Developing Practical Phosphorus and Potassium Tissue Test Recommendations and Utilizing Struvite in Modern Alfalfa Systems

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Abstract: (Limit 200-300 words)
Tissues testing whole alfalfa plants at harvest can more accurately direct nutrient decisions. Developing critical nutrient levels in-season improves recommendations and applications, saving producers time, expense and effort since many growers take samples for hay quality. These three experiments were designed as follows: 1) Phosphorus Rate study with differing rates of P_2O_5 using monoammonium phosphate (MAP); including: 0, 30, 60, 120, 240 lbs P_2O_5/acre on an 6.7 ppm P soil (Olsen P method); 2) Potassium Rate study with differing rates of K_2O using potassium sulfate: 0, 40, 80, 160, 240, 320 lbs K_2O/acre; 3) Struvite study (magnesium ammonium phosphate, $MgNH_4PO_4 \cdot 6\ H_2O$) application at 144 lbs. of P_2O_5 /acre in differing ratios of MAP:Struvite in alfalfa including: 100:0, 75:25, 50:50, 37.5:62.5, 25:75, 12.5: 87.5, 0:100 and an unfertilized check. The following is second year results. The Phosphorus Rate study showed that 150 and 160 lbs P_2O_5/acre maximized gross revenue after fertilizer costs for \$150 and \$200/ton alfalfa, respectively. When the hay price is \$150/ton the optimum P alfalfa tissue content was 0.34, 0.40, 0.36, 0.34, and 0.32 percent for first through fifth cut, respectively, and at \$200/ton was 0.35, 0.41, 0.37, 0.34, and 0.32 for first through fifth cut, respectively. Cutting interacted with Potassium rate, where the 80 lbs/acre rate ranged from 1.6 to 2.3% K from the first to second cuts, respectively. Due to variation, >2.4% K at second cutting is recommended. Replacing or supplementing MAP with struvite had no effect on first cut or second year yield, but had a quadratic influence on phosphorus content. The Struvite study showed that even under very low phosphorus situations, MAP could be replaced with struvite on a P_2O_5 basis. Collectively, these studies provide second year alfalfa recommendations for phosphorus and potassium.

Introduction:

Most inorganic phosphorus (P) fertilizers are derived from phosphate rock, where 98% of the reserves are in other countries; with the USA only holding 2% (Stewart, 2002; USGS, 2020). Dairy farms accumulate P through manure, and each farm has a unique need for P outlets and removal to reach a whole farm P nutrient balance (WA Dept. of Ecology). In contrast, alfalfa (*Medicago sativa*) producers need to reverse the trend of declining soil test P content to maintain high crop yield and quality. To compound the problem, just a few years ago the price of commercial P fertilizers soared to record high prices, and will likely do so again as reserves diminish and struggle to accommodate increasing demand. A viable solution is the adoption of technology to capture P from liquid manure in the form of 'struvite' (magnesium ammonium phosphate, $MgNH_4PO_4 \cdot 6\ H_2O$), a slow release form of P based fertilizer. Currently Pacific Northwest (PNW) struvite NPK fertilizer has an analysis of (6 – 29 – 0) including 16% magnesium. Struvite is easy to handle and transport due to low moisture content and sand-like texture.

With high P and K fertilizer costs it is important to apply required nutrients accurately. Current soil sampling guidelines are calibrated from one foot soil tests, yet alfalfa plants can remove potassium and other nutrients from much deeper depths creating disproportional inaccuracy between crop response and soil test results. Tissue testing provides the opportunity to direct nutrient decision making based on accurate critical levels for in-season recommendations that could include possible applications between cuttings or through fertigation. California scientists have developed the alfalfa tissue testing protocols; however, producers are not adopting them because the test uses the middle third of alfalfa at one-tenth bloom for P & K (Meyer et al., 2007). One-tenth bloom is well past dairy quality hay stages for most PNW producers, making this California recommendation impractical. Alfalfa tissue testing has been proposed in New Mexico, which recommended a wide range from 2.0 to 3.5% K in the upper third of the plant at early bloom (Flynn et al., 1999). The current PNW alfalfa fertilizer guide states a critical K level of 2.0 to 2.5% for the whole plant at first bloom, but needs further refinement (Koenig et al., 1999). Research conducted in Israel suggests that K levels should remain above 2.5% at harvest for maximum alfalfa yield (Kafkafi et al., 1977). This research and others reveal P & K concentrations decline with crop maturity indicating the importance of the timing of tissue testing.

Fertilizer is the largest single expense in an irrigated alfalfa budget for the western U.S. Even at modest rates, fertilizer can easily reach over $216 per acre with P & K being the largest component (Norberg and Neibergs, 2014). More K is removed from the soil by alfalfa than any other nutrient (Koenig and Barnhill, 2006). Alfalfa can remove 8 lbs P_2O_5 and 54 lbs K_2O per ton of alfalfa produced (Koenig, et al., 2009), which for yields of 10 tons per acre attainable by excellent producers in the PNW, result in 80 lbs P_2O_5 and 540 lbs K_2O removed per acre per year. We have proposed using a harvest time mid to late bud stage (typical harvest timing for first cutting in PNW) and the use of whole plant samples, which could be taken at the same time and using the same method currently being used for quality analysis. We have emphasized first cutting because it's the one most desired by the dairy industry and the most likely cutting to be nutrient limiting due to cold soils. We have also proposed to test all alfalfa cuttings. Struvite is a slow release option to MAP and our hypothesis is that combining the two could provide the best overall results.

This is the second year of this research funded by National Alfalfa and Forage Alliance and was conducted near Prosser, Washington on a low phosphorus testing soil 6.7 ppm (method: Olsen et al., 1954) for the phosphorus study and 86 ppm potassium soil (ammonium acetate method). We aimed to: 1) Develop and calibrate phosphorus (P_2O_5; Phosphorus Rate study) & potassium (K_2O; Potassium Rate study) nutrient recommendations for bud stage alfalfa using tissue testing for maximum profit, yield and direct comparison to current soil testing recommendations; 2) Compare efficacy of combinations of MAP and struvite (Struvite study) for fertilization of alfalfa; 3) Evaluate quality of hay samples at different P and K rates and tissue concentrations.

Materials and Methods:

We established three experiments, two at low P soil test field ("Phosphorus Rate" & "Struvite"), and one on a low K soil test field ("Potassium Rate"). Studies were in a randomized complete block design with four replications at establishment of a spring stand of alfalfa and harvested 3 times in 2018. Nutrients were applied on the surface for the second year of the experiment on April 11, 2019. Alfalfa was harvested 5 times in 2019. The experiments' treatments and descriptions are listed below.

"Phosphorus Rate" – Studying the influence of P_2O_5 rates of MAP (0, 30, 60, 120, 240 lbs P_2O_5/acre) to develop/refine tissue testing recommendations for P.

"Potassium Rate" – Response of alfalfa to six differing rates of Potassium Sulfate (0, 40, 80, 160, 240, 320 lbs K_2O/acre) to develop/refine tissue testing recommendations for K.

"Struvite" – Alfalfa response to six mixtures of MAP:Struvite (0:0, 100:0, 75:25, 50:50, 37.5:62.5, 25:75, 12.5: 87.5, 0:100) to determine if any quick release P is needed from MAP to supplement the slower release of P in struvite for spring planted alfalfa.

Struvite and MAP was applied according to treatments desired with a Gandy drop spreader after calibration.

Tissue samples were analyzed for P and K by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP). Yield results were compared to P and K concentrations to determine critical values required for maximum yield and economic returns. Calibration of P and K shortages were compared to optimum rate at harvest along with P and K concentrations of tissue samples pulled to determine appropriate fertilizer recommendations for each cutting or averaged over cuttings if similar results were found.

To determine the maturity at harvest we used the maturity ratings of Mueller and Teuber (2007) where: "growth stage 2" is late vegetative stage when stem length is greater than 12 inches, no visible buds, flower or seed pods; "growth stage 3" is early bud when 1-2 nodes have visible buds and have no flowers or seed pods; and "growth stage 4" is late bud when ≥ 3 nodes have visible buds, with no flowers or seed pods. "Growth stage 5" is early Flower when one node has an open flower and no seed pods; and "growth stage 6" is late flower when ≥ 2 nodes have open flowers and no seed pods. The growth stage of ten stems was determined and then used to calculate the average for each plot.

Plots for the experiment were harvested with a flail harvester (Carter Manufacturing) at 33 inches wide and 25 foot long. Subsamples that were taken by hand from 5 feet of 1 row in each plot were weighed, dried and weighed again for harvest moisture and dry matter yield determination.

These experiments determined how P and K status affects feed quality and value as stated in objective 3. To accomplish this, whole plant samples were collected from each treatment plot at bud stage at each harvest. All harvested samples were dried in forced air ovens at 60^{o}C until no weight loss occurred. Samples were ground through a Wiley Mill (Thomas Scientific, Swedesboro, NJ) to 2 mm in length, then ground with Udy Cyclone Sample Mill (Udy Corporation, Fort Collins, CO) to 1 mm before scanning and prediction for DM, CP, ADF, aNDF, ash, starch, fat and TDN by FOSS 6500 Near Infrared Reflectance Spectroscopy (NIRS) using 10 percent of samples for wet lab validation by the methods of Shenk et al. (1989). Ground samples were utilized for both nutrient and forage quality analysis. Statistical analysis was run in SAS using Proc GLM.

