Ca) content in manure. Higher concentrations of Ca in dairy manure requires more acid to break the bond between Ca and phosphorus in the pre-treatment settling phase, subsequently the inorganic phosphorus is then able to attach to magnesium and ammonia to form struvite during the treatment process. If enough acid is not added, the phosphorus (P) will not be available to form struvite in the nutrient removal phase.
    - *Result*: We have seen several farms with much higher than expected Ca. We have modified our protocols to test for calcium in samples obtained weeks prior to utilizing the manure with the mobile system, allowing more time to plan for the uniqueness of manure from each farm.
- *Challenge*: High concentrations of Iron (Fe) in the manure.
    - *Result*: Similar to the issue with Ca - we modified the pre-treatment procedures by determining Fe levels 2-3 days before the manure is treated through the cone. The Fe data from material similar to that of which went through the cone provides more information about the amounts of sodium hydroxide and sulfuric acid that will be used.
- *Challenge*: Low ammonia (NH_3) concentration in the manure.
    - *Result*: Typical manures contain adequate amounts of NH_3. We had several manures from Eastern WA (hot and dry climate) that may have had insufficient amounts of NH_3 for effective formation of struvite. In the time series sampling runs, we used aqueous ammonia as a pH modifier during the chemical process involved in the formation of struvite which alleviates this challenge of insufficient ammonia.
- *Challenge*: Farms have extremely variable ranges of manure total solids and manure total suspended solids which can lead to issues with foaming and overflow during the pre-treatment process.
    - *Result*: We have determined that running the fluidized bed at a much slower flow rates (approximately 12-15 hour run time treating 3,000 gallons) helps to decrease these challenges. Also, that manure with a TSS above 10,000 mg/L is extremely challenging to produce struvite crystals that are large enough to harvest after the manure treatment in the fluidized bed cone. A more detailed explanation as to why TSS concentrations above 10,000 mg/L are not compatible with the fluidized bed system is given in the discussion below.
- *Challenge*: The team has also identified that there may be fine struvite crystals being formed that are leaving the cone and thus not being harvested. This is seen from higher levels of ortho-phosphorus (OP) reduction than total phosphorus (TP) reduction after treatment.
    - *Result*: Some modifications have been developed to alleviate the problem of fine struvite leaving the cone since the start of the project. A secondary mesh screening of the outflow to capture the fine struvite crystals slightly helped, but did not alleviate the problem. Also, a sluice box was experimented with but also did not retain as much fine struvite crystals as expected. Two modifications have been made to address the issue of bed recovery. A diaphragm 40 GPH pump was purchased in late July 2018 to allow for the addition of a higher volume of diluted sodium hydroxide into the cone to best

achieve a better mixing at the base of the cone. In addition, the flow rate was reduced (from approximately 7 gallons per minute to 4 gallons per minute) based on the viscosity of the manure. The team evaluated these modifications and decided to implement using a diaphragm pump, a longer pretreatment time and a higher treated volume (6,000 gallons vs. 3,000 gallons).

- *Challenge*: Quantitative production of struvite crystals and the challenges of field lab testing to determine ideal cone conditions to produce the struvite crystals.
  - *Result*: Understanding the viscosity of the manures is key to determine the conditions of which struvite crystals can be formed before running the cone processes. The viscosity, along with the total suspended solids and certain mineral impediments (mentioned above) can all contribute to the formation or lack of formation of struvite crystals. The team has sent manure samples to Midwest labs in Nebraska to determine specific manure viscosity, but the time required to send out samples and receive analysis is not efficient to run the cone process in a timely manner. We purchased a viscometer to conduct field analysis of manure viscosity. Unfortunately the field viscometer readings did not prove to be accurate or consistent. The field lab analysis during the runs included: conducting pre-tests for the needed amount of pH modifiers, reducing the flow rate used to run the process, and adding a higher volume of dilute NaOH at the base of the cone. These steps were to develop the best conditions which would allow for good formation of struvite crystals, OP and TP reduction and to restrict the amount of the struvite fine particle sized crystals to exit the cone with the manure effluent.

c. *Alternative pH modifiers*:

The team evaluated oxalic acid as an organic alternative to sulfuric acid and aqueous ammonia as an organic alternative 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 see section b). 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 (Brown et. al., 2018).

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.

Batches of 2,500 to 3,000 gallons of manure were 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 aqueous ammonia). 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.

Aqueous ammonia was 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 will 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 used commercial aqua ammonia as a pH modifier in this demonstration.

From the time series runs, the overall range of the average OP% reduction using oxalic acid as a pH modifier to reduce the pH in the settling tanks was 41-44%, and the overall range of the average TP% reduction was 22-49% in non AD sourced manure. When sulfuric acid was used to reduce the pH in the settling tanks, the average OP % reduction was 23-60% and the average TP% reduction was 13-44% using non AD manure. Using AD manure, the average OP % reduction was 33-84% and the average TP% reduction was 41-73% reduced when using a combination of both pH reducers, oxalic and sulfuric acid. Using only sulfuric acid as a pH reducer with AD manure, the average OP% reduction was consistent at 60-62%, and the average TP% reduction was 57-61%.

Using aqueous ammonia used as a pH modifier to increase the pH in the fluidized bed had slightly higher OP reduction levels when compared to sodium hydroxide, an alternative pH modifier.,. The overall range of the average OP% reduction was from 37-62% and the range of the average TP% reduction was 25%-41% in the batch runs using the aqueous ammonia (non AD manure only). Using AD manure with aqueous ammonia as the pH modifier to increase the pH in the fluidized bed, the % OP reduction was 33-84 %, and the TP % reduction was 54-73 %. When sodium hydroxide was used as the pH modifier to increase the pH, the average reduction was a 23-44% reduction in % OP and 18-44% TP reduction using non- AD manure. Sodium hydroxide was not used to increase the pH in the fluidized bed cone using AD manure, because the alternative, aqueous ammonia was clearly a more effective at reducing the nutrient content of the manure through the struvite crystallization process.

The positive yields of struvite product that were harvested and collected at the end of the time series process runs averaged approximately 7 lbs (per tank ran through the fluidized bed, n=18). Using the sodium hydroxide (n=5 tanks) no positive yields were collected, 8-9 lbs (per tank ran) was collected using the oxalic acid with AD manure (n=3 tanks) and 8 lbs/run (n=7 tanks) using the aqueous ammonia as a pH reducer from runs with both AD and non-AD manure.

Hourly consecutive samples (9-23 hours) 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 was used to grow the struvite crystals was dissolving into the treatment liquid which was creating a higher concentration (5% increase) of OP in the cone. This issue was mostly rectified in the second hour and a 13% average decrease in OP content than the original pretreated material was observed as the struvite is in the formation process. Also, the use of aqueous ammonia as a pH modifier to increase the fluidized bed, coupled with a higher rate of flow seemed to alleviate the bed dissolution problem in the initial start of the run.

d. Time series sampling

The time series sampling (every hour) during the fluidized bed process showed a wide variation of nutrient removal. As noted in the previous challenges section, the occurrence an elevated value of OP and TP at the first event/hour sampling point was because the bed is suspected of being dissolved early in the process (*figure time series 1 and 2*). Hours 4 through 8 (the 'sweet spot') of the process typically had the highest nutrient removal considering the variation. The variation is based on many different factors as discussed previously. Figure 3 clearly demonstrates the removal of OP over time during a time series run using aqueous ammonia as a pH modifier. The maximum decrease in OP (mg/L) is demonstrated at hour 6 with a 56% reduction in OP.

The time series graphs 4 and 5 below display the variation of the nutrient removal throughout the process expressed in 3 different ways: 1. by using an average overall reduction of the batch run, 2. the average % nutrient reduction of the sweet spot (hours 4-8 hours) and 3. the maximum % removal (one single data point) at a given time of sampling (varying amongst separate runs).

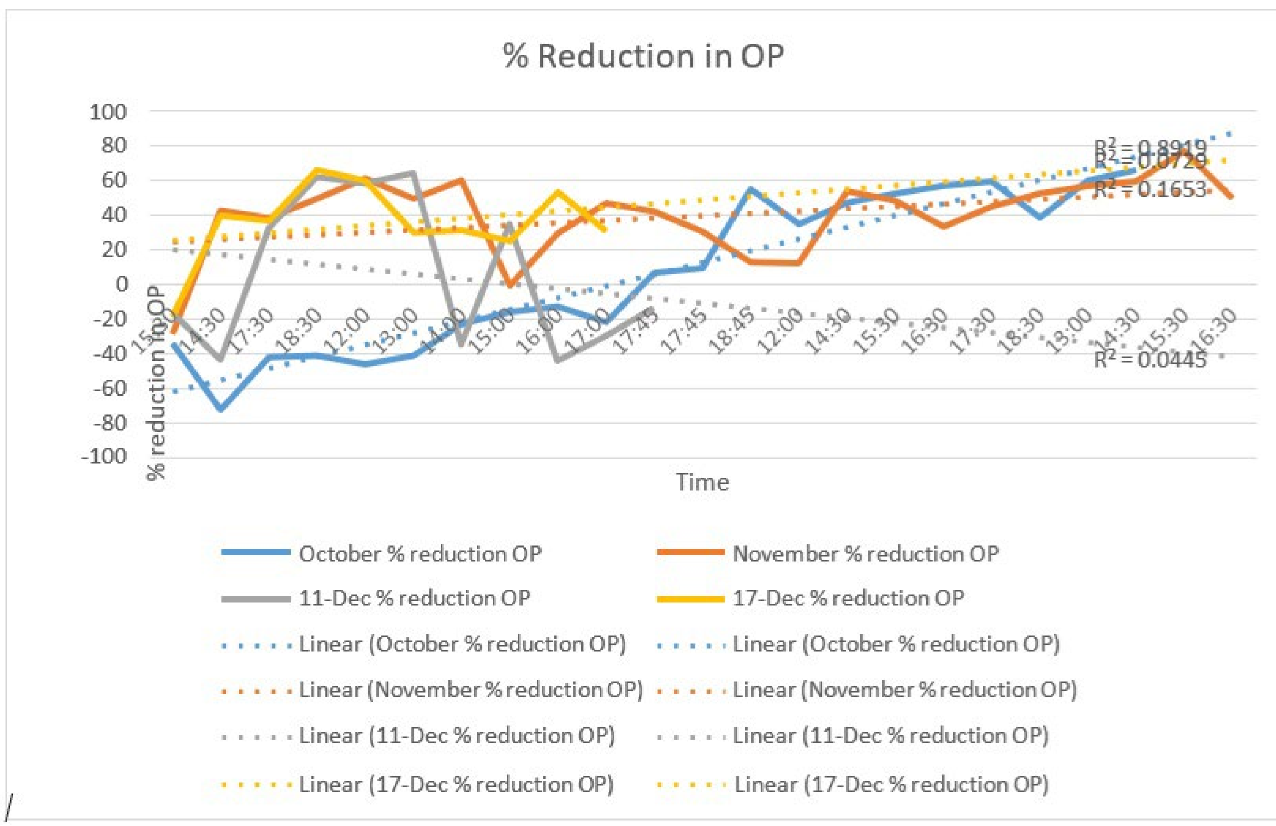


Figure time series 1. The percent reduction *of Ortho P in hourly samples taken during the fluidized bed process.*

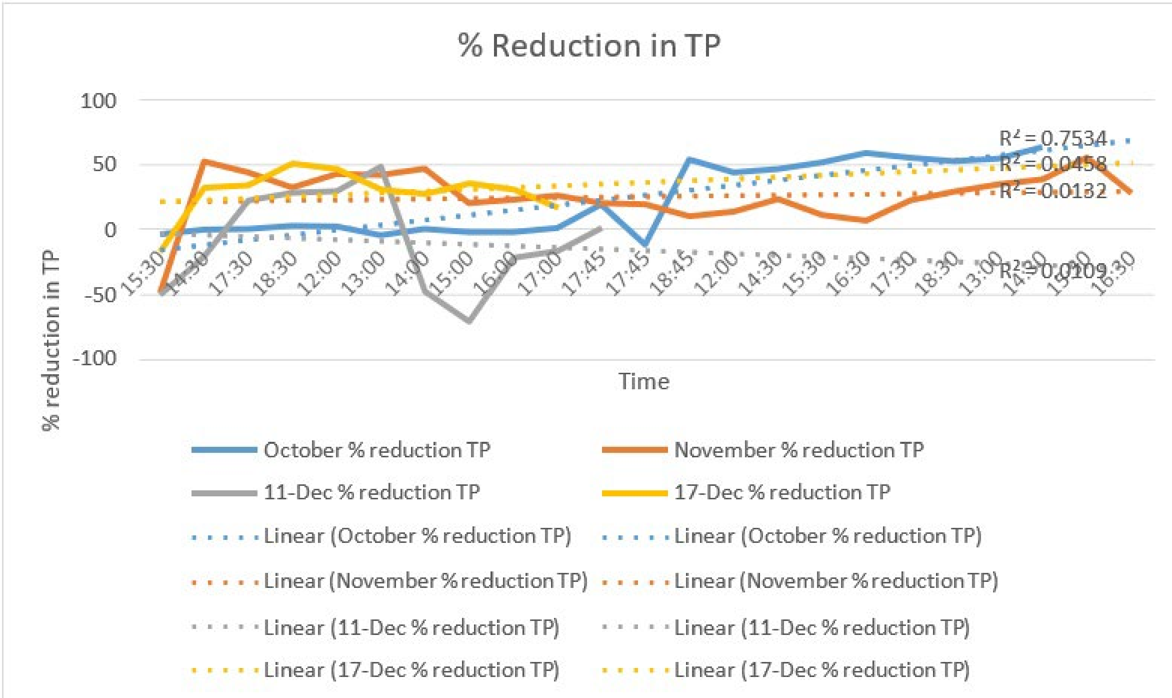


Figure time series 2. The percent REDUCTION of Total P in hourly samples taken during the fluidized bed process.

