# PHOSPHORUS AND POTASSIUM: HOW LOW CAN YOU GO IN ALFALFA

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**Abstract**

Tissues testing whole alfalfa plants at harvest may 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. Two experiments were designed as follows: 1) Phosphorus (P) Rate study with differing rates of $P_2O_5$ using monoammonium phosphate (MAP); including: 0, 30, 60, 120, 240 lb $P_2O_5$ acre$^{-1}$ on a low testing P soil <10 ppm (Olsen P method); 2) Potassium (K) Rate study with differing rates of $K_2O$ using potassium sulfate: 0, 40, 80, 160, 240, 320 lb $K_2O$ acre$^{-1}$ on an <100 ppm K soil (ammonium acetate method). The following is summation of the three years of results harvested at mid-bud stage for all cuttings on the same field. Increasing P rate from 0 to 240 lb $P_2O_5$ acre$^{-1}$ increased yield by 0.9, 1.5 and 1.6 tons acre$^{-1}$ in 2018, 2019 and 2020, respectively (Figure 1.) Yield increase of treatments in the first cutting peaked at 120 lb $P_2O_5$ acre$^{-1}$ in 2018 and 2019 but in 2020 the 240 lb $P_2O_5$ acre$^{-1}$ was the highest yielding treatment. Optimum economic $P_2O_5$ rates were 140, 150, 150 lb $P_2O_5$ acre$^{-1}$ for \$150 ton$^{-1}$ hay in 2018, 2019, and 2020 respectively. For \$200 ton hay, regression showed the 160 lb $P_2O_5$ acre$^{-1}$ maximized gross income after fertilizer costs for all three years. Averaged over years, the whole plant tissue level at the economic optimum was 0.355 and 0.36% at mid-bud stage for 150 and \$200 ton$^{-1}$ of hay, respectively. No potassium first cutting or total cutting yield response was found in the first year (2018) but in years two and three (2019 & 2020) alfalfa hay yield response to K was significant (1.14 and 1.26 tons lb $K_2O$ acre$^{-1)}$. About 80% of total seasonal yield increased occurred in the first and second cuttings. Optimum K rate that optimized economic return after fertilizer costs varied considerably from year to year. When hay prices are \$150 ton$^{-1}$ optimum K rates were 80 and 220 lb $K_2O$ acre$^{-1}$ for 2019 and 2020, respectively. Increasing the hay price to \$200 ton$^{-1}$ the optimum rates were 320 and 240 lb $K_2O$ acre$^{-1}$ for 2019 and 2020, respectively. Optimum P content was consistent over both years at 0.36%, however, K content varied widely between years and in low testing soils whole plant tissue testing appears to be problematic.

**Introduction:**

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 developed alfalfa tissue testing protocols, but producers are reluctant to adopt because the test demands the middle third of alfalfa of the plant at one-tenth bloom for P & K (Meyer et al., 2007). One-tenth bloom is well past dairy quality hay for most PNW producers, making this 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). 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. 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 is most desired by the dairy industry and most likely to be nutrient limiting due to growth in cold soils.

This research was funded all three years by National Alfalfa and Forage Alliance (NAFA) and was conducted near Prosser, Washington, on a low phosphorus soil at 5.4 ppm (Olsen et al., 1954) for the phosphorus study and 79 ppm potassium soil (ammonium acetate method). Our Objectives included: 1) Develop economic critical phosphorus and potassium tissue contents for bud stage alfalfa using tissue testing for maximum profit, yield.

**Materials and Methods:**

The P experiment occurred in a low P soil test field (< 10 ppm P), and the K experiment on a low K soil test field (< 100 ppm K). Studies were in a randomized complete block design with four replications at establishment of a spring alfalfa stand and harvested three 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 Study" – What do $P_2O_5$ rates from MAP applied at 0, 30, 60, 120, 240 lb $P_2O_5$/acre have on the on refining tissue testing recommendations for P.

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

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.

**Results and Discussion – Phosphorus Study**

The field selected for this work had been in switchgrass for over 5 years with no fertility put back in the field and resulted in soil test of 8 ppm P (Olsen) and 101 ppm K (Ammonium Acetate). Visually the 0, 30, and 60 lb $P_2O_5$/acre plots had stunted growth going into the 2$^{nd}$ and

3rd spring of the 3-year study. No leaflet symptoms were present. Increasing P rate from 0 to 240 lb $P_2O_5$ acre$^{-1}$ increased yield by 0.9, 1.5 and 1.6 tons acre$^{-1}$ in 2018, 2019 and 2020, respectively (Figure 1.). In 2020, yield response to P was mostly in the first and second cuttings and averaged over rates made up 79% of the total increase in yield. Yield increases of treatments in the first cutting peaked at 120 lb $P_2O_5$ acre$^{-1}$ in 2018 and 2019 but in 2020 the 240 lb $P_2O_5$ acre$^{-1}$ was the highest yielding treatment. Since MAP was used in this study some nitrogen would be applied, however research has found that late season harvests are most likely to have a N response (Raun et al. 1999) and only 19% of the total yield increase in this experiment was from cuttings 3, 4 and 5.