Results and Discussion

<u>Phosphorus Rate Experiment:</u>

A visual difference was apparent between the plots in regard to growth in plots with lower applications from year one affecting growth in early April (Figure 1). This photo was taken on April 10, 2019, the day before the second year MAP treatment applications occurred. On the second-year alfalfa stand, phosphorus rate increased first cut yield from 2.4 to 3.2 tons of dry matter (DM) per acre and total yield from 8.77 to 10.34 tons DM/acre for 0 and 120 lbs P_2O_5/acre, respectively. In 2019, assuming MAP was \$560/ton and hay price was 150 or 200 \$/ton, the optimum P_2O_5 rate was 150 and 160 lbs/acre (Figure 2). Phosphorus rate also had a linear influence on whole plant tissue content (Figure 2). Averaged over cuttings, tissue P content increased from 0.19 to 0.34 % for 0 and 120 lbs P_2O_5/acre when harvested at mid-bud stage. The percent P found in the plant at a given rate varied by cutting (Figure 4). The optimum percent P for each hay price is given in Table 1. These P levels are higher than last year's findings (0.24-0.28 % and 0.25-0.29 % P when the alfalfa hay price of \$150 and \$200 per ton, respectively) suggesting that first year alfalfa is willing to grow at lower tissue P concentration levels and increase requirements the second year. Even though yield did not continue to increase, P content went as high as 0.40 %, showing the same as the first year results that alfalfa is a "luxury" consumer of P (Figure 1). Alfalfa is a luxury consumer of both P and potassium (K), which means we need to be as accurate as possible or producers will be paying for more fertilizer than they need to maximize profit. More P_2O_5 fertilizer was removed in hay (160 lbs/acre) than was applied at the 120 lbs/acre rate (Table 3). Soil samples taken during the fall of 2019 appear to consistently decrease from fall of 2018. The decline in soil test P_2O_5 in 2019 is probably tied to the fact that over twice as much P_2O_5 was removed in 2019 as compared to 2018, 160 and 77 lbs/acre, respectively.

Increasing phosphorus rate had the largest impact on the first cutting where yields increased from 2.41 to 3.24 by adding 120 lbs P_2O_5/acre (Figure 5). Relative feed quality (RFQ) was positively affected by increasing phosphorus rate – raising from 169 to 211 units during the first cutting (Figure 6). Relative feed value (RFV) was not greatly affected when averaged over all cuttings. Total nutrient value followed the same trends of RFV but shows first cutting hay value was increased from $256 (0 lbs P_2O_5/acre) to as high as $308/ton in value (Figure 7). The average hay nutrient value in this experiment was between $280 and $290 per ton based on phosphorus rate. Starch content and net energy of lactation (NEL) of the whole plant linearly increased with increasing phosphorus rate (Table 4). One of the amazing findings was that crude protein content in the first cutting of hay increased from 19.3 to 24.5 % with increasing P rate (Table 5). Also interesting was that increasing from 120 lbs P_2O_5 to 240 lbs P_2O_5 increased crude protein content from 21.6 to 24.5%. Our current situation is that hay is typically sold by RFV which does not include protein content in its calculation, meaning this would provide no value on the hay market. Protein content did not change much in other cuttings (Table 5). Lignin content decreased in the first cutting from 6.25% to 5.15% with increasing phosphorus rate; however, other cuttings were not affected much (Table 5). Content of aNDF was decreased in the first cutting from 35.5 to 30.2% and aNDF digestibility (NDFD48 hr.) was increased from 42.8 to 49.7% for the first cutting of alfalfa by applying 240 lbs of P_2O_5/acre (Table 5). Once again, these impacts were only in the first cutting. Ash content was also inconsistent across cuttings with increasing ash content at first cutting and decreasing ash content in the other cuttings (Table 5). Interestingly ash and protein content both had similar increasing trends at first cutting with increasing phosphorus rate.

To summarize, when phosphorus was limiting yield it also had a beneficial effect on many traits, but only starch and energy (NEL) were consistently increased across all cuttings. RFV was strongly affected increasing it from 169 to 211 units in the first cutting. Later in the season the influence of P disappeared as soils warmed up.

Figure 1. Field views in the Phosphorus Rate Study between the control and 240 lbs P_2O_5/acre treatment on April 10, 2019 at Prosser, WA prior to phosphorus fertilizer applications. Soils had a beginning Olsen P concentration varying from 3 to 6 ppm.

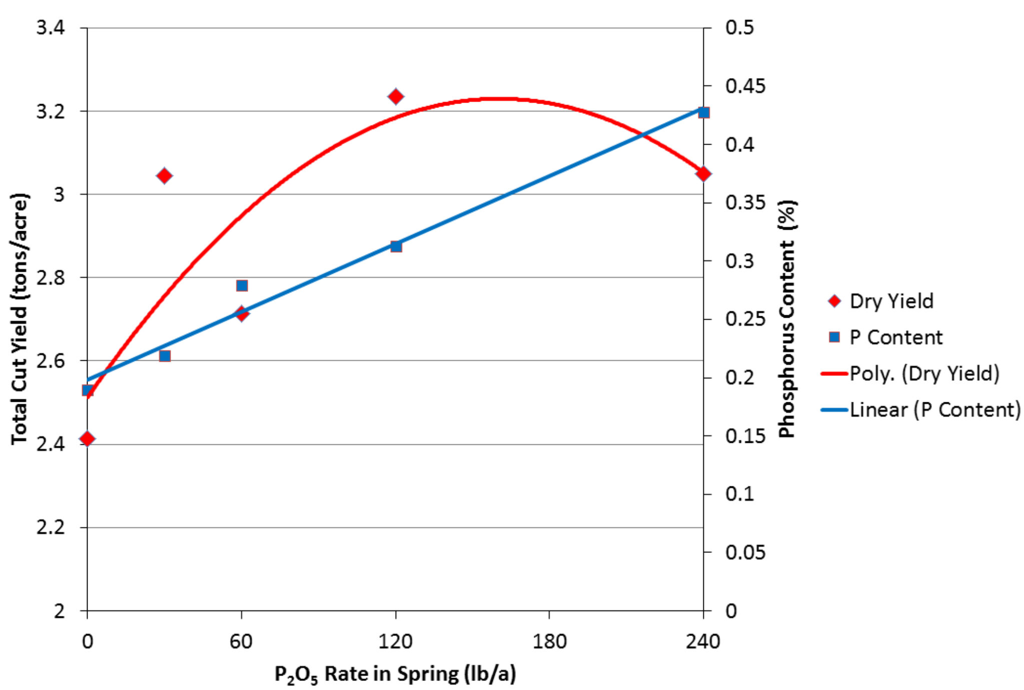

Figure 2. Rate of P_2O_5/acre monoammonium phosphate influence on first cut yield and phosphorus content in second year alfalfa at Prosser, WA.

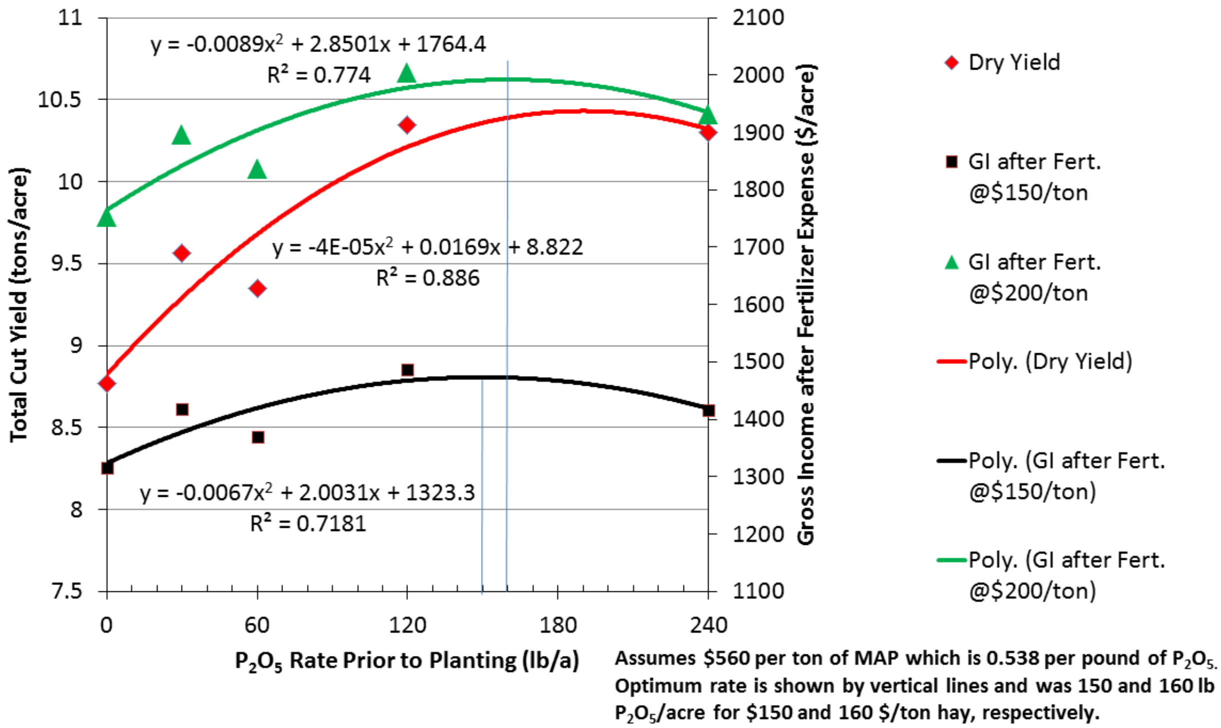

Figure 3. Rate of P_2O_5/acre monoammonium phosphate influence on total yield and gross income after fertilizer expense applied to second year alfalfa in the spring of 2019.