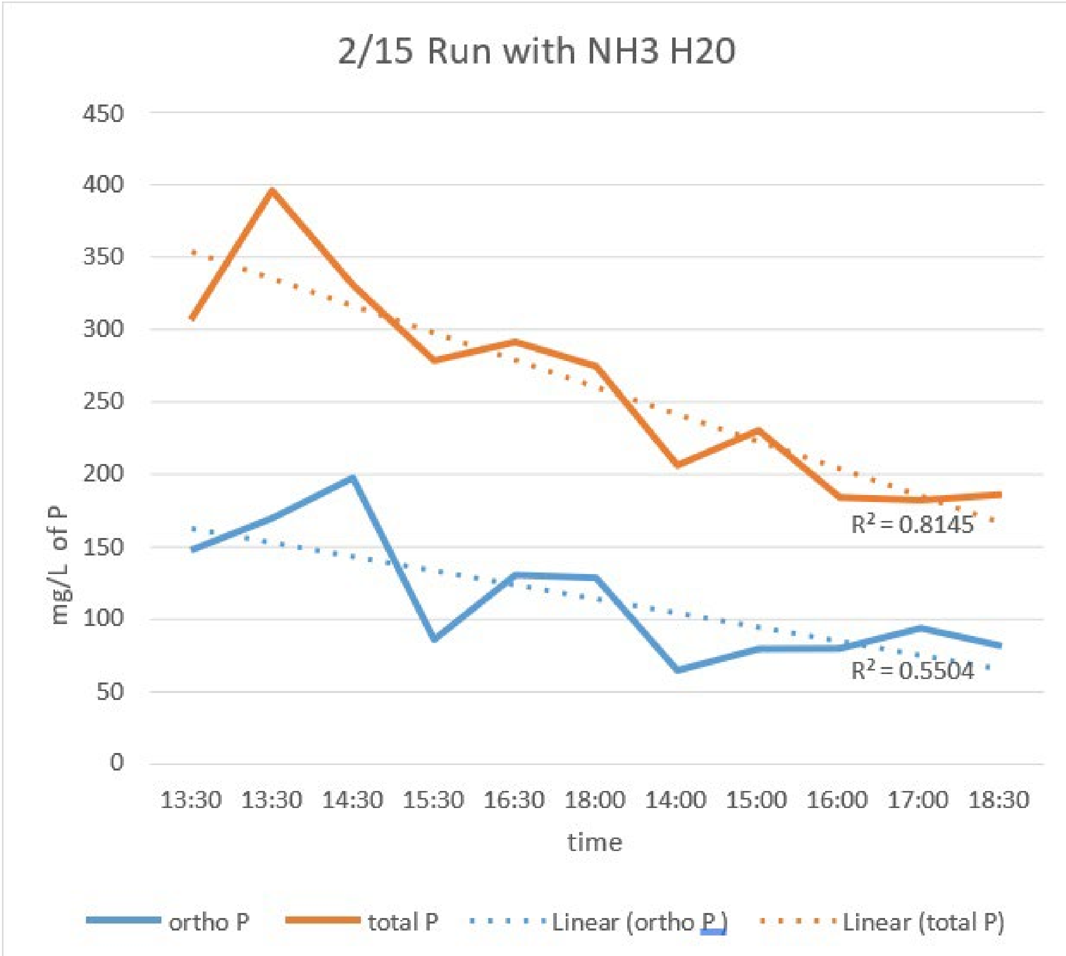
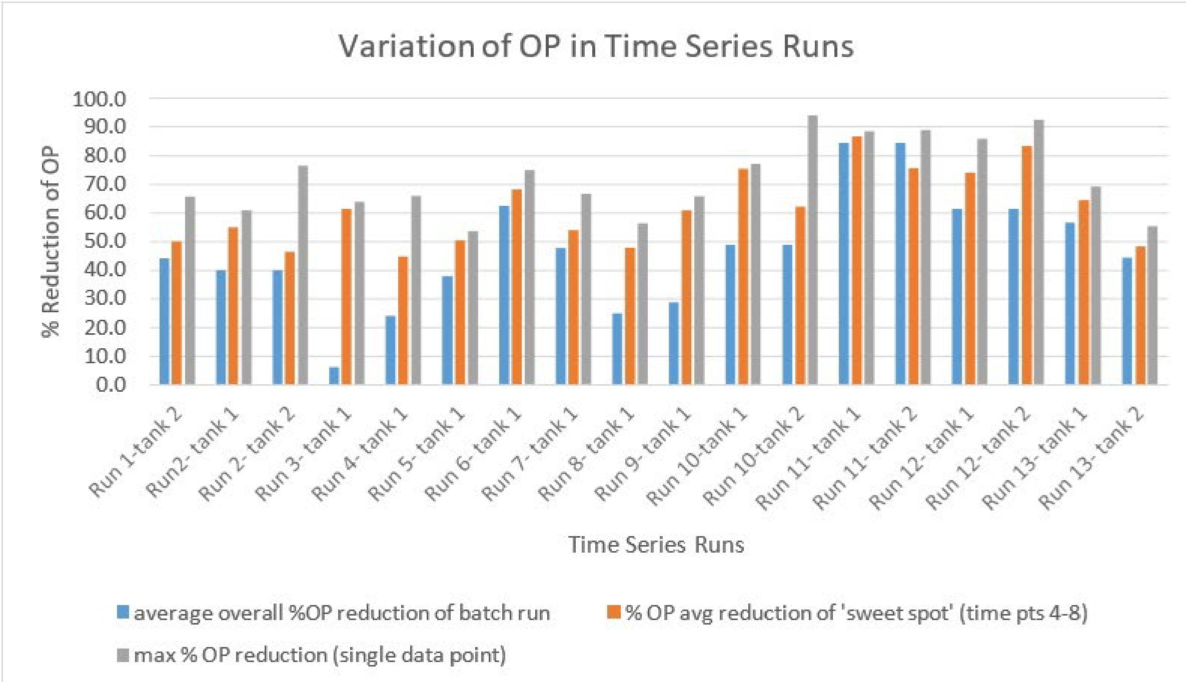
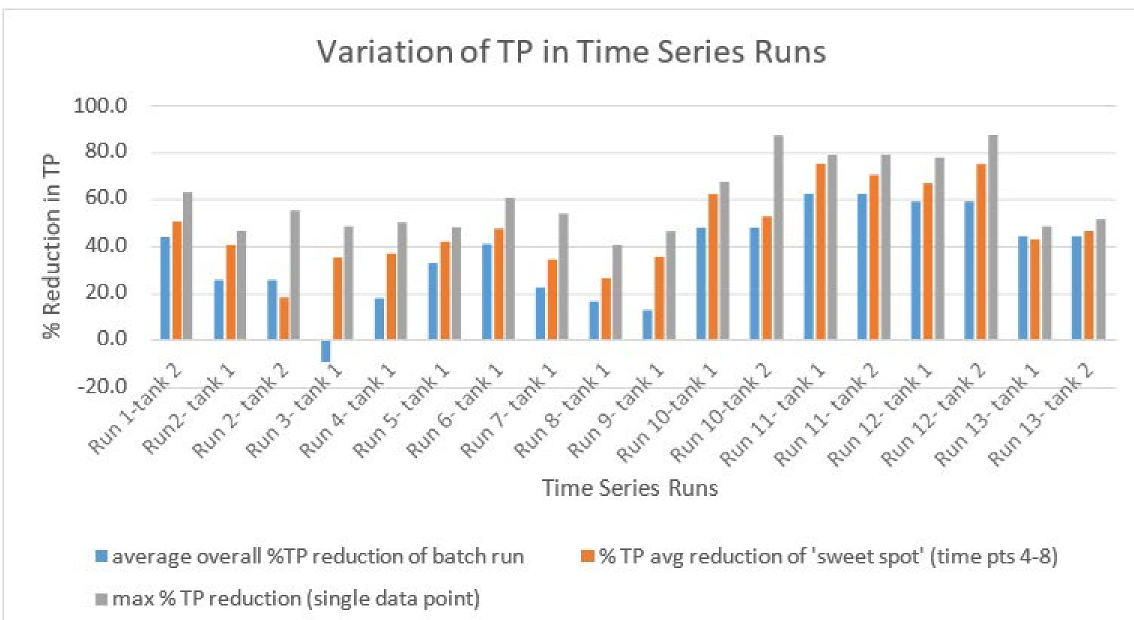


Figure 3. Hourly samples taken during the fluidized bed process using aqueous ammonia as a pH modifier. The decrease in OP is demonstrated at hour 6 with a 56% reduction in OP.

Time series 4. % OP Reductions in time series runs



Time series 5. % TP Reductions in time series runs



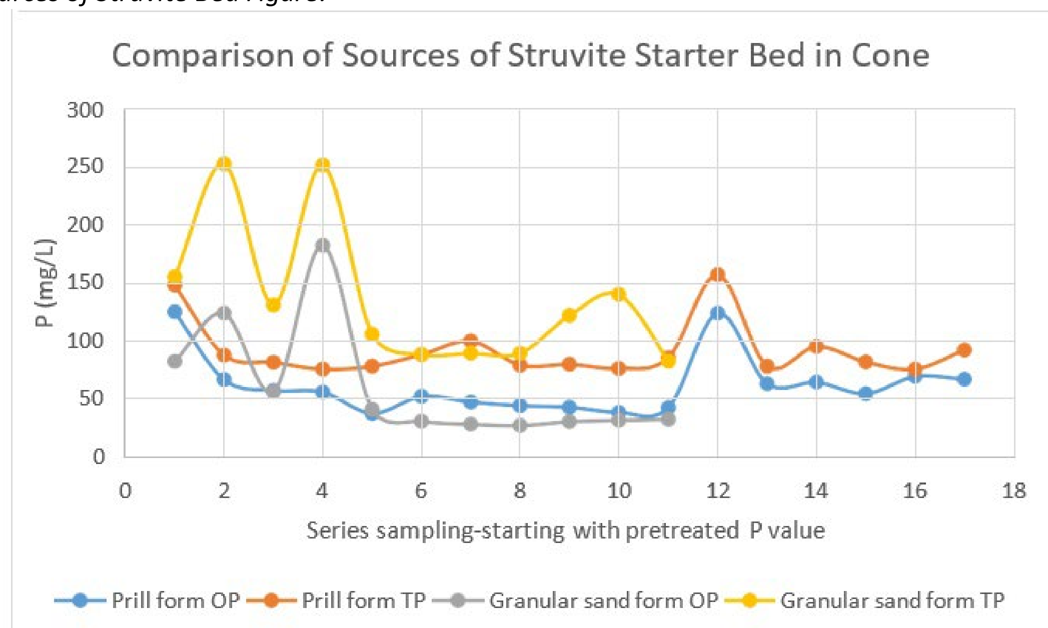
e. *Struvite production*

Struvite production was variable throughout the farm demonstrations due to the multiple factors (i.e. TSS, Ca, environmental, flow rate, etc.) discussed previously in the challenges (section *b*). From runs with positive struvite production, the average production from one run was 10.3 lbs. (entire harvest) or 3.6 lbs. (expressed on a per 1000 gallon basis; n=11).

f. *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 prill 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. As shown in the sources of bed figure below, the second data point for the 0.9 mm pelletized prill is a decreased value showing P removal is occurring during the treatment run. However, when the sand form of bed was used, 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 prill 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:



Graph (above) information:

* Data (May 2019) is from using the 0.9 mm prill form of struvite

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

Component 2: ***Agronomic land application of struvite to commercial alfalfa fields***

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. In 2018, the struvite fertilizer applications occurred on August 17th (Farm 2) and October 10th (Farm 1).