By-harvest dry matter yield increases due to applied N were only found in late-season harvests, consistent with late-season decreased N2-fixing capacity in alfalfa documented by others.

Gross income after fertilizer expenses were calculated using regression to determine optimum fertilizer rates for the study using two prices of hay \$150 and \$200 ton$^{-1}$ of hay and a $P_2O_5$ price of 0.538 lb$^{-1}$. Optimum economic $P_2O_5$ rates were 140, 150, 150 lb $P_2O_5$ acre$^{-1}$ for \$150 ton$^{-1}$ hay in 2018, 2019, and 2020 respectively. For \$200 per ton hay, regression showed that 160 lb $P_2O_5$ acre$^{-1}$ maximized gross income after fertilizer costs for all three years. Averaged over years, the whole plant tissue level at the economic optimum was 0.355 and 0.36% at mid-bud stage for 150 and \$200 ton$^{-1}$ of hay, respectively.

When tissue testing the stage of maturity and what part of the plant is being tested both must be considered when selecting a critical level. Our experimental results indicate the optimum level of P in the plant is higher than previously published (Meyer et al., 2008, Koenig et al., 2009). Our results indicate that even which cutting tested can affect the P tissue testing results (Figure 2). Koenig et al., 2009 recommends 0.2 - 0.25% P at first flower using the whole plant and Meyer et al., 2008 recommends 0.26 - 0.28% P for whole plant tissue at bud stage or early bud stage, respectively. In 2019, on our very low P soil with no P reached 0.26% at the second cutting (Figure 2). Interestingly, the soil level test levels continued to drop at all P rates (Table 1) except for the 120 and 240 $P_2O_5$ lb a$^{-1}$ rates in 2018 which only had 3 cuttings in the first year as it was a spring planting. Crops seasons 2019 and 2020 each had five cuttings.

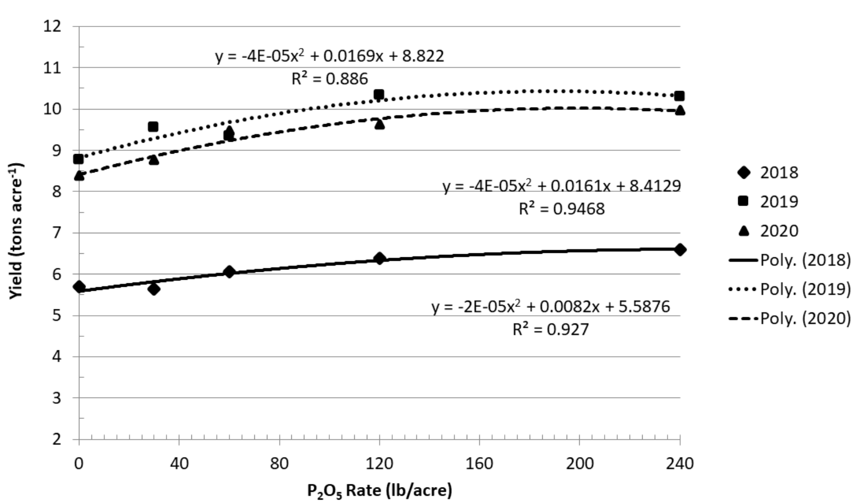


Figure 1. Influence of phosphorus fertilizer rate on total yield in 2018-2020 at Prosser, WA.

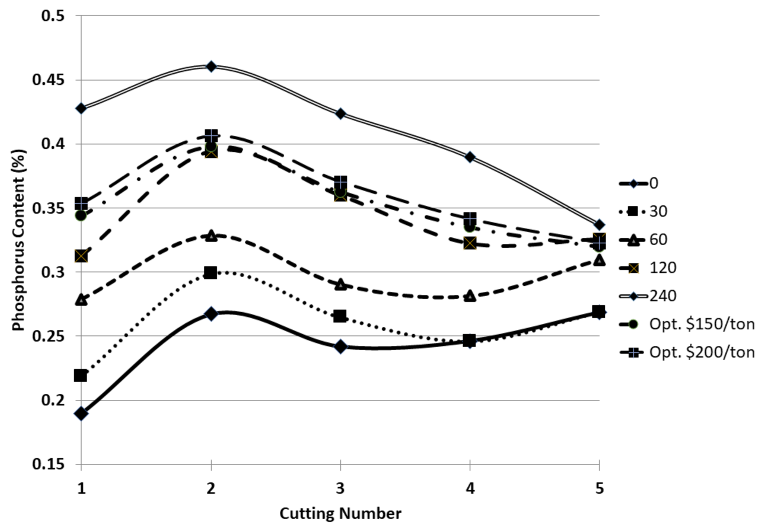


Figure 2. Influence of rate of P2O5 fertilizer and cutting on phosphorus content (%) in 2019. Economic optimum phosphorus content by cutting is given when hay is \$150 or \$200 ton$^{-1}$.