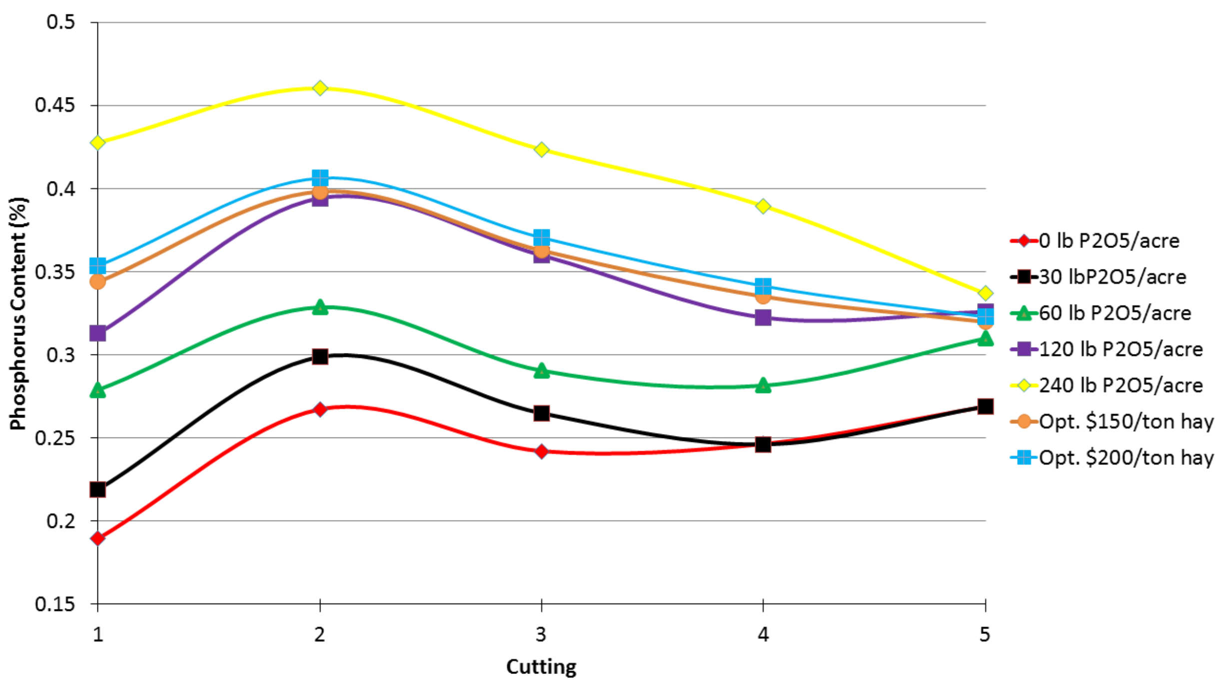

Figure 4. Phosphorus content of harvested alfalfa tissue (whole-plant, 2” cutting height) at mid-bud stage as influenced by cutting and rate of P_2O_5/acre (monoammonium phosphate) applied in the spring at Prosser, WA.

Table 1. Optimal percent phosphorus in harvested alfalfa hay to maximize alfalfa gross income after fertilizer expense by cutting and seasonal average at two hay prices.

Hay Price	Optimum P Averaged over Cuttings (%)	Optimal % P in Harvested Hay to Maximize Alfalfa Gross Income After Fertilizer Expense ---------------------------Cutting of Hay--------------------				
$/Ton	**Avg. P (%)**	**First**	**Second**	**Third**	**Fourth**	**Fifth**
150	0.35	0.34	0.40	0.36	0.34	0.32
200	0.36	0.35	0.41	0.37	0.34	0.32

Table 2. Phosphorus budget showing amounts applied and amount removed from the treatments. Note: 1 lb P = 2.29 lb P_2O_5.

Treatment P_2O_5 Rate (lbs/acre)	P Rate Applied (lbs/acre)	Yield (Tons/ Acre)	P Conc. (%)	P Removed (lbs/acre)	P_2O_5 Removed (lbs/acre)
0	0	8.77	0.24	41.66	95.47
30	13	9.56	0.26	48.65	111.49
60	26	9.35	0.30	55.25	126.60
120	52	10.34	0.34	70.09	160.62
240	105	10.30	0.40	83.99	192.46

Table 3. Change in Olsen phosphorous soil test values from fall of 2017, fall of 2018 and fall of 2019 by treatment and pounds of P_2O_5.

Treatment P_2O_5 Rate (lbs/acre)	P_2O_5 Removed (lbs/acre)	Soil Test P 2017	Soil Test P 2018	Soil Test P 2019
0	95	8.4	4.5	4.3
30	111	8.6	6.0	5.8
60	126	7.9	5.5	4.0
120	160	7.6	7.8	6.3
240	192	9.1	9.7	8.3

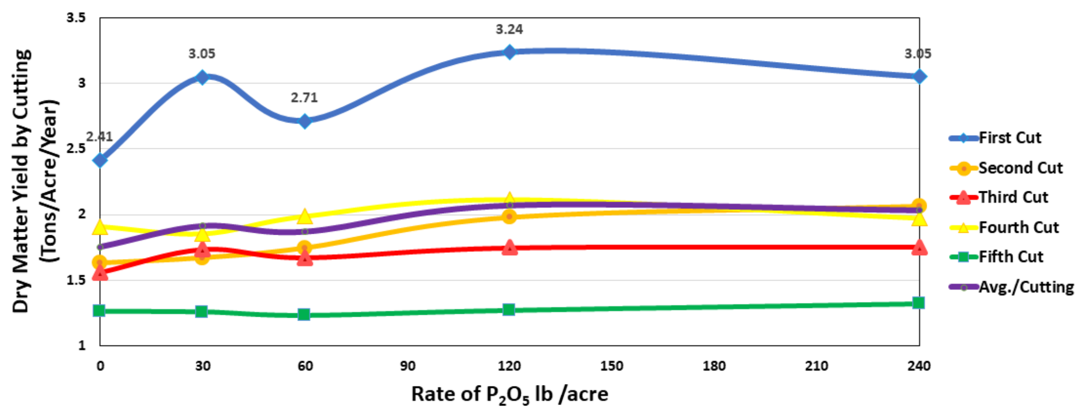

Figure 5. Phosphorus rate influence on yield (tons per acre) of each cutting of alfalfa in 2019.

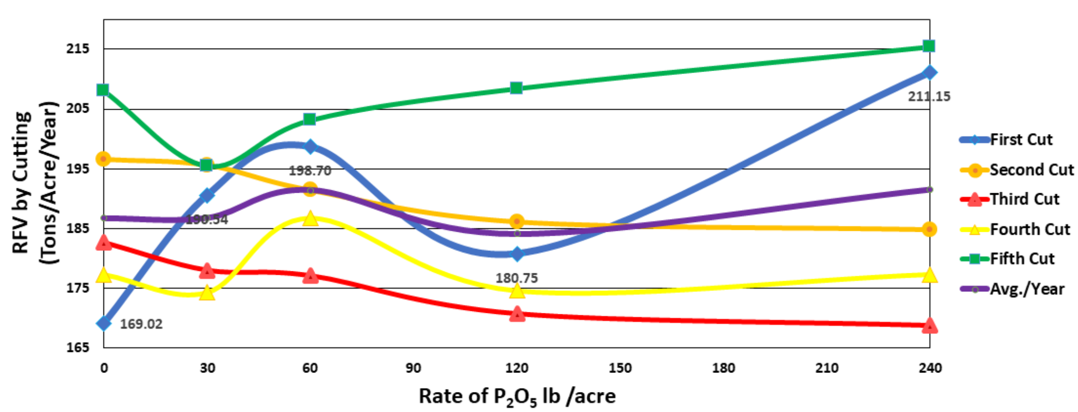

Figure 6. Phosphorus rate impact on relative feed value for each cutting of alfalfa in 2019.