Yields

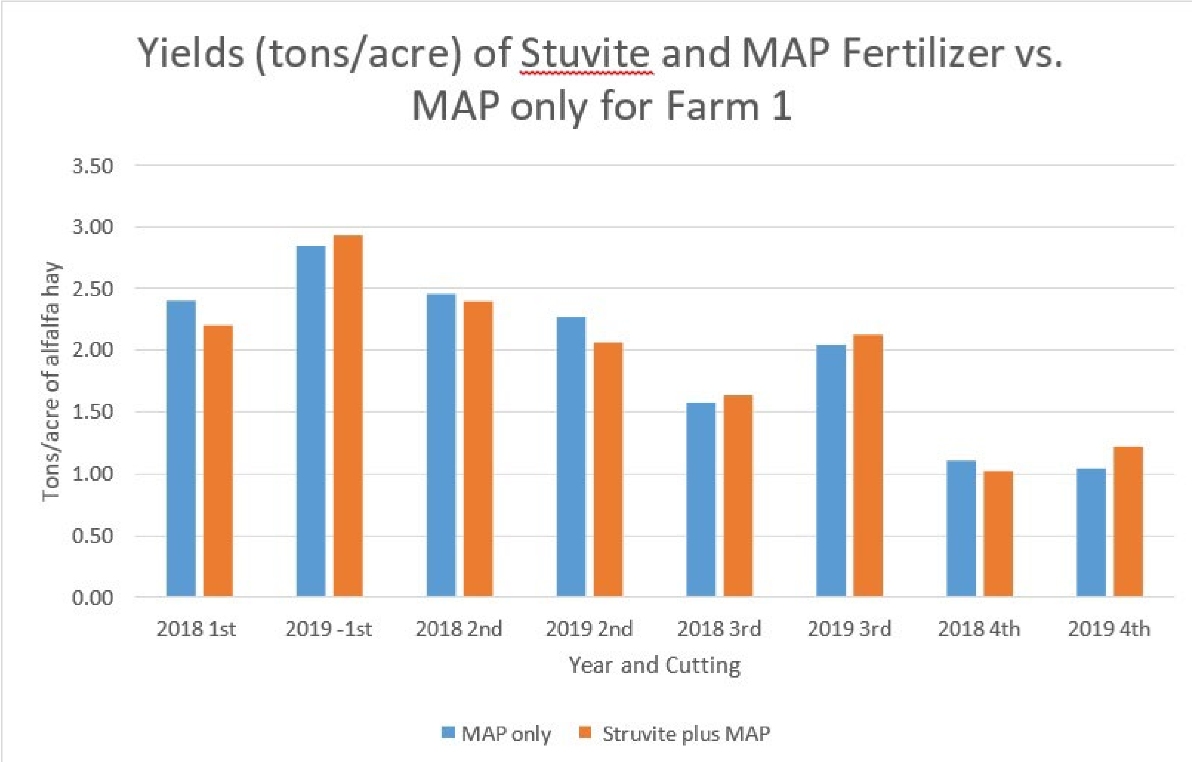
Farm 1. The second application of struvite (1st in 2018) was applied to an existing stand of alfalfa after the fourth cutting on a commercial alfalfa operation in Moses Lake WA on October 10, 2018.

Forage and soil samples were taken at every bailing event after each cutting in 2019 using the same fields, procedures and protocol as the previous year. Yield were obtained from the producer based on bale counts and estimated bale weight. The treatment area received 87 lbs. of P_2O_5 as Mono Ammonium Phosphate (MAP) and 311lbs of P_2O_5 as Struvite per acre. In 2019, the demonstration area has had 4 cuttings (1st on 5/27/2019, 2nd on 7/5/2019, 3rd on 8/14/2019 and 4th on 9/23/2019).. The control field or grower managed field also had 4 cuttings (same dates listed previously), fertilized with MAP (259 lbs/acre applied in fall 2018). The struvite fertilizer plus MAP field performed very similarly in comparison to the MAP only/control field in 2019. The first cutting on 5/27/2019 from the struvite plus MAP treated field yielded 2.93 tons/acre of alfalfa hay compared to the 2.84 tons/acre harvested from the MAP only/ control field. The struvite plus MAP field produced 2.06 tons/acre vs. the 2.26 tons/acre from the MAP only/control field on the second harvest (7/5/2019). The third cutting on 8/14/2019 yielded 2.12 and 2.03 tons/acre, from the struvite plus MAP and the MAP only/control fields, respectively. The struvite plus MAP field had a 1.21 tons/acre yield on the last cutting of the year (9/23/2019) vs. the MAP only/control field which yielded a 1.03 tons/acre.

The demonstration field also had 4 cuttings in 2018 (1st on May 23rd, 2018; 2nd on July 2, 2018; 3rd on August 7, 2018; and 4th cutting on September 19, 2018). Similarly to this year (2019), 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 fertilizer source 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.

In the second year of the project both the struvite plus MAP and the MAP only/ grower managed field had the same total annual yield of 7.1 tons/acre. In 2018, the Struvite plus MAP fertilized field yielded 7.1 tons/acre vs the MAP only fertilized field which yielded 7.5 ton/acre. Please see the graph below comparing 2018 and 2019 hay yields by cutting.

Farm 1. Yield graph



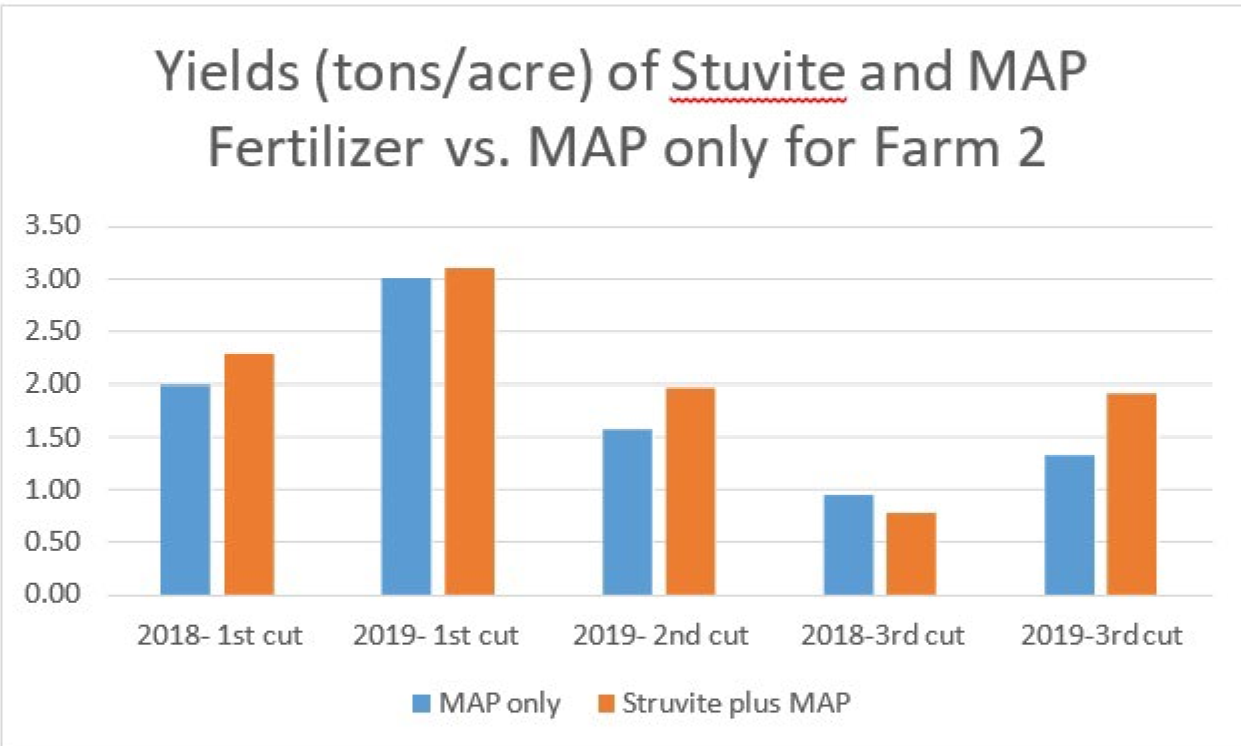
Farm 2. The struvite treatment was originally applied to a new alfalfa seeding on a commercial hay operation in Kittitas, WA on September 6, 2017. The field was reseeded in April 2018, as many of the alfalfa plants experienced die off and were affected by freezing winter temperatures. The August 2018 land fertilizer application used 123 lbs. of P_2O_5 as Mono Ammonium Phosphate (MAP)/acre on the MAP only/control field and 221 lbs of P_2O_5 as Struvite plus MAP/acre on the treatment field. Forage and soil samples were taken at every bailing event after each cutting in 2019 using the same fields, procedures and protocol as the previous year. Yield were obtained from the producer based on bale counts and estimated bale weight.

The first cutting on 6/7/2019 yielded 3.09 tons per acre of alfalfa from the struvite plus MAP field vs 3.00 tons per acre from the MAP only/ grower managed field. The struvite plus MAP fertilized field yielded considerably more alfalfa (1.96 tons/acre) compared to the MAP only field (1.57 tons/acre) for the second cutting on 7/14/2019. Similarly the third cutting had the same effect with the Struvite plus MAP field yielding substantially more alfalfa than the MAP only/treated side (1.91 tons/acre vs. 1.32 tons/acre; respectively.

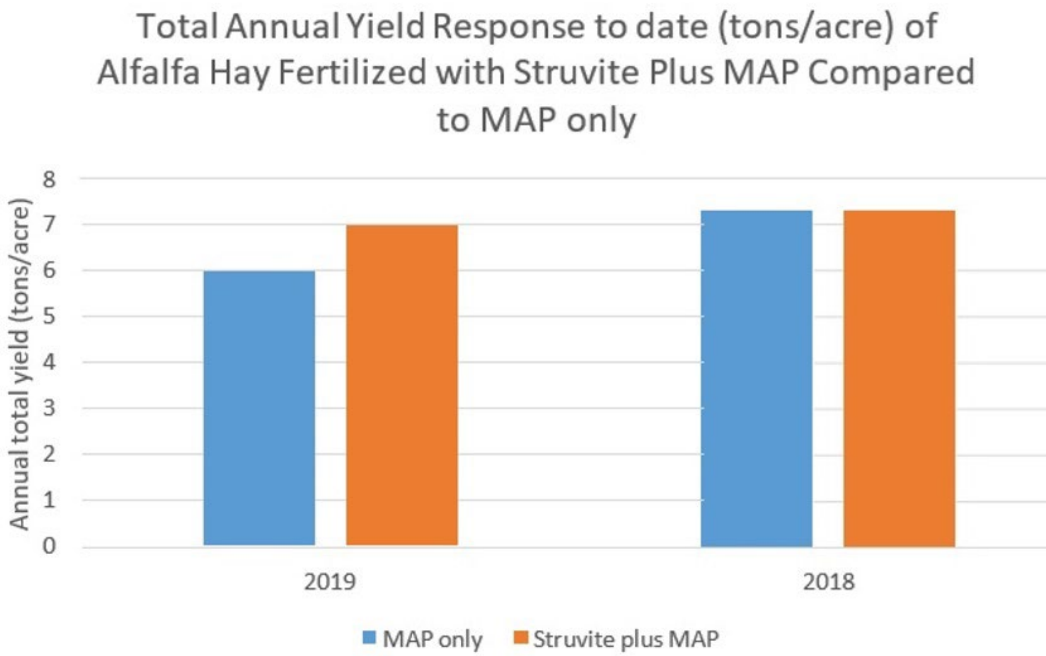
The first year of yields (2018) after the initial application in 2017 proved struvite plus MAP fertilizer had similar yields to the MAP only fertilizer yields of alfalfa. The first cutting of 2018 on 6/27/2018 yielded 2.3 tons/acre of alfalfa/acre for the treated struvite field and 2.0 tons/acre for 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.

Farm 2 had a higher yield response effect from the struvite plus MAP fertilizer producing 7.0 tons per acre compared to the MAP only fertilizer producing 5.9 tons/acre on an annual total yield basis in 2019. The higher yield from the struvite plus MAP fertilizer was the same or slightly higher (by a difference of 1.1 ton total annual ton/acre basis) in the second year of using the struvite fertilizer compared to the first. This suggests the slow release properties of the P in struvite are advantageous to supporting plant health and growth, as demonstrated in the second year of this project. Please see the yield graph below comparing treatments and yields by cutting from 2018 and 2019.

Farm 2. Yield graph



Farm 2. Graph of Total Annual Yields



Plant Quality Components

Soil samples, and plant tissue samples were collected and evaluated for nutrient content and forage quality for both Farm 1 and 2. A summary of soil analyses and forage analyses are shown in the table below.