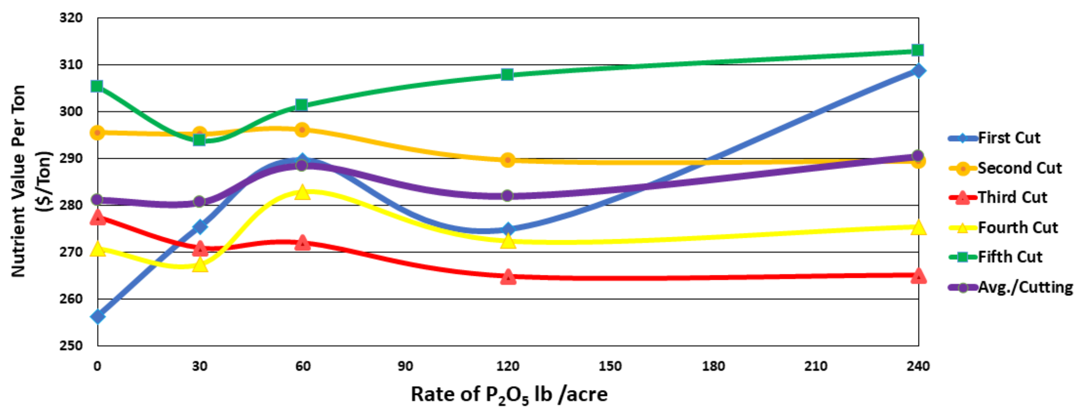

Figure 7. Phosphorus rate impact on total nutrient value (dollars per ton) by cutting.

Table 4. Phosphorus rate influence on starch and net energy for lactation (NEL).

Rate	**Starch[1]**		**NEL[1]**	
lb. P_2O_5/acre	**%**		Mcal / lb.	
0	3.53	c	0.606391	b
30	3.53	c	0.605386	b
60	3.61	bc	0.616956	ab
120	3.74	ab	0.611714	ab
240	3.79	a	0.618417	a
C.V.	7.0		2.5	
Anova Rate P>F =	0.0033		0.0198	
Contrast Rate Linear P>F =	0.0002		0.0081	

[1] Rates within the same column with different letters are significantly different.

Table 5. The influence of cutting and phosphorus rate on: crude protein (CP) content, aNDF, ash content, lignin content, NDFD 48hr., and relative feed quality of alfalfa in 2019.

Cutting	Rate	CP	aNDF	Ash	Lignin	NDFD48	RFQ
	lb. P_2O_5/acre	%	%	%	%	%	%
1	0	19.25	35.51	10.54	6.25	42.82	178
1	30	20.46	32.75	11.67	5.61	44.34	205
1	60	22.10	31.51	11.75	5.50	46.78	221
1	120	21.60	34.00	11.08	5.97	45.38	196
1	240	24.53	30.21	11.80	5.15	49.71	241
2	0	23.59	31.39	12.83	5.05	50.26	231
2	30	23.67	31.54	12.88	5.00	50.21	229
2	60	24.19	32.19	12.16	5.15	50.43	225
2	120	23.66	32.88	12.01	5.29	49.32	215
2	240	23.68	33.07	11.76	5.32	49.34	214
3	0	21.52	33.12	12.03	5.54	45.85	204
3	30	20.90	33.82	11.92	5.63	44.60	195
3	60	21.18	33.97	11.50	5.73	45.52	196
3	120	20.62	34.95	11.17	5.84	43.57	184
3	240	21.21	35.32	11.42	5.88	44.71	184
4	0	21.39	33.95	12.74	5.72	45.25	196
4	30	21.03	34.35	12.47	5.76	44.67	191
4	60	22.23	32.70	12.27	5.49	46.18	209
4	120	21.85	34.48	11.75	5.82	45.51	193
4	240	21.94	33.95	11.77	5.73	44.92	195
5	0	23.79	30.00	12.03	5.17	48.87	241
5	30	23.15	31.61	11.89	5.39	47.41	221
5	60	23.22	30.52	11.38	5.27	47.53	231
5	120	23.92	29.93	11.44	5.16	48.48	240
5	240	24.46	29.45	11.41	5.05	49.63	250
C.V.		4.2	5.4	3.6	5.6	3.3	8.4
Mean		22.34	32.71	11.82	5.50	46.82	211
Anova Rate PR>F =[1]		0.0003	NS	<0.0001	NS	0.0314	NS
Anova Cutting*Rate PR>F =		0.0006	0.0598	0.0006	0.0185	0.0020	0.0172
Contrast Linear Rate PR>F=[1]		0.0001	NS	<0.0001	NS	0.0300	NS
Contrast Quadratic Rate PR>F=[1]		NS	NS	0.0285	NS	NS	NS

[1]Since the Cutting*Rate interaction is significant these probability results must be looked at with extreme caution.

Potassium Rate Experiment:

Previous year results showed no response to potassium applications, but the following spring growth showed significant potassium deficiency symptoms (April 10, 2019, Figures 8a and 8b) Fertilizer was applied on April 11, 2019 and the highest first cutting yield was obtained with 320 lbs K_2O/acre (Figure 9). The greatest total yield and average potassium content also came from 320 lbs K_2O/acre -- a similar trend as yield at first cutting (Figure 10). Interestingly, the calculated optimum for gross return from hay sales at $150/ton hay was 80 lbs K_2O/acre, but at $200/ton hay the optimum was at 320 lb K_2O/acre (Figure 11). This provides solid recommendations for producers who are more likely to apply more fertilizer when hay prices are high than when hay prices are down.

In our spring applied experiment, the K content of the forage at mid-bud stage varied depending on cutting and was much higher in the second cutting versus the first cutting (Figure 12). Another challenge was that the K tissue concentration at every harvest but the second was lower at the 80 lbs K_2O/acre rate than the 0 and 40 lbs K_2O/acre rates (Figure 12). However, the 80 lbs K_2O/acre rate took up a similar amount of K (lbs/acre) as the 0 and 40 lbs K_2O/acre rates (Table 6). This is likely because increasing the K rate to 80 lbs K_2O/acre rate stimulated growth and yielded about 0.7 ton/acre more and potassium remaining in the roots (Figure 11). This data would suggest that a potassium tissue recommendation of greater than **2.4% potassium for the whole plant at second cut** when harvested at mid-bud would optimize income after fertilizer expense. Again, yields appear to increase with higher rates paying for the fertilizer but no increase in income but would be dependent on hay prices and assuming fertilizer price is at or near $0.36/lb K_2O.

Even applying 320 lbs of K_2O per acre in this soil where the field in the 80 – 90 ppm range in 2019 did not make up for the 616 lbs/acre of K_2O removed from the soil in the hay from a 10.4 ton yield (Table 6). This soil test in 2019 shows a decline of 8 ppm even from the first year of this experiment when only 3 cuttings were made in this spring planting (Table 7). We take soil samples from the same time each year to avoid seasonal variations in nutrient availability if possible.

Just as in the phosphorus experiment, the largest yield increase from adding potassium was found in the first cutting when soil temperatures are the coldest, thus reducing availability (Figure 13). Relative feed value (RFV) increased from 170 to 220 units in the first cutting by adding 320 lbs of K_2O per acre (Figure 14). There was a jump in RFV at first cutting after increasing potassium rate to 240 lbs of K_2O/acre or more, which was greater increase than at any other cutting. Most of the nutrient value of the alfalfa comes from energy and protein which comprises about $100 acre each (Figure 15). Errors in valuing hay comes when you only look at the energy component of the hay. The total value of the hay ranged from $273 to $291 averaged over all cuttings in this experiment. This is much higher than producers typically get, which shows alfalfa hay is undervalued to the dairyman. Although RFV followed total nutrient value as potassium rate increased, calculating total nutrient value gives what the current hay is worth (Figure 16). In this study a 179 RFV hay was worth $273 worth of protein, energy, fiber, and adjusting for fiber fill to the dairy cow. Hay with a RFV of 192 was worth $291 per ton in nutrients.

Increasing potassium at the optimum economic rate (80 lbs/a K_2O) in this experiment increased crude protein by 1.4%, decreased fat content by 0.12%, increased starch content by 0.18%, and NEL (energy content) was not significantly changed (Table 8). Protein and NEL have similar responses averaged over the year (data not shown) as does aNDF and lignin content with increasing potassium content.

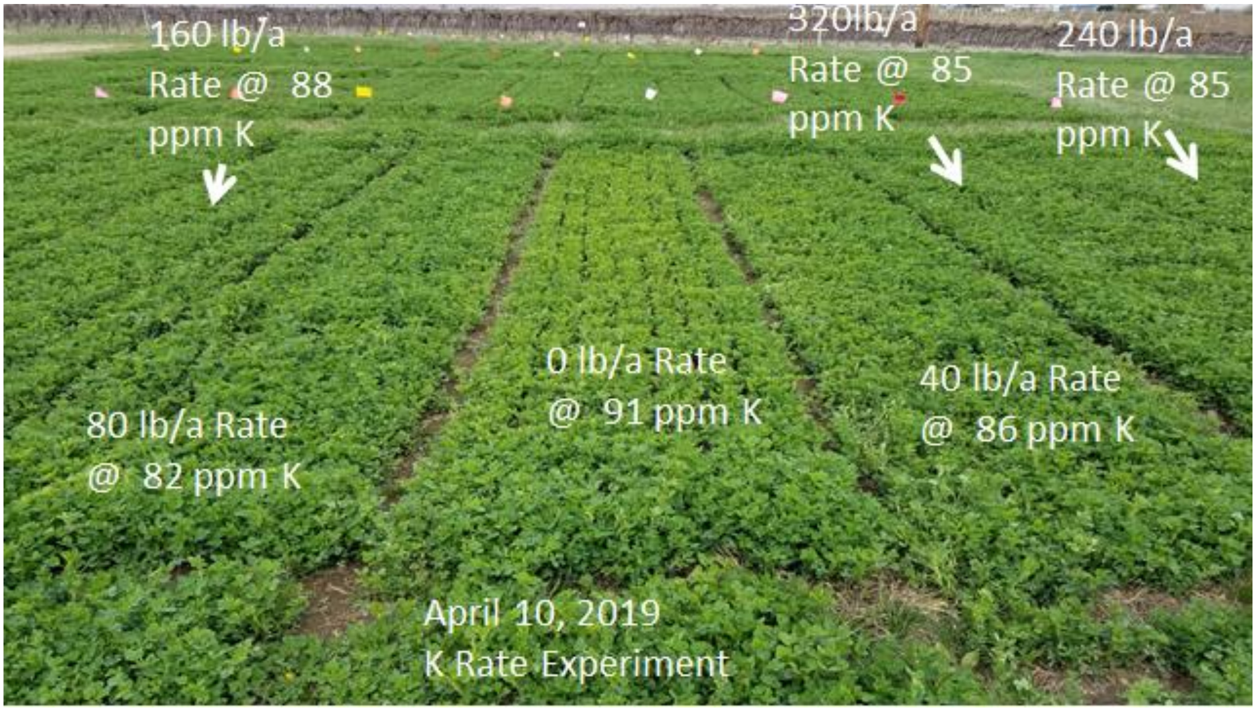

Figure 8a (top) and 8b (bottom). Figure 8a shows potassium deficiency by treatment as it appeared as a light coloring from a distance on April 10th. The soil tests results for each plot taken are shown with the

0 rate showing the worst signs at a soil test of 91 ppm K. Figure 8b shows the close up view of potassium deficiency in the leaf almost reaching the mid-rib of the leaflet.

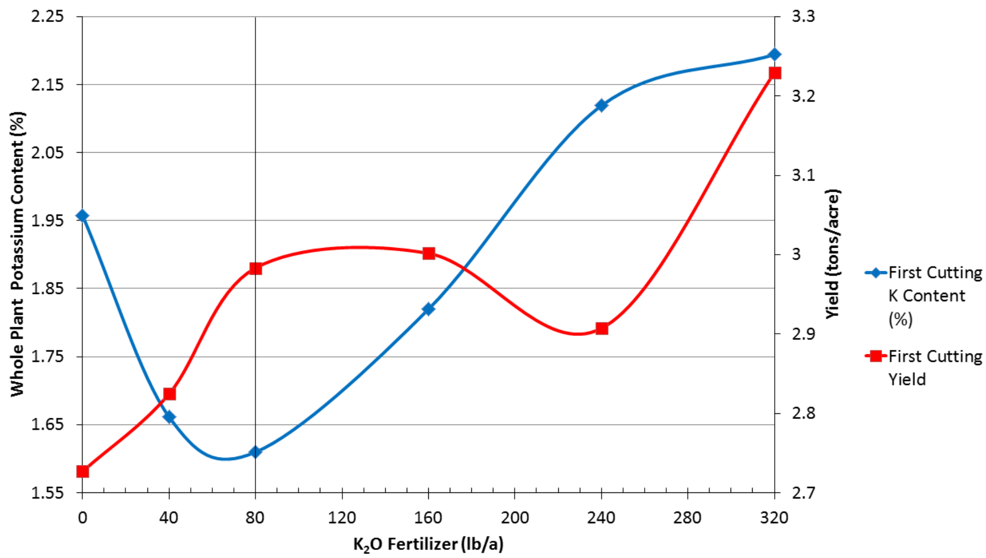

Figure 9. Influence of rate of K_2O on first cutting yield and potassium content, in 2019 near Prosser, WA.

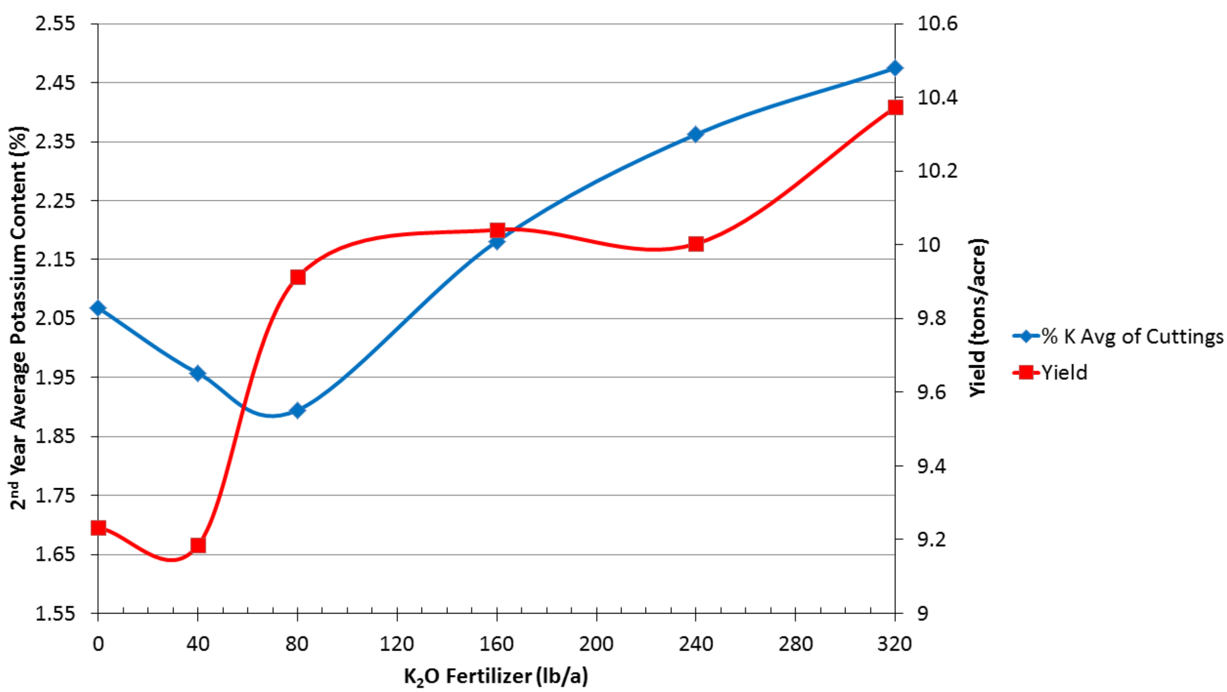

Figure 10. In 2019, the influence of rate of K_2O on total yield and average potassium content over all five cuttings near Prosser, WA.

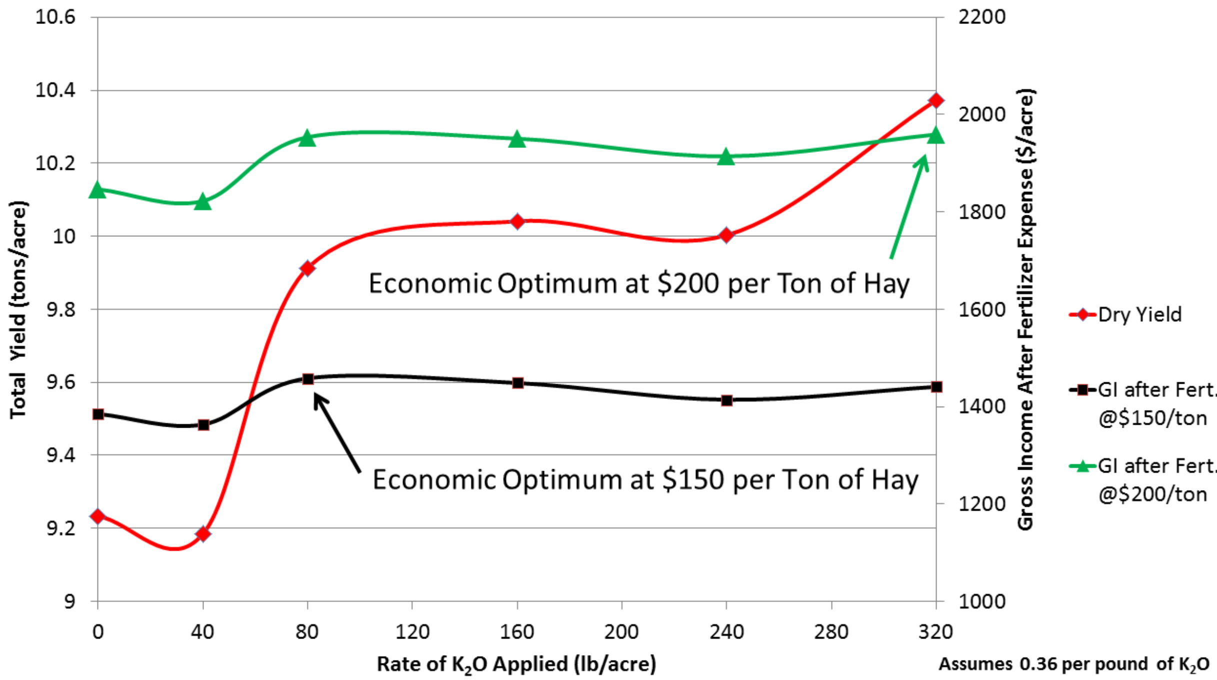

Figure 11. In 2019 near Prosser, WA, total yield and gross income assuming hay prices at $150 and $200 /ton minus fertilizer expenses at $0.36 /lb of K_2O applied in the spring.