The forage quality was well within the range of quality alfalfa forage characteristics, and mostly similar between the struvite and MAP fertilized field and MAP only fertilized field. The first year of the project in 2017, the project team evaluated the cooperator grower's fields for the first two harvests, since we weren't able to apply fertilizer treatments until August. The first sample taken was one single sample considering it was before the treatment plots were established. To show comparison of before and after, the data is written into both the control and treatment sections- although it was obtained as one sample (Farm 1 table below). The P content of the alfalfa plant tissue and the yields were recorded in 2017 to compare the subsequent treatment and control fertilizer treatments on the existing stand of alfalfa.

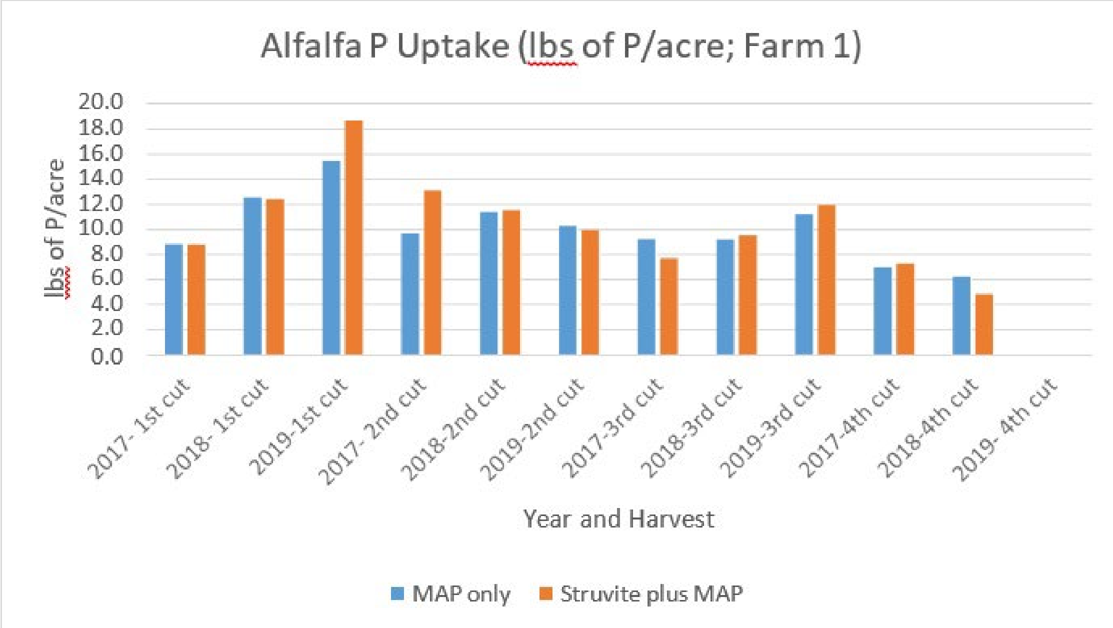
Farm 1. The P content in the forages were very similar by treatments within each cutting. The other quality parameters- crude protein (CP), relative feed value (RFV), potassium (K), fibers (ADF and NDF) and calcium (Ca) were also similar between treatments within plant cuttings (please see data table below).

Farm 1. Alfalfa Plant Quality Component Table

		Control	*Treated*	*Control*	*Treated*	*Control*	*Treated*
Date	***Cutting***	***P***	***P***	***CP***	***CP***	***RFV***	***RFV***
5/31/2017	1	0.27	0.27	21.6	21.8	154	154
7/6/2017	2	0.32	0.30	22.6	21.8	145	154
8/7/2017	3	0.36	0.35	24.1	24	170	169
9/3/2017	4	0.32	0.35	23.9	23.6	176	181
5/30/2018	1	0.26	0.28	18.4	19.6	137	140
7/11/2018	2	0.23	0.24	18.2	18.7	137	142
8/14/2018	3	0.29	0.29	20.8	16.4	152	163
9/28/2018	4	0.28	0.26	21.0	22.7	192	215
6/3/2019	1	0.27	0.32	20.9	20.0	156	145
7/13/2019	2	0.23	0.24	19.2	19.2	138	124
8/14/2019	3	0.27	0.28	21.0	20.0	145	136
9/23/2019	4						
AVG 2019	annual	0.26	0.28	20.4	19.8	146.3	134.6
AVG 2018:	annual	0.27	0.27	19.6	19.4	154.6	165.1
AVG 2017:	annual	0.32	0.31	22.8	22.5	156.3	159.0

The total annual P uptake from the alfalfa content is greater in the plants fertilized with struvite plus MAP compared to MAP only in 2019 (40.3 vs. 36.6 lbs. P/acre). In 2018, there was a 1 lbs. of P/acre difference in P uptake from struvite plus MAP fertilized field and the MAP only fertilized field (38 vs. 39 lbs. P/ acre, respectively). In 2017, the first year of the project, there was an approximate 2 lbs. of P/ acre difference (total annual lbs. of P/acre) between the fields, regardless of a treatment effect. The pre-MAP only field had a 34.4 lbs. of P/acre uptake and the pre- struvite plus MAP field had a 36.6 lbs. of P annual total P uptake. These results indicate that the slow release form of P from struvite is advantageous for P removal in the first couple of cuttings, 2 years after struvite plus MAP fertilizer is applied.

Farm 1. Phosphorus Uptake Graph



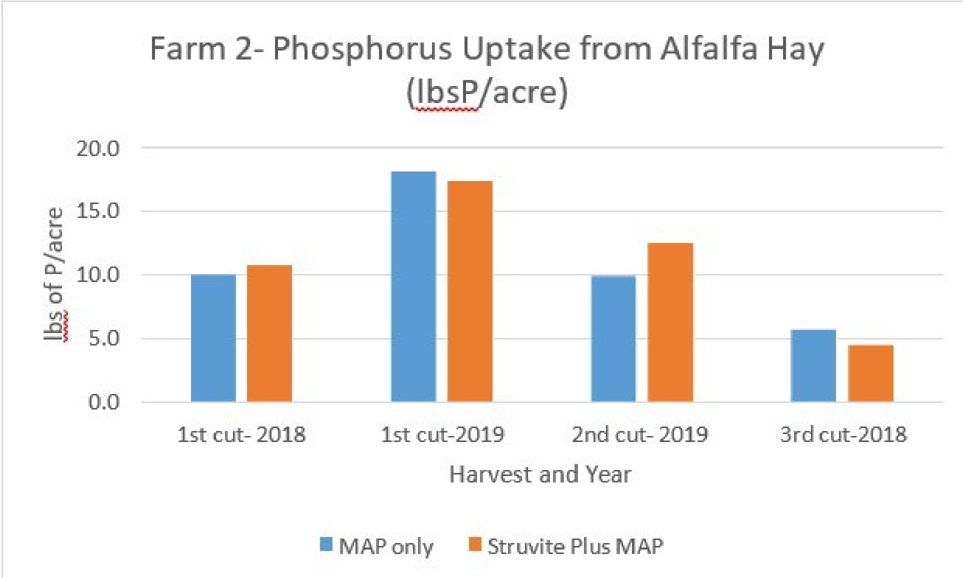
Farm 2. The P content in the forages were very similar by treatments within each cutting. The other quality parameters- crude protein (CP), relative feed value (RFV), potassium (K), fibers (ADF and NDF) and calcium (Ca) were also similar between treatments within plant cuttings (please see data table below).

Farm 2. Alfalfa Plant Quality Component Table

		Control	*Treated*	*Control*	*Treated*	*Control*	*Treated*	*Control*	*Treated*
Date	***Cutting***	***P***	***P***	***CP***	***CP***	***RFV***	***RFV***	***K***	***K***
7/2/2018	1	0.25	0.24	17.4	18.3	156.5	155	1.69	1.3275
8/16/2018	2	0.30	0.30	20.0	20.1	147.7	154.8	2.04	1.47
10/3/2018	3	0.30	0.29	24.3	21.8	239	194.8	2.00	1.54
6/7/2019	1	0.30	0.28	19.9	19.9	176	158.5	2.32	1.57
7/14/2019	2	0.31	0.32	22.9	22.8	167.5	170.3	1.56	1.43
8/28/2019	3								
AVG 2019	annual avg	0.31	0.30	21.39	21.35	171.75	164.38	1.94	1.50
AVG 2018:	annual avg	0.28	0.27	20.57	20.05	181.06	168.17	1.91	1.45

The total annual (to date) P uptake from the alfalfa is very similar in the plants fertilized with struvite plus MAP compared to MAP only in 2019 (to date from 2 harvest yields, 29.8 vs. 27.8 lbs. P/acre, respectively). Also, there was a similar annual total uptake of P in 2018- 40.5 vs. 41.7 lbs. of P/acre, respectively.

Farm 2. Phosphorus Uptake Graph



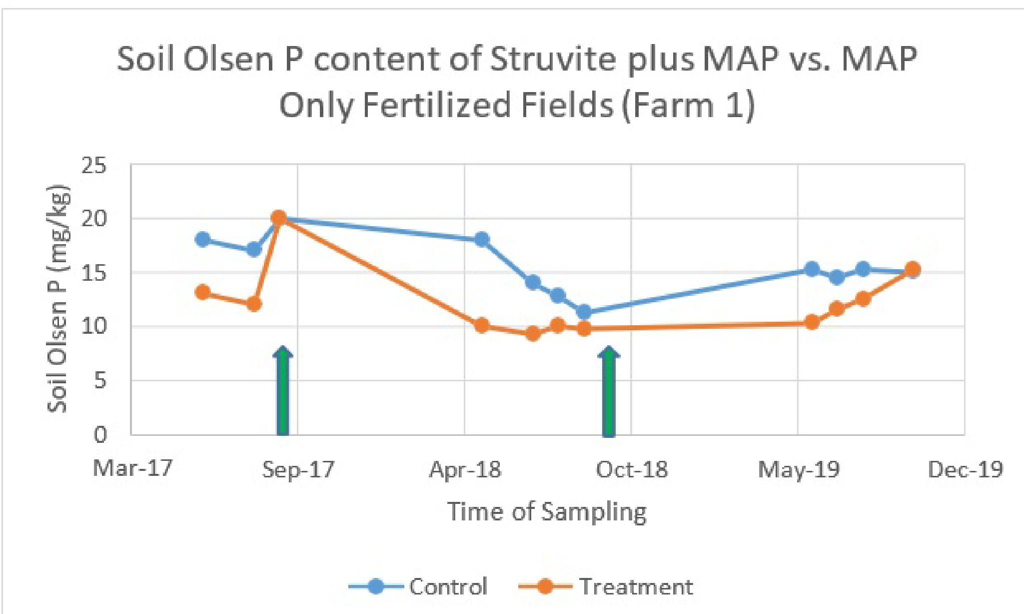
This suggests that struvite, when applied to the soil surface in the second year, could replace MAP as the P source for alfalfa without affecting yield. Results also suggest that supplementing struvite with MAP fertilization leads to greater P uptake by alfalfa in the second year.

Farm 1. The Olsen P soil measurements from the treated field- struvite plus MAP was less than the Olsen P content of the soil from the MAP only control field for the majority of the project's almost 3 growing seasons. The 2017 soil data (before the struvite plus MAP treatment was applied) show slightly lower initial Olsen P content than the control field, so the soil might have had historically lower levels. Also, the higher 1st and 2nd cutting yields of the struvite plus MAP field in 2019 would help explain the larger difference in soil Olsen P content in the different fields. A higher yield of alfalfa with similar plant P content will remove more P from the soil compared to a lower yield of alfalfa. Similar to the Olsen P, the same lower content of potassium (K) is clear of the treated field (Struvite plus MAP) compared to the control field (MAP only).