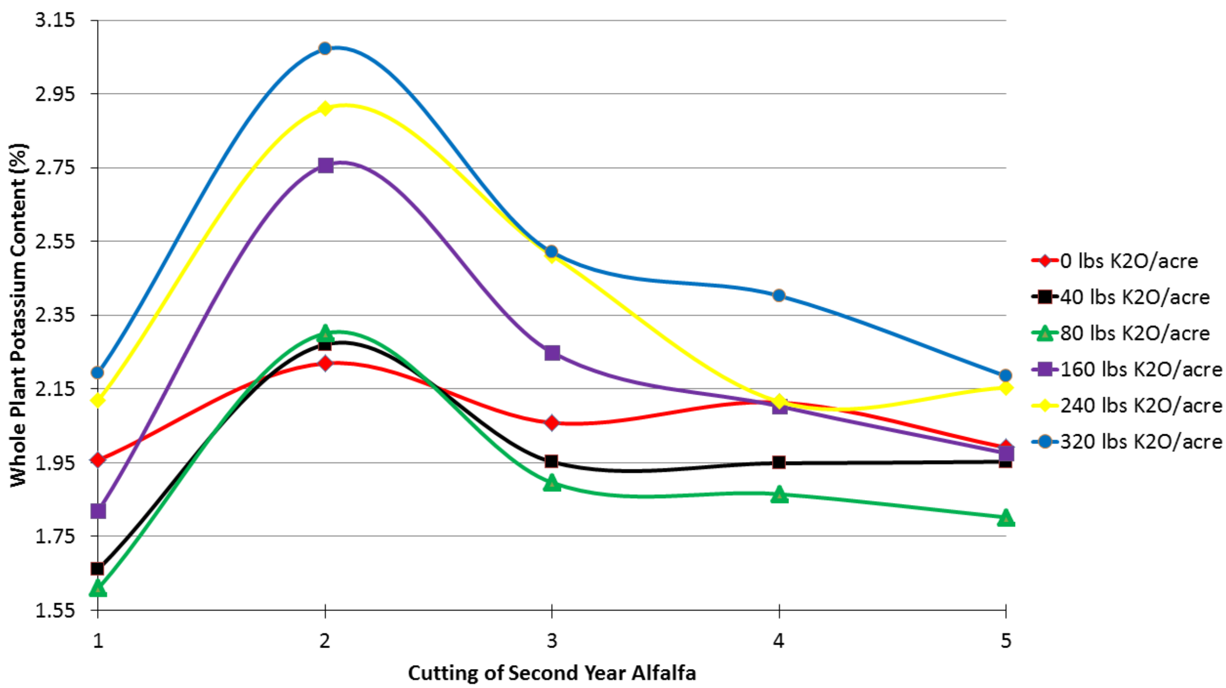

Figure 12. 2019 Tissue K Concentration at Harvest by Cutting and Rate after Spring Applications of K_2O (lbs/acre). Potassium tissue recommendation is >2.35% potassium for the whole plant at second cut when harvested at mid-bud.

Table 6. Rate of K_2O/acre influence on yield, whole plant K (%), K removed (lbs/acre), and K_2O removed (lbs/acre) in second year alfalfa during the 2019 summer season, near Prosser, WA.

K_2O Rate (lbs/acre)	K Rate Applied (lbs/acre)	Yield (tons/ acre)	Whole Plant K (%)	# of K Removed (lbs/acre)	K_2O Removed (lbs/acre)
0	0.0	9.2	2.1	382	458
40	33.3	9.2	2.0	360	432
80	66.7	9.9	1.9	376	451
160	133.3	10.0	2.2	438	526
240	200.0	10.0	2.4	473	567
320	266.7	10.4	2.5	514	616

Table 7. Soil test values from spring soil tests in 2018 and 2019 and the amount of K_2O removed (lbs/acre) in 2018 and 2019, near Prosser, WA.

K_2O Rate (lbs/a)	Soil Test K 2018 (ppm)	Soil Test K 2019 (ppm)	2018 K_2O Removed (lbs/a)	2019 K_2O Removed (lbs/a)
0	106.8	90.5	196	458
40	104.3	85.8	212	432
80	87.0	82.3	214	451
160	106.0	88.0	239	526
240	106.3	85.0	308	567
320	92.8	84.8	300	616

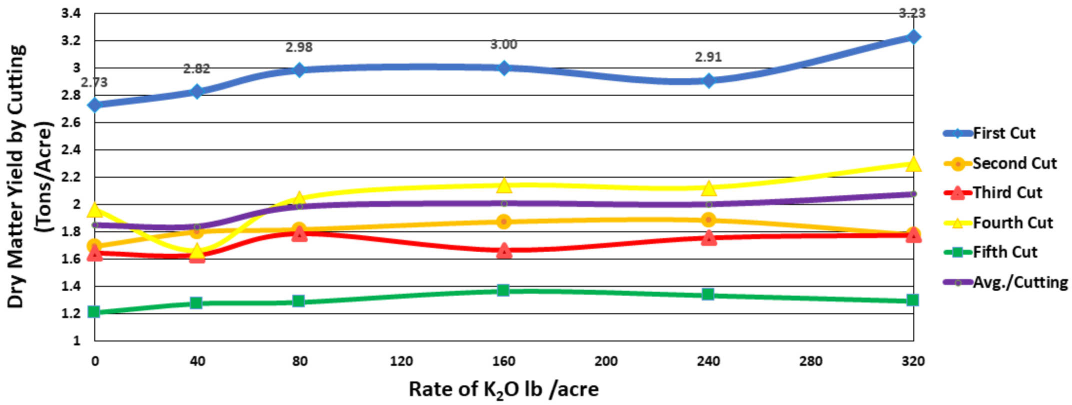

Figure 13. Yield at 100% dry matter as influenced by potassium rate and cutting at Prosser, WA in 2019.

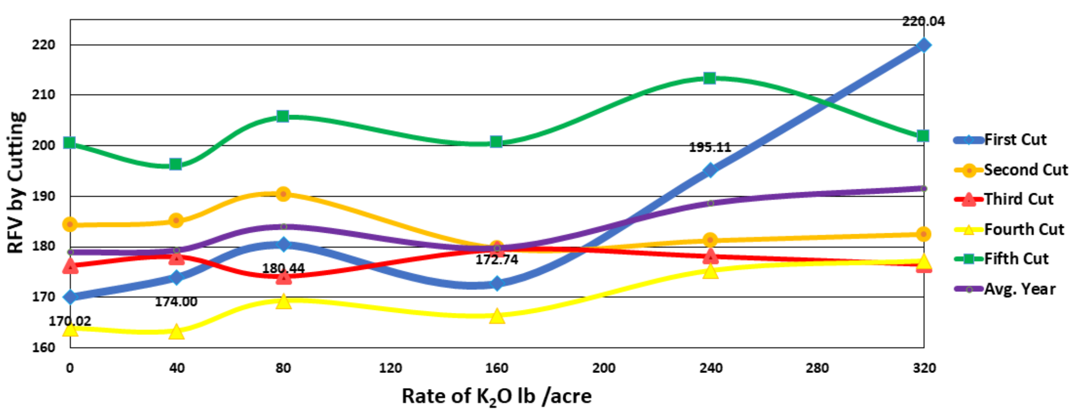

Figure 14. Relative feed quality as influenced by potassium rate and cutting at Prosser, WA in 2019.

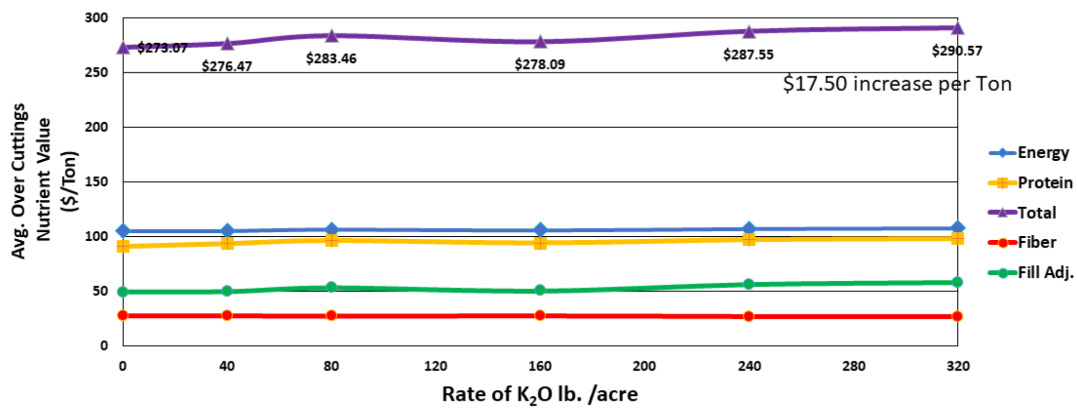

Figure 15. Nutrient value averaged over cuttings as influenced by potassium rate and cutting at Prosser, WA in 2019.