Farm 1 Table. Soil Analysis comparing MAP Only vs. Struvite plus MAP Fertilized Fields

FARM 1	**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	0.8	1.9	2.1
8/9/2017	17	12	84	63	2.0	2.0	1.0	1.0
9/28/2017	20	20	133	118	2.1	2.0	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	2.0
6/3/2019	15.3	10.3	104.6	85	2.1	2.1	2.0	1.9
7/13/2019	14.5	11.5	88	71	1.9	2.1	2.0	1.9
8/20/2019	15.3	12.5	106	93.3	2.0	2.20	2.2	2.2
10/4/2019	15.0	15.3	108.3	94.8	1.90	2.13	2.2	2.2
2019 AVG:	15.0	12.4	101.8	86.0	2.0	2.1	2.1	2.0
2018 AVG:	14	9.8	119.4	91.6	2.1	2.2	2.1	2.0
2017 AVG:	18.3	15.0	91.3	76.7	1.7	1.6	1.7	1.9

Farm 1 Graph. Olsen P Soil Analysis comparing MAP only vs. Struvite plus MAP Fertilized Fields



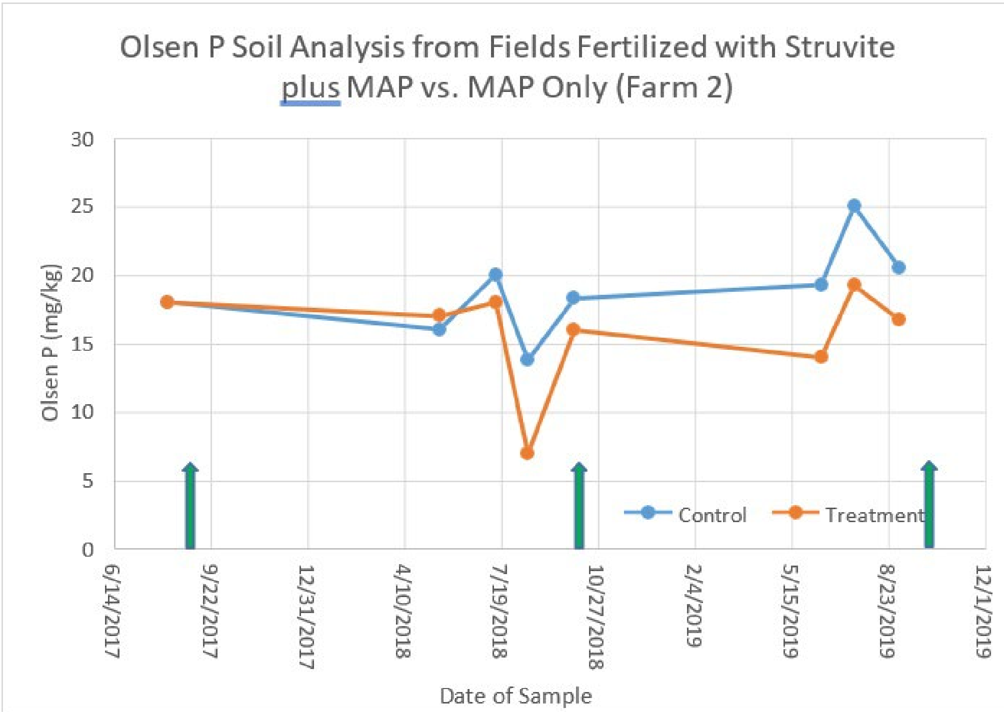
*** Arrows in the table above indicate fertilizer applications to the fields*

Farm 2. Similar to Farm 1, the soil Olsen P and K content were lower in the treated field (Struvite plus MAP) compared to the control (MAP only) field. The second harvest of 2019 had a higher yield from the treated field which would help explain the lower soil Olsen P and K components.

Farm 2 Table. Soil Analysis comparing MAP only vs. Struvite plus MAP Fertilized Fields

Farm 2	**Olsen P (mg/kg)**		**K (mg/kg)**		**Mg (mg/kg)**		**OM (mg/kg)**	
New Seeding	*Control*	*Treatment*	*Control*	*Treatment*	*Control*	*Treatment*	*Control*	*Treatment*
8/8/2017	18.0	18.0	112.0	86.0	3.5	3.4	3.0	3.5
5/16/2018	16.0	17.0	133.0	142.0	3.2	4	1.1	1.1
7/13/2018	20.0	18.0	137.0	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	18.3	16.0	115.5	101.5	3.1	3.9	2.2	2.2
6/14/2019	19.3	14.0	104.5	94.0	3.2	4.0	2.7	2.4
7/18/2019	25.0	19.3	127.0	83.5	3.2	4.2	2.6	2.4
9/3/2019	20.5	16.8	91.25	85.0	3.15	3.6	2.1	2.2
2018 Avg:	17.0	14.5	121.8	105.8	3.3	4.0	2.0	2.0
2019 Avg to date	21.6	16.7	107.6	87.5	3.2	3.9	2.5	2.3

Farm 2 Graph. Olsen P Soil Analysis comparing MAP only vs. Struvite plus MAP Fertilized Fields



*** Arrows in the table above indicate fertilizer applications to the fields*

Plot Studies Conducted at Prosser and Pasco, Washington

The effect of struvite and MAP variation combinations

Plots were randomly fertilized at a constant rate with one of 7 different mixtures of MAP: Struvite (100:0, 75:25, 50:50, 37.5:62.5,12.5:87.5, 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 or annual season, regardless of planting time (tables and figures below).

Results indicate that alfalfa from treatments 100:0 and 0:100 were similar in quality, DM yield, and P uptake across the entire season and at first cutting. This suggests that struvite, when incorporated into the soil before planting, could replace MAP as the P source for alfalfa without affecting yield or quality in the first year.

*P Uptake and Yield Table***.** Summary of dry matter yield and nutrient uptake of fall-planted alfalfa as affected by ratio of monoammonium phosphate (MAP) to struvite. Means account for all cuttings across first annual growing season (year 1).

MAP:struvite	**Total[†] DM Yield**	**Avg[†] DM Yield***	**Total P Uptake**	**Total K Uptake**	**Avg P Uptake***	**Avg K Uptake**	**Avg. Tissue P**	**Avg. Tissue K**
	Megagrams ha^{-1}		----------	kg ha^{-1}	----------		------ % DM	----
0:0	22.1	4.4 ^{b}	53	677	10.7 ^{b}	135	0.24	3.1
100:0	26.2	5.2 ^{a}	64	789	12.8 ^{a}	158	0.25	3.1
75:25	24.9	5.0 ^{a}	60	738	12.2 ^{ab}	150	0.25	3.1
50:50	24.7	4.9 ^{a}	63	766	12.5 ^{a}	153	0.25	3.1
37.5:62.5	24.2	4.8 ^{ab}	61	737	12.3 ^{ab}	147	0.26	3.1
25:75	26.3	5.3 ^{a}	68	815	13.6 ^{a}	160	0.26	3.1
12.5:87.5	24.5	5.0 ^{ab}	63	714	12.6 ^{a}	143	0.26	2.9
0:100	24.6	4.9 ^{ab}	64	725	12.9 ^{a}	145	0.26	2.9
SE	0.5	.07	1.46	21.03	0.21	2.44	0.01	0.02
Treatment[‡]	NS	0.05	NS	NS	0.08	NS	NS	NS
Cut[‡]	N/A	<0.01	N/A	N/A	<0.01	<0.01	NS	<0.01
Trt x Cut[‡]	N/A	NS	N/A	N/A	NS	NS	NS	NS
Block[‡]	NS	0.02	NS	NS	<0.01	<0.01	<0.01	<0.01

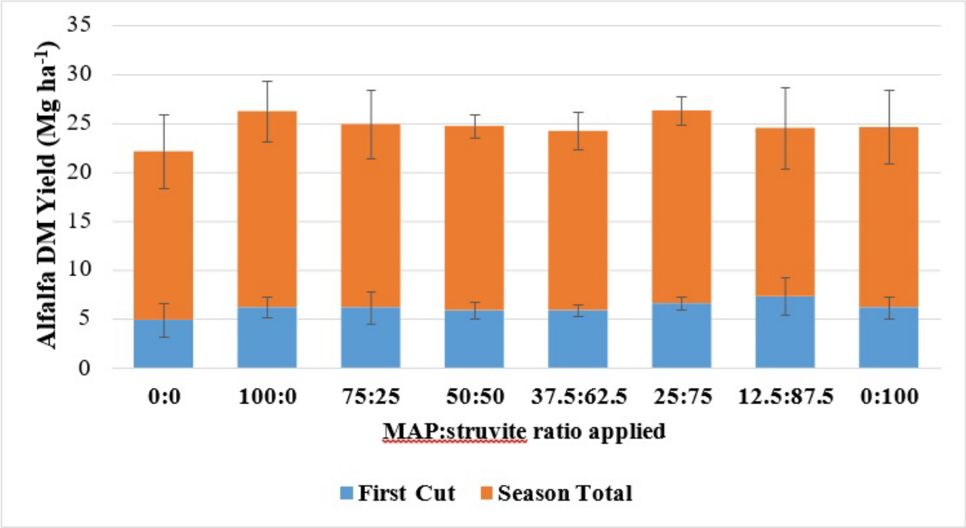
* Unlike superscript letters indicate statistically significant differences between the means in the column ($P < 0.05$).
[†] Total represents the sum of all cuttings from the first year within a plot, then averaged across all replicates within the treatment. Avg represents the average of all cuttings from the first year within the treatment.
[‡] Effect expressed as statistical *P*-values when $P < 0.1$), or NS when effects are not statistically significant ($P \geq 0.1$).
N/A = not applicable and appears for Cut and Trt x Cut under parameters that were Totals from the first year because Cut was not a covariate.
DM = dry matter

Fall Planting Hay Quality Table. Summary of hay quality of fall-planted alfalfa as affected by ratio of monoammonium phosphate (MAP) to struvite. Means account for all 5 cuttings across first growing season, except for maturity, which accounts for only cuts 3-5.

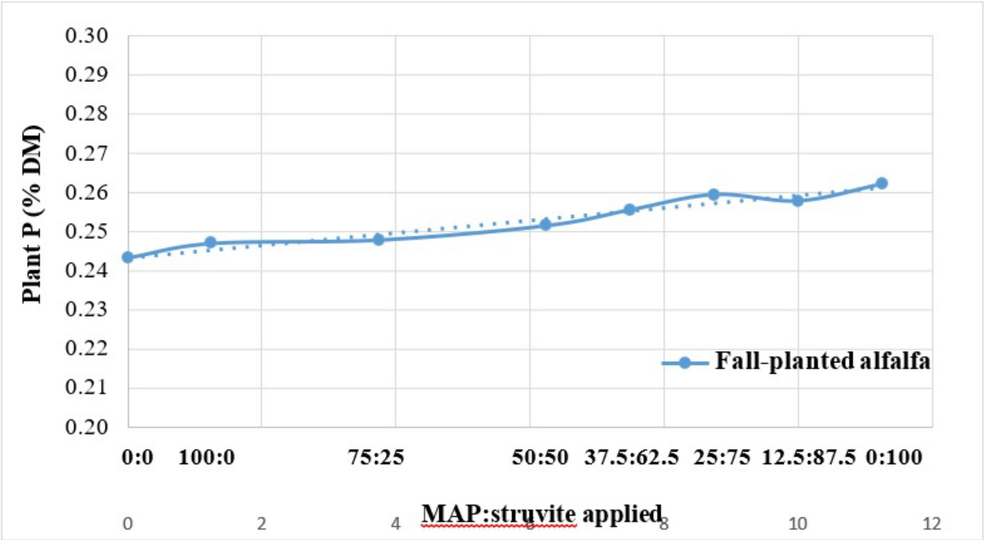
Map:Struvite	**RFV***	**RFQ***	**Lignin* (% DM)**	**aNDF* (% DM)**	**NDFD (% DM)**	**Maturity +**
0:0	191 [a]	210 [a]	5.31 [c]	32.9 [c]	16.1	2.61
100:0	176 [b]	194 [b]	5.60 [a]	34.8 [a]	16.7	2.74
75:25	189 [a]	208 [a]	5.29 [c]	33.1 [bc]	16.2	2.78
50:50	180 [b]	197 [b]	5.51 [abc]	34.1 [ab]	16.5	2.88
37.5:62.5	190 [a]	209 [a]	5.35 [bc]	33.0 [bc]	16.2	2.62
25:75	179 [b]	195 [b]	5.58 [a]	34.4 [a]	16.5	2.84
12.5:87.5	182 [ab]	200 [ab]	5.54 [ab]	34.0 [abc]	16.5	2.63
0:100	181 [b]	197 [b]	5.57 [ab]	34.2 [ab]	16.3	2.76
SE	1.08	1.26	0.03	0.15	0.07	0.03
Treatment‡	<0.01	<0.01	0.01	0.01	NS	NS
Cut‡	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Treatment*Cut‡	NS	NS	NS	NS	NS	NS
Block‡	<0.01	<0.01	NS	<0.01	<0.01	<0.01

***** Unlike superscripts indicate statistically significant differences between the means in the column ($P < 0.05$).
†Maturity was recorded as growth stages according to Mueller and Teuber (2007) from 10 plants per replicate, one day prior to each harvest during the first year.
‡ Effect expressed as statistical P-values when $P < 0.1$), or NS when effects are not statistically significant ($P \geq 0.1$).
NS = not significant ($P \geq 0.1$).

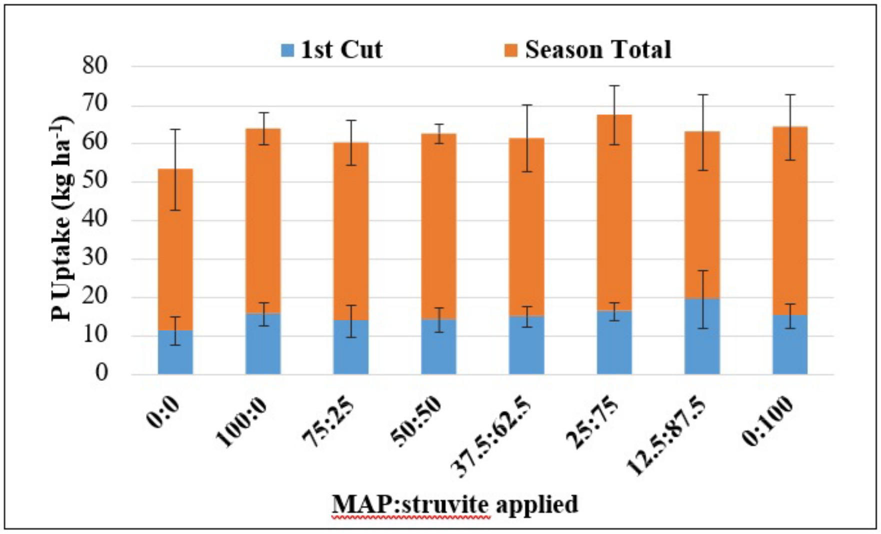
*Fall Planting Yields Figure***.** Total dry matter yield (megagrams hectare^{-1}) of fall-planted alfalfa as affected by fertilization with different monoammonium phosphate (MAP) to struvite ratios across all 5 cuttings in the first year and specifically at the first cutting. Error bars represent the standard deviation.



*Hay Phosphorus Concentration Figure***.** Average plant P concentration of the aboveground, whole-plant at harvest (across all cuttings) of fall-planted alfalfa fertilized with different ratios of monoammonium phosphate (MAP) to struvite.



*Fall Planting P Uptake Figure***.** P uptake by fall-planted alfalfa at first cutting and across the entire season as affected by ratio of monoammonium phosphate (MAP) to struvite applied at a constant rate. Error bars represent the standard deviation.



Year 2 of Plot Studies Conducted in Pasco and Prosser, Washington

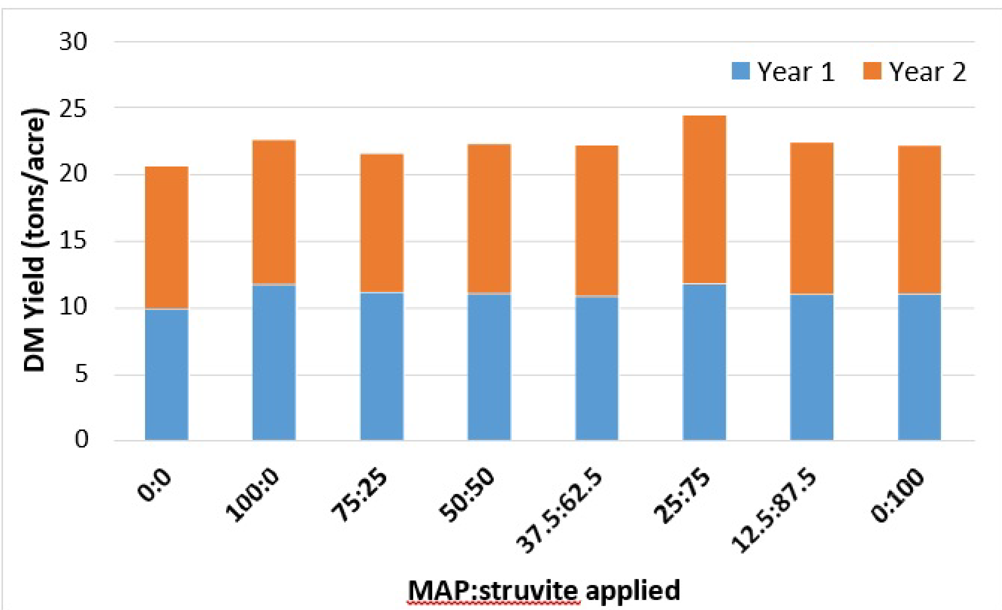
Results indicate that alfalfa from treatments 100:0 and 0:100 were similar in DM yield, and P uptake across the entire season. However, the greatest yield and P uptake was produced from treatment 25:75. Alfalfa fertilized with this treatment produced 1.8 tons DM acre^{-1} and took up 19 lbs P acre^{-1} more than treatment 100:0, on average. This suggests that struvite, when applied to the soil surface in the second year, could replace MAP as the P source for alfalfa without affecting yield. Results also suggest that supplementing struvite with MAP fertilization leads to greater P uptake by alfalfa in the second year.

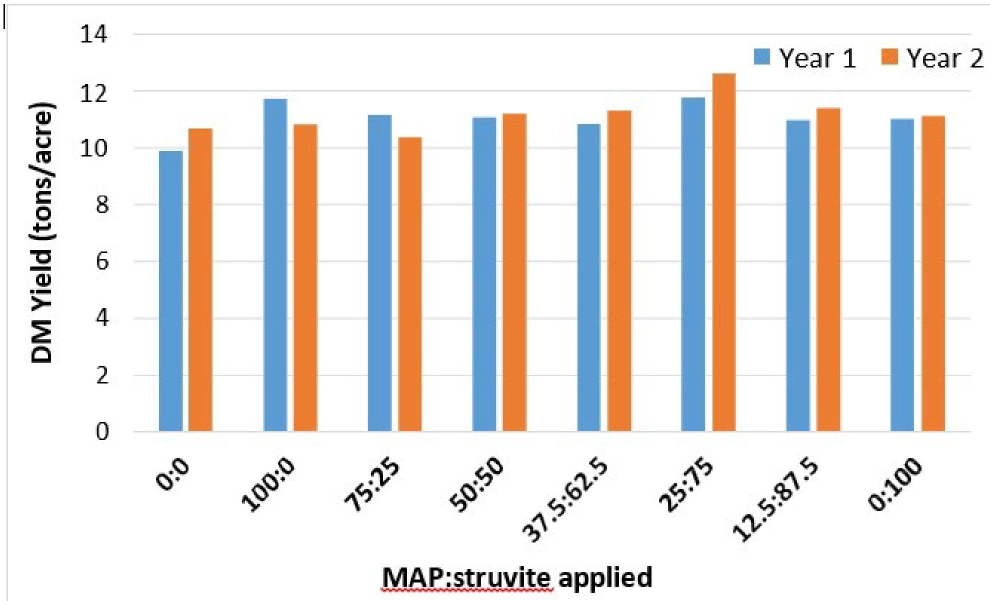
*Yield and Nutrient Uptake Table***.** Summary of dry matter yield and nutrient uptake of fall-planted alfalfa as affected by ratio of monoammonium phosphate (MAP) to struvite. Means account for all cuttings across second growing season.

MAP:Struvite ratio applied	**Total† Dry Matter Yield (tons/acre)**	**Total† P Uptake* (lbs/acre)**	**Avg.† Plant P* (% DM)**	**Total† K Uptake* (lbs/acre)**	**Avg.† Plant K (% DM)**
0:0	10.64	61 ^{d}	0.277 ^{e}	713	3.31 ^{a}
100:0	10.78	72 ^{bcd}	0.332 ^{d}	678	3.15 ^{ab}
75:25	10.34	70 ^{cd}	0.339 ^{cd}	638	3.06 ^{bc}
50:50	11.15	77 ^{bc}	0.346 ^{bcd}	649	2.89 ^{c}
37.5:62.5	11.26	76 ^{bc}	0.335 ^{d}	711	3.15 ^{ab}
25:75	12.57	91 ^{a}	0.357 ^{abc}	744	2.93 ^{c}
12.5:87.5	11.35	86 ^{ab}	0.364 ^{ab}	706	3.05 ^{bc}
0:100	11.08	83 ^{ab}	0.369 ^{a}	662	2.97 ^{c}
SE	0.52	5	0.007	39	0.06
Treatment	NS	0.004	<0.0001	NS	<0.0001

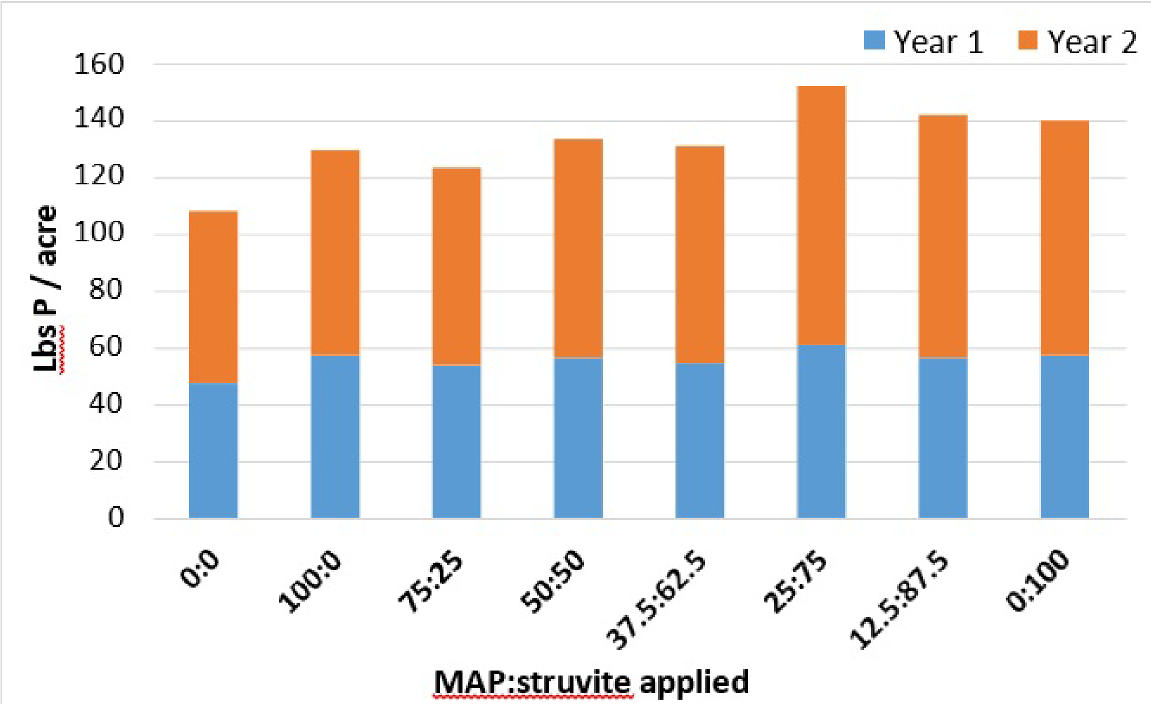
* Unlike superscript letters indicate statistically significant differences between the means in the column ($P < 0.05$).
† Total represents the sum of all cuttings from the first year within a plot, then averaged across all replicates within the treatment. Avg represents the average of all cuttings from the first year within the treatment.
‡ Effect expressed as statistical P-values when $P < 0.05$, or NS when effects are not statistically significant ($P \geq 0.05$).

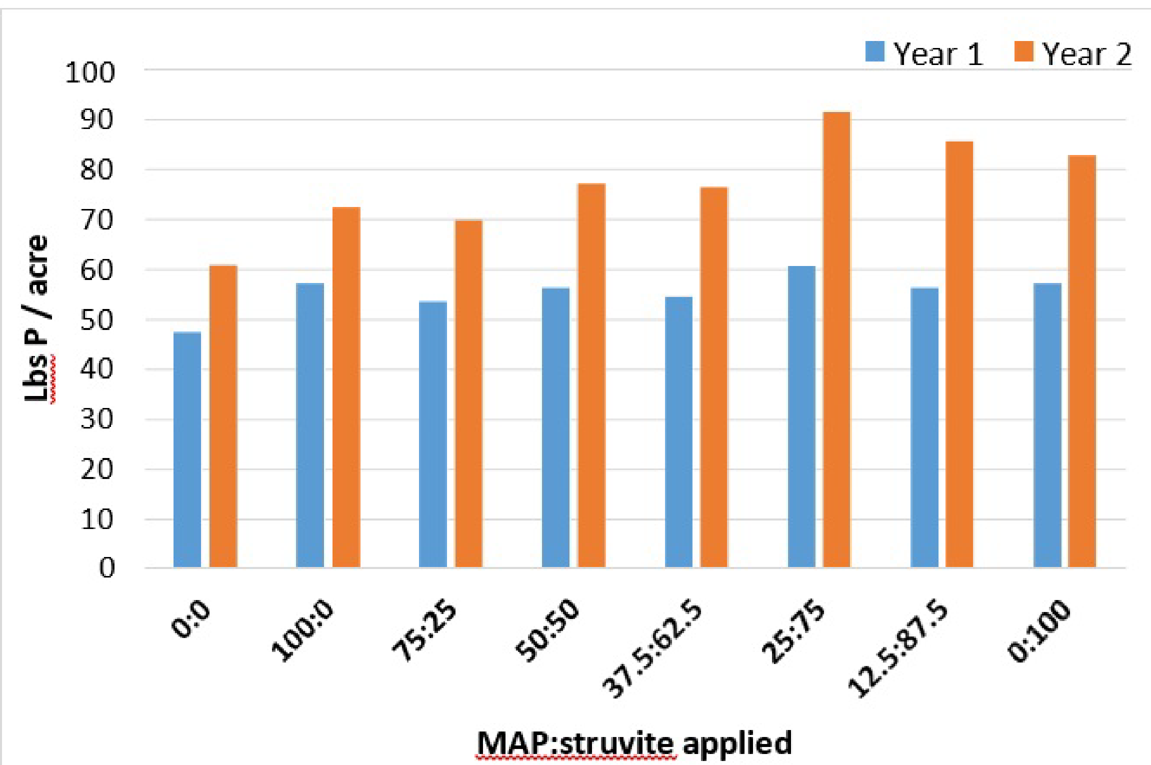
DM and Yields Figure. Total dry matter (DM) yield (tons acre^{-1}) of fall-planted alfalfa as affected by fertilization with different monoammonium phosphate (MAP) to struvite ratios the first two years, with 5 cuttings per year.