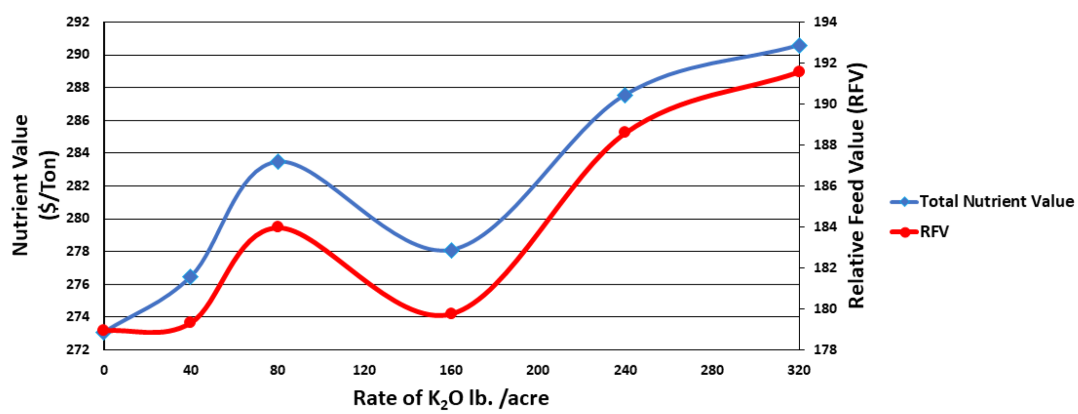

Figure 16. Relative feed value and total nutrient value averaged over cuttings as influenced by potassium rate and cutting at Prosser, WA in 2019.

Table 8. Crude Protein, fat, starch, net energy for lactation (NEL) of alfalfa as influenced by potassium rate near Prosser, WA in 2019.

Rate	Crude Protein[1]		Fat[1]		Starch[1]		NEL[1]	
lb. K_2O/acre	%		%		%		Mcal / lb.	
0	21.37	c	2.15	a	3.60	b	0.6052	c
40	22.03	bc	2.07	bc	3.62	b	0.6066	bc
80	22.73	ab	2.03	c	3.78	a	0.6129	abc
160	22.20	ab	2.02	c	3.84	a	0.6093	bc
240	22.95	a	2.07	b	3.82	a	0.6160	ab
320	23.16	a	2.10	ab	3.71	ab	0.6191	a
C.V.	5.1		4.8		6.0		2.5	
Anova Rate P>F =	<.0001		0.0018		0.0018		0.0303	
Contrast Rate Linear P>F =	0.0003		0.0712		0.0005		0.0288	
Contrast Rate Quadratic P>F =	NS		0.0003		0.0132		NS	

[1] Rates within the same column with different letters are significantly different. NS= Not Significant

Table 9. The influence of the interaction of cutting and potassium rate on: aNDF content, ash content, lignin content, NDF digestibility at 48 hours and relative feed quality in alfalfa at Prosser, WA in 2019.

Cutting	Rate	aNDF	Ash	Lignin	NDFD48	RFQ
	lb. K_2O/acre	%	%	%	%	%
1	0	35.74	10.53	6.23	44.73	182
1	40	35.08	10.21	6.12	44.70	187
1	80	34.08	11.39	5.84	45.35	196
1	160	35.37	10.64	6.17	45.00	186
1	240	32.00	11.86	5.51	48.22	220
1	320	29.21	12.03	5.07	51.20	255
2	0	33.29	11.75	5.43	47.51	207
2	40	33.23	11.59	5.38	47.79	209
2	80	32.43	11.61	5.29	48.87	217
2	160	33.83	11.79	5.45	48.67	206
2	240	33.56	11.63	5.40	48.59	208
2	320	33.42	11.74	5.33	49.70	212
3	0	34.29	11.23	5.78	44.32	191
3	40	34.00	11.42	5.74	43.89	192
3	80	34.50	10.78	5.88	43.06	186
3	160	33.76	10.93	5.70	44.99	196
3	240	33.91	11.27	5.71	44.58	194
3	320	34.09	11.35	5.68	43.98	191
4	0	36.23	12.25	6.08	44.46	178
4	40	36.27	12.28	6.13	43.74	175
4	80	35.28	12.17	5.95	44.16	183
4	160	35.74	11.62	6.01	43.78	179
4	240	34.60	12.04	5.91	45.49	193
4	320	34.18	12.47	5.69	46.98	199
5	0	31.01	11.12	5.39	47.21	227
5	40	31.55	11.50	5.42	47.13	222
5	80	30.34	11.08	5.29	47.39	233
5	160	30.92	11.08	5.36	47.69	229
5	240	29.43	11.40	5.09	48.42	245
5	320	30.70	11.28	5.28	47.46	229
	C.V.	5.2	4.4	5.7	3.7	8.8
	Mean	33.40	11.47	5.64	46.30	204.00
	Anova Rate PR>F =[1]	0.0044	0.0099	0.0018	<.0001	0.0009
	Anova Cutting*Rate PR>F =	0.0554	0.0069	NS	0.0333	0.0182
	Contrast Linear Rate PR>F=[1]	0.0128	NS	0.0132	0.0021	0.0057
	Contrast Quadratic Rate PR>F=[1]	NS	0.0732	NS	NS	NS

[1]Since the Cutting*Rate interaction is significant these probability results must be looked at with extreme caution.

Struvite Study:

Results and Discussion

All treatments except the unfertilized check received different ratios of MAP:struvite equaling 100% of a constant rate (144 lbs P_2O_5/acre), as determined by the soil test. The unfertilized check yielded as much as 1 ton DM per acre less than the highest yielding treatment showing the need for phosphorus (Figure 17). Replacing MAP (100:0) with struvite (0:100) did not affect alfalfa yield, with total yield ranging from 9.80 to 10.34 tons DM/acre in the second year for alfalfa that received phosphorus application (Figure 17). The greatest numeric yields were produced by treatments comprised with 50% (50:50) and 75% struvite (25:75), at 10.31 and 10.34 tons/acre, respectively. However, phosphorus source did have a significant effect on average tissue P content at harvest averaged across all cuttings ($P < 0.01$; Figure 18), but not at first cutting ($P > 0.05$; Figure 19). Phosphorus source also influenced total P uptake across the growing season ($P < 0.01$; Figure 18). Alfalfa fertilized with mixtures of MAP and struvite had significantly greater P uptake ($P < 0.01$) and tissue P content ($P < 0.001$) at harvest than plants fertilized with MAP or struvite alone (Figure 18). For example, including struvite as 50-75% of the P source increased P uptake by 6-10 lbs P/acre across all 5 cuttings compared to alfalfa fertilized with 100% MAP. The treatment with struvite as 75% of the P source produced the greatest tissue P concentration at all cuttings but one (3^{rd} cut; Figure 19), averaging 0.395% per cutting; also, it produced the greatest total P uptake of 81 lbs P/acre across all 5 cuttings (Figure 18). Fertilizing with 100% MAP resulted in the lowest tissue P concentration among P fertilized treatments for 2^{nd} through 5^{th} cuts (Figure 19). Phosphorus source and concentration of P in the plant did not influence maturity of the stand at harvest (data not shown). Also, the ratio of MAP:Struvite did not influence any nutrient quality parameter studied. All the parameters studied in the previous two experiments (Phosphorus and Potassium) were also studied in this experiment.

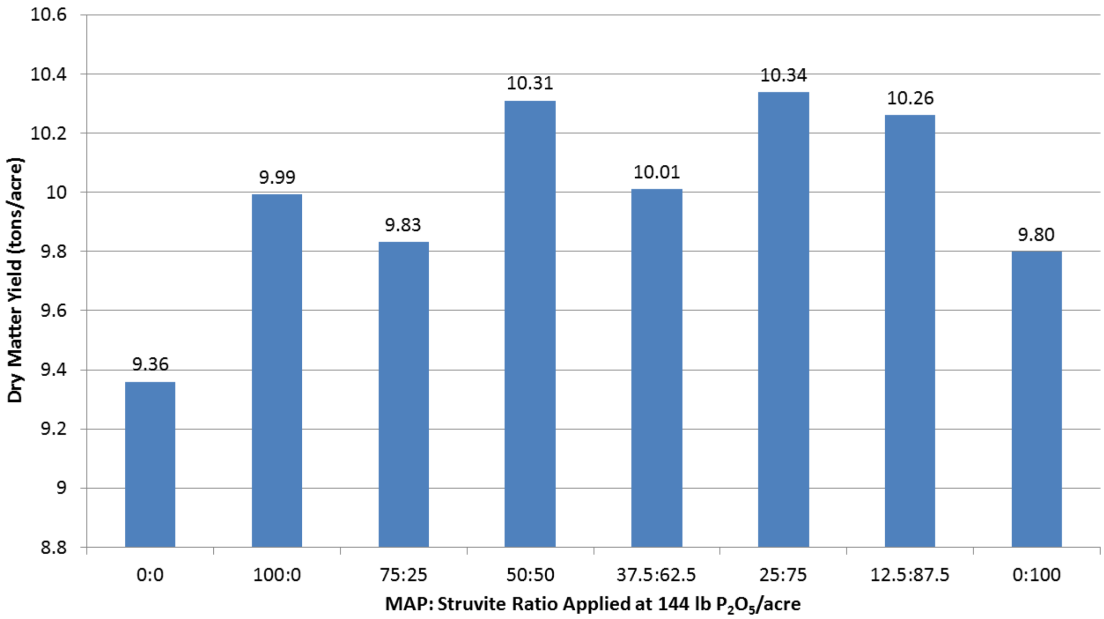

Figure 17. Influence of monoammonium phosphate (MAP) to struvite ratio at 144 lb P_2O_5 /acre on total yield from all 5 cuttings of second year alfalfa. Legend 0:0 is the unfertilized check. Contrast: unfertilized check (0:0) vs all combinations of MAP:Struvite P>F= 0.0091 and Contrast Struvite rate linear=0.6751.

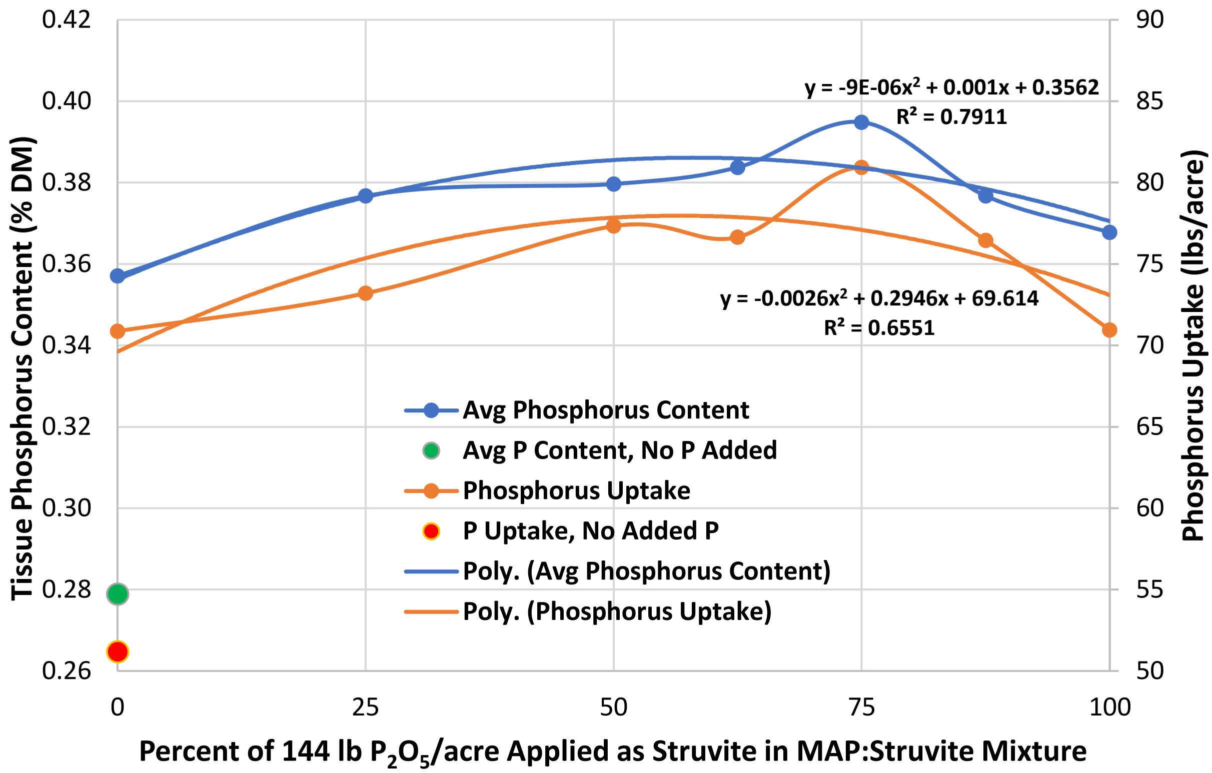

Figure 18. Influence of monoammonium phosphate (MAP) to struvite ratio at 144 lbs P_2O_5 /acre on total phosphorus uptake from all 5 cuttings in second year alfalfa and on average whole-plant phosphorus tissue content at harvest. No added P represents 0:0 unfertilized check, whereas 0% struvite on the x-axis represents 100% MAP (100:0). Contrast: Struvite ratio in the mixture quadratic impact of phosphorus content in plant tissue quadratic PR>F 0.003; Struvite ratio in the mixture quadratic impact on phosphorus uptake PR>F 0.0009.

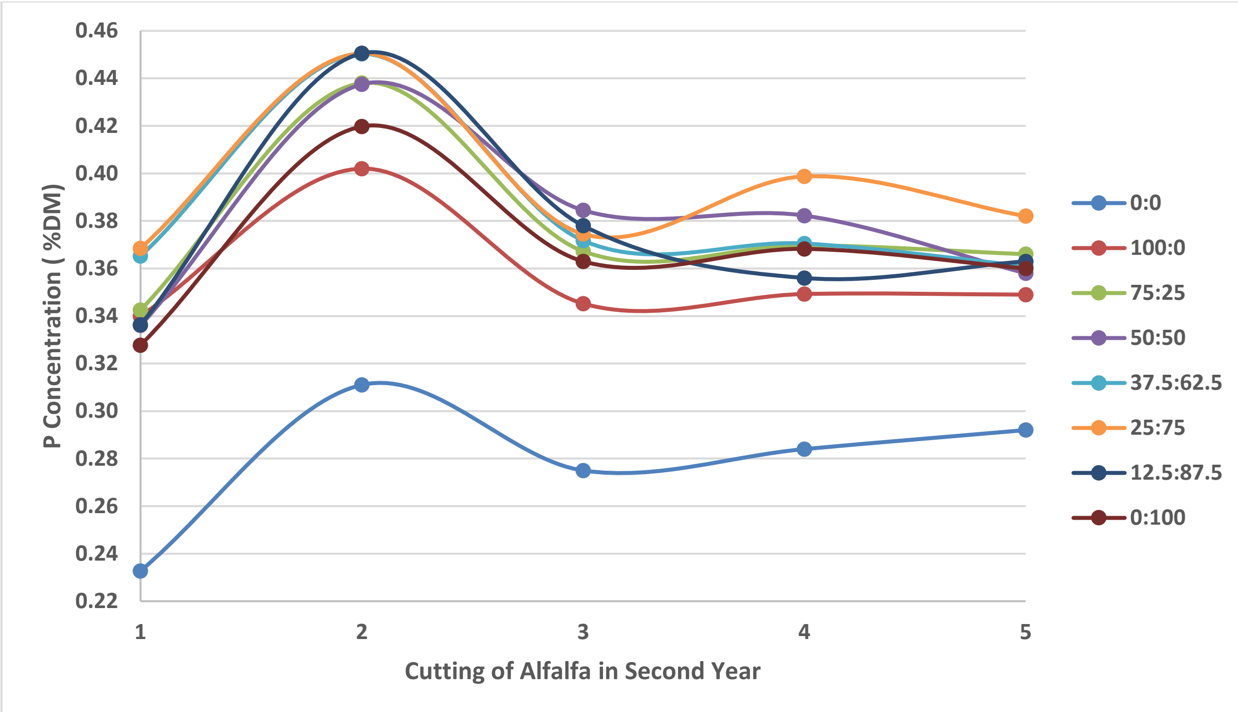

Figure 19. In second year alfalfa in 2019, phosphorus content of harvested tissue by cutting and monoammonium phosphate (MAP) to struvite ratio at 144 lbs P_2O_5 /acre. Legend, first number is monoammonium phosphate the second number is struvite. Legend 0:0 is the unfertilized check.

Management Recommendations/Conclusions From The Second Year:

- Phosphorus and potassium needs are greater in the second production year, thus % P should be greater. For second year alfalfa, optimum P alfalfa tissue phosphorus content and current yields should be based on hay price and cutting at mid-bud stage. For $150/ton hay, P contents of: 0.34, 0.40, 0.36, 0.34, 0.32 for cuttings one, two, three, four and five, respectively. For $200/ton hay, P contents of 0.35, 0.41, 0.37, 0.34, 0.32 % for cuttings one, two, three, four and five, respectively.
- The second harvest is the ideal time to test for potassium based on our data. For mid-bud harvests, K content of hay should be >2.4% K when hay price is $150/ton. Alfalfa yield may continue to increase, paying for additional K fertilizer, if hay price is at $200/ton or more.
- First and second year data show that struvite can be used alone or in combination with monoammonium phosphate (MAP) without a yield loss even on a soil averaging 8.1 ppm (Olsen method).

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Keywords: Alfalfa, Phosphorus, Potassium, Struvite, Yield, Hay Quality