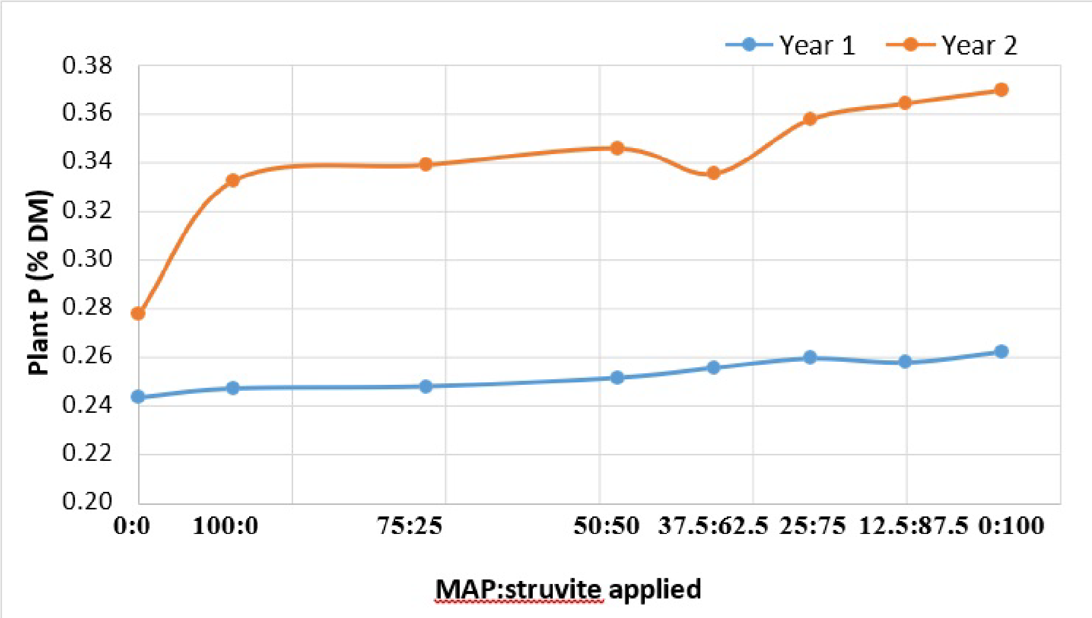

14
12
10
8
6
4
2
0
DM Yield (tons/acre)
Year 1
Year 2
0:0
100:0
75:25
50:50
37.5:62.5
25:75
12.5:87.5
0:100
MAP:struvite applied

Fall Planting P Uptake Figure. Total phosphorus uptake (lbs P acre^{-1}) of fall-planted alfalfa as affected by fertilization with different monoammonium phosphate (MAP) to struvite ratios the first two years, with 5 cuttings per year.





Fall planting Plant P Concentration Figure. Plant phosphorus concentration (% DM) in fall-planted alfalfa fertilized with different ratios of monoammonium phosphate and struvite over two years. Plant P is averaged across 5 cuttings per growing season for each fertilizer treatment.



In summary, 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 plot demonstrations and commercial field studies has shown struvite is available to meet the immediate needs for early establishment of alfalfa. Also when struvite is applied to the soil surface in the second growing year, could replace MAP as the P source for alfalfa without affecting yield. Results also suggest that supplementing struvite with MAP fertilization leads to greater P uptake by alfalfa in the second year.

Laboratory Incubation Study

The objectives in this laboratory project was 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 laboratory incubation and soil extraction data found for both fall and spring incubations, Olsen P concentration (OP) was significantly affected by the interaction between time in incubation and MAP:struvite ratio applied. OP for all fertilizer treatments decreased linearly as temperature decreased and time increased, but treatment 0:100 had significantly less OP than all other fertilized treatments after 63 days of fall incubation (tables and figures, below). As time and temperature increased, OP for MAP:struvite treatments did not increase or decrease congruently. Even though time and MAP:struvite had a significant effect on OP, the pattern and underlying cause was unclear from the data collected.

Fall Incubation Olsen P Table. Summary of Olsen P concentrations (mg kg^{-1}) as affected by time and ratio of monoammonium phosphate (MAP) to struvite during the Fall Incubation.

	Days in Incubation									
	0	4	7	14	21	28	34	47	56	63
	Fall Temperature (Celsius)									
	26.0	**25.1**	**25.1**	**23.8**	**23.8**	**23.8**	**20.9**	**19.0**	**17.0**	**14.7**
0:0	12.3^{b}	12.3^{b}	12.3*^{c}	7.4*^{d}	9.5^{b}	8.9^{c}	6.5*^{c}	7.0^{b}	7.7^{c}	7.9^{b}
100:0	22.9^{a}	16.0*^{a}	15.5^{bc}	12.5*^{c}	14.9*^{a}	13.8^{ab}	12.8^{a}	11.8^{a}	12.7^{a}	12.1^{a}
75:25	22.3^{a}	15.6*^{a}	17.2^{bc}	15.2^{b}	15.0^{a}	15.8^{a}	13.1*^{a}	10.3*^{a}	11.6^{a}	10.6^{a}
50:50	22.5^{a}	16.2*^{a}	19.2*^{ab}	15.2*^{b}	16.6^{a}	13.2*^{b}	12.3^{ab}	12.2^{a}	10.6^{ab}	10.8^{a}
25:75	22.0^{a}	16.2*^{a}	19.3*^{ab}	17.9^{a}	14.5*^{a}	10.0*^{c}	11.3^{ab}	11.4^{a}	9.1*^{bc}	10.3^{a}
0:100	21.2^{a}	16.8*^{a}	20.4*^{a}	16.4*^{ab}	11.5*^{b}	10.7^{c}	10.1^{b}	10.3^{a}	7.6*^{c}	7.7^{b}

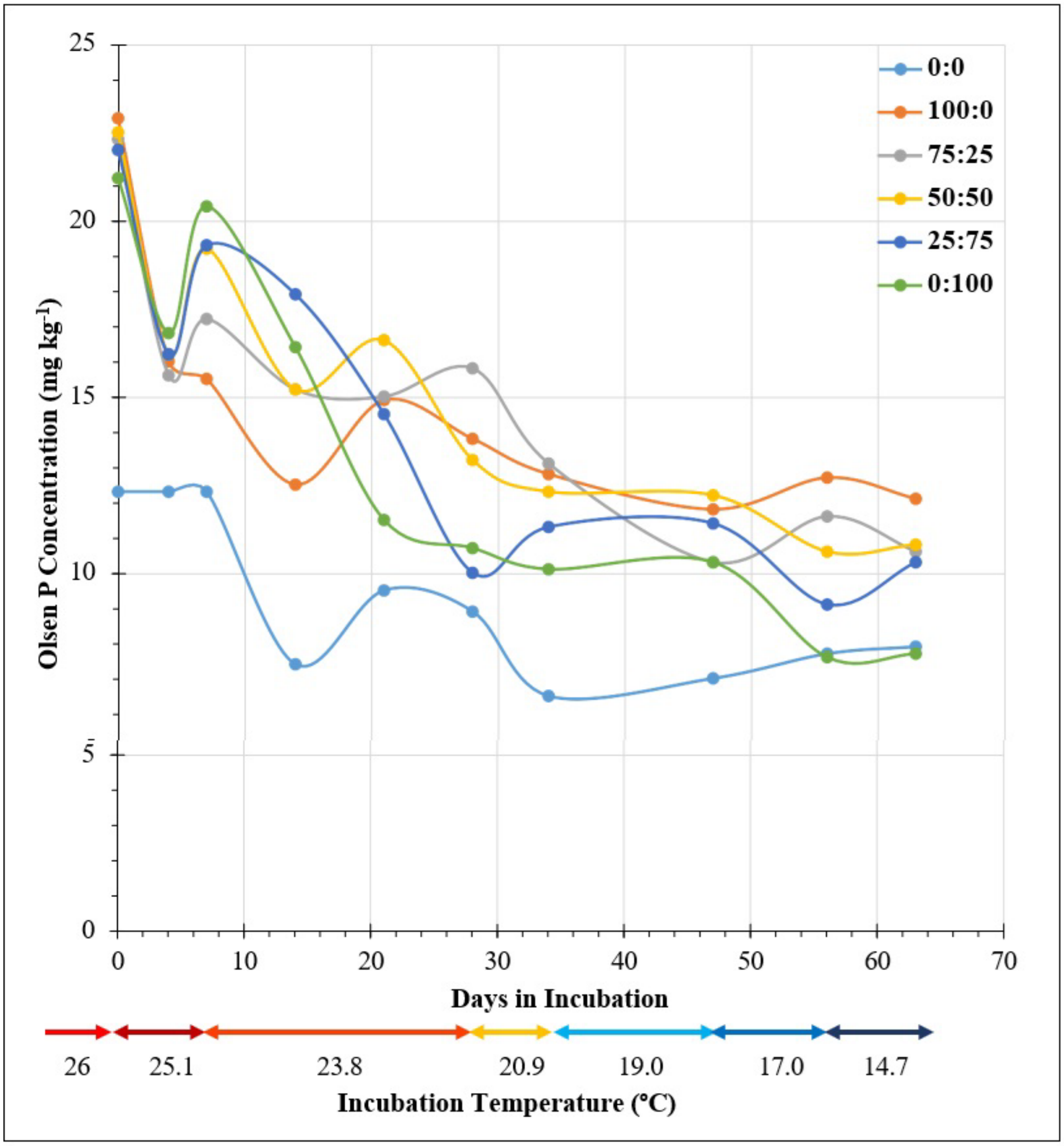
***** Indicates a mean that is significantly different ($P < 0.05$) from the previous mean in the same row. Because there was a highly significant two-way interaction ($P < .0001$) between MAP:Struvite and days, interaction means were used. Standard error for all cell means was 0.8124. Means within a column with unlike superscripts differ ($P < 0.05$).

Spring Incubation Olsen P Table. Summary of Olsen P (mg kg^{-1}) concentrations as affected by time and ratio of monoammonium phosphate (MAP) to struvite during the Spring Incubation.

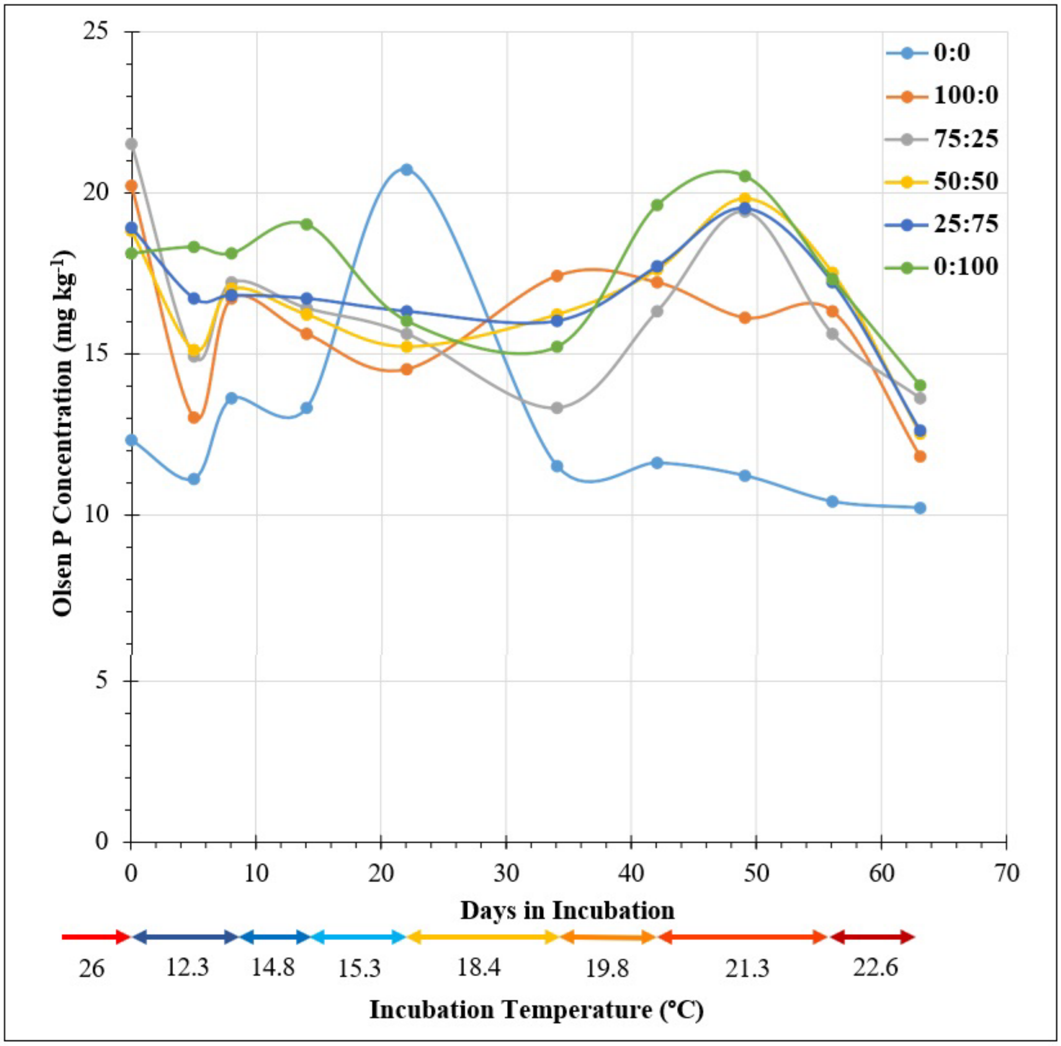
	Days in Incubation									
	0	5	8	14	22	34	42	49	56	63
	Spring Temperature (Celsius)									
	26	**12.3**	**12.3**	**14.8**	**15.3**	**18.4**	**19.8**	**21.3**	**21.3**	**22.6**
0:0	12.3^{c}	11.1^{d}	13.6^{b}	13.3^{c}	20.7*^{a}	11.5*^{c}	11.6^{c}	11.2^{c}	10.4^{b}	10.2^{b}
100:0	20.2^{ab}	13.0*^{cd}	16.7*^{a}	15.6^{bc}	14.5^{b}	17.4*^{a}	17.2^{ab}	16.1^{b}	16.3^{a}	11.8*^{ab}
75:25	21.5^{a}	14.9*^{bc}	17.2^{a}	16.4^{b}	15.6^{b}	13.3^{bc}	16.3*^{b}	19.4*^{a}	15.6*^{a}	13.6^{a}
50:50	18.8^{b}	15.1*^{bc}	17.0^{a}	16.2^{b}	15.2^{b}	16.2^{a}	17.6^{ab}	19.8^{a}	17.5^{a}	12.5*^{ab}
25:75	18.9^{b}	16.7^{ab}	16.8^{a}	16.7^{ab}	16.3^{b}	16.0^{a}	17.7^{ab}	19.5^{a}	17.2^{a}	12.6*^{ab}
0:100	18.1^{b}	18.3^{a}	18.1^{a}	19.0^{a}	16.0*^{b}	15.2^{ab}	19.6*^{a}	20.5^{a}	17.3^{a}	14.0*^{a}

* Indicates a mean that is significantly different ($P < 0.05$) from the previous mean in the same row. Because there was a highly significant two-way interaction ($P < .0001$) between MAP:Struv and days, Olsen P interaction means were used. Standard error for all interaction means was 0.8973. Means within a column with unlike superscripts differ ($P < 0.05$).

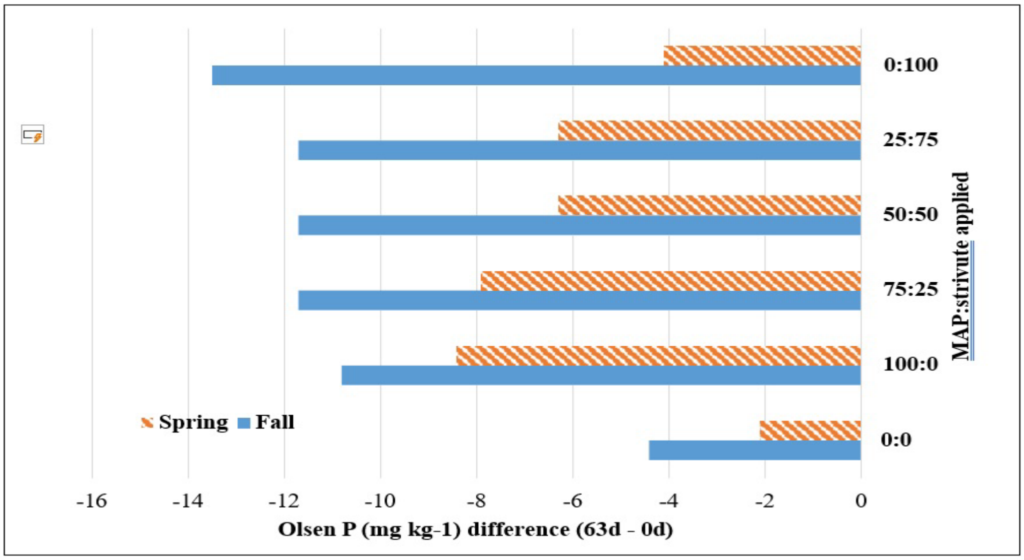
*Fall Incubation Soil OP Concentrations Figure***.** OP concentrations of soils fertilized with MAP:struvite as affected by time during Fall Incubation.



Spring Incubation Soil OP Concentrations Figure. OP concentrations of soils fertilized with ratios of MAP:struvite as affected by time during Spring Incubation.



Soil Olsen P Incubation Duration Figure. Difference between Olsen P concentrations in soils at the initiation (Day 0) and end (Day 63) of incubation for both fall 2017 and spring 2018. Soils were fertilized with different ratios of monoammonium phosphate (MAP) to struvite before Olsen P extraction on Day 0.



<u>Describe significant results, accomplishments, and lessons learned. Compare actual accomplishments to the project goals in your proposal:</u>

The goals of this demonstration project was to:

1. *Successfully demonstrate the mobile unit at numerous dairies*

   As explained in the previous section- after sourcing manure from 30 different dairies, the mobile P removal technology has demonstrated OP and TP removal from dairy wastewater in Washington State. The nutrient recovery runs from approximately 30 farms with positive nutrient reductions has yielded a range of 1 to 76 % reduction in OP% and 2 to 72 % reduction in TP.

2. *Develop an effective regional P recycling relationship between the WA dairy industry and forage growers (alfalfa hay)*

   The WA dairy farmers have seen the mobile unit coordinated events such as the annual dairy meetings, and also the nutrient recovery field day. The dairy farmers have had significant exposure with the mobile unit showing up on their farms and hearing about the nutrient removal efforts and resulting recycling aspects with its fertilizer benefit in the field. The dairy farmers that sourced their manure for this project will be receiving a report for the nutrient removal on their operations at the end of 2019, when the project terms. Also, the hay growers have heard about the project through annual WA state hay growers meeting (2017, 2018 and 2019). The two commercial hay growers that are partnered in this project hold significant leadership roles in the state alfalfa board and realizing the value of struvite, have leveraged national alfalfa board funds (2018 and 2019) to support additional research using struvite as a fertilizer with alfalfa.

3. *Increase the understanding of phosphorus management by both industries*

Extension and outreach of this nutrient removal technology demonstration project to reduce on-farm nutrients and adoption of a regional recycling concept has been shared on the following occasions:

- This struvite project was featured from a successful field day on April 20, 2018 in Lynden, WA (mentioned in component 1). Sandy Means from the NRCS was able to attend. This struvite project has been featured at several of regional dairy and alfalfa meetings mentioned previously. We hope to have additional interest in the mobile nutrient recovery system with subsequent data as the completion of the first growing season is almost underway and the goal of visiting 30 dairy farms has been accomplished.
- 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 ' Alfalfa Checkoff: Developing practical phosphorus and potassium tissue test recommendations and utilizing struvite in modern alfalfa systems' was published in July of 2019 in the Progressive Forage Magazine. https://www.progressiveforage.com/news/industry-

news/alfalfa-checkoff-developing-practical-phosphorus-and-potassium-tissue-test-recommendations-and-utilizing-struvite-in-modern-alfalfa-systems

- Three project videos are now available for viewing:
  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.

Describe the work that you anticipate completing in the next six-month period:

Component 1: *Mobile demonstration of the nutrient recovery system*

a. The total suspended solids (TSS) and buffering capacity have proved to be the influential contributors of inhibiting struvite production. Also one cannot ignore the high cost associated with the chemicals used to buffer the manure in accordance with running the cone. The team has collected samples of low (< 5,000 mg/L TSS) TSS manure (i.e.: as a product stream from a dissolved air flotation system) to demonstrate if the TSS and the resulting buffering capacity of high dairy TSS in manure is the largest obstacle in producing struvite using the fluidized bed cone treatment. The DAF system samples that fit into the reduced nutrient and low TSS range and pre-treatment profile will undergo the struvite treatment using the previously demonstrated pH modifiers.

a. The data from the fluidized bed cone runs will be analyzed for further summarization.

Component 2: *Agronomic land application of struvite to commercial alfalfa fields*

a. For the remainder of this fall we will continue to analyze the data from the last plant tissue samples to evaluate and summarize the response to the previous treatment applications.
b. The agronomist involved with this project, Dr. Steve Norberg, was also was able to receive funds from the National Alfalfa & Forage Alliance (NAFA) to extend this piece of the agronomic struvite demonstration trial. Dr. Norberg is looking at developing practical phosphorus and potassium tissue test recommendations and using struvite in modern alfalfa systems.
    a. The major factors to address for understanding the value of struvite can be defined as three objectives. Each objective has the primary goal of establishing the relative nutritive value of struvite as a P source.

1) Evaluate the response to fall or spring application,
2) Determine the optimum ratio of struvite: MAP,
3) Evaluate the rate response of P as struvite or MAP

Controlled replicated alfalfa plot studies will be continued until next year (2019 – 2020) at WSU – Prosser to evaluate: 1) the influence of struvite as a phosphorus fertilizer on yield of new alfalfa seedings in the fall or spring, 2) comparison of the efficacy of combinations of mono-ammonium phosphate (MAP) and struvite for fertilization of alfalfa, and 3) evaluation of nutrient quality and yield of forage samples at different rates of P (including struvite) and potassium sulfate.

Plots- Six mixtures of MAP:Struvite in alfalfa: 0:0 100:0, 75:25, 50:50, 37.5:62.5, 25:75, 12.5: 87.5 0:100; are being evaluated to determine if any quick release P is needed to supplement the slower release of P in struvite for spring planted alfalfa. In addition the design will also include a P Phosphorus response to five differing rates of P2O5 of Struvite in the fall; including: 0, 35, 70, 140, 280 lbs/acre to develop/refine tissue testing recommendations for P. Treatments with 35 & 70 lbs/acre will be fall applied and incorporated whereas the 140 and 280 lbs/acre will be spring broadcast and not incorporated. Response to five differing rates of spring application of P_2O_5 as MAP or struvite; including: 0, 30, 60, 120, 240 lbs/acre to develop/refine tissue testing recommendations for P. Dry matter yield and plant composition (N, P, K, ADF, NDF, ADL) will be obtained at each cutting (early bud stage of growth), and soil tests (Olsen P and complete soil test – Nitrate, ammonium, P, K, S, B, pH, OM, and micro-minerals) will be conducted at the beginning and end of each growing season.

Commercial Fields – Fertilization studies at ~ 50 acre portions of alfalfa fields at commercial growers will be continued until next year (2019 – 2020) and evaluated for yield and quality of forage when fertilized with either MAP or a MAP/struvite mixture. Soil samples will be analyzed for Olsen P and complete soil test – Nitrate, ammonium, P, K, S, B, pH, OM, and micro-minerals, and forage will be analyzed for N, ADF, NDF, ash, Ca, P, Mg, and K.

b. The request to the CIG program for a 1 year no-cost extension was granted in January 2019. This additional year (2019) allowed the team to further examine the struvite fertilizer compared to the MAP in the agronomic field demonstration in terms of performance yields, quality and economics.

References

Brown, K., Harrison, J. H., Bowers, K. (2018). Struvite Precipitation from Anaerobically-Digested Dairy Manure. Water, Air, and Soil Pollution.