Table 1. Soil test values, application rates and removal rates of P2O5 for crop years 2018 to 2020 at Prosser, WA. Soil test in 2017 was taken just prior to the experiment.

| $P_2O_5$ Rate Applied | Total Applied in 3 Years | Total # of Removed in 3 Years | Fall Soil Test P 2017 | Fall Soil Test P 2018 | Fall Soil Test P 2019 | Fall Soil Test P 2020 |
|---|---|---|---|---|---|---|
| ($P_2O_5$ lb a$^{-1}$) | ($P_2O_5$ lb a$^{-1}$) | ($P_2O_5$ lb a$^{-1}$) | (ppm) | (ppm) | (ppm) | (ppm) |
| 0 | 0 | 228 | 8.4 | 4.5 | 4.3 | 5.5 |
| 30 | 90 | 265 | 8.6 | 6.0 | 5.8 | 4.8 |
| 60 | 180 | 293 | 7.9 | 5.5 | 4.0 | 3.3 |
| 120 | 360 | 382 | 7.6 | 7.8 | 6.3 | 6.0 |
| 240 | 720 | 455 | 9.1 | 9.7 | 8.3 | 7.5 |

**Potassium Rate Experiment:**

The first year of the potassium study (2018) no response to potassium fertilizer was found in the first cutting or total yield for the year. The study was planted in 2018 so only 3 cuttings were harvested. Like the phosphorus study, the K level in 2018 soil was low at 101 ppm yet only a 0.18 ton acre$^{-1}$ increase occurred by increasing K rate from 0 to 320 lb $K_2O$ acre$^{-1}$ (Figure 2). The beginning soil test for sulfur was 13, 13, 17 ppm so any additional sulfur from potassium sulfate should have had minor to no increases in yield in the experiment and not continue up to 108 lb acre$^{-1}$ sulfur per acre which is in the 320 lb acre$^{-1}$ rate of potassium sulfate. In years two and three (2019 & 2020) the response to K was significant at 1.14 and 1.26 tons lb $K_2O$ acre$^{-1}$. Except for the 40 lb $K_2O$ acre$^{-1}$ rate, most of the yield increase (80%) occurred in the first and second cuttings. Virtually no yield increase occurred in the 3$^{rd}$ cutting compared to the control at any of the rates. Optimum K rate that optimized economic return after fertilizer costs varied considerably from year to year. In 2018, the lack of yield response put the economic optimum as no application. However, in the following spring the control plots had significant visual potassium deficiency symptoms. When hay prices are \$150 ton$^{-1}$ optimum rates were 80 and 220 lb $K_2O$ acre$^{-1}$ for 2019 and 2020, respectively. However, when hay prices are \$200 ton$^{-1}$ the gross income after K fertilizer costs was similar across a wide range of K rates and was \$1,847, \$1,813, \$1,944, \$1,941, \$1,905, \$1,950 for 0, 40, 80, 160, 240, 320, lb $K_2O$ acre$^{-1}$ rates, respectively. These results give a wide range of K rates for producers to choose but 320 lb acre$^{-1}$ rate was the maximum in 2019. In 2020, the optimum K rate was 240 lb $K_2O$ acre$^{-1}$, but again a wide range of rates could be chosen with 160 and 320 lb $K_2O$ acre$^{-1}$ rate being within \$15 and \$4 acre$^{-1}$ gross return after K application, respectively. Soil test K in hay fields have been decreasing and this experiment was no different, even at the highest K rate, dropping from 93 ppm K at the beginning of the experiment to 78 ppm K after 3 years of alfalfa (Table 2.). At the 320 lb $K_2O$ acre$^{-1}$ rate after converting K in plant tissue to lb $K_2O$ acre$^{-1}$, 1,298 was removed in hay and only 960 applied leaving a 338 lb $K_2O$ acre$^{-1}$ deficit. It seems impossible in this situation to determine an optimum %K content across years and cuttings, probably due to dilution of K with increases in yield and relatively high content in the plant. In 2019 and 2020 many of the K application rates had a lower K content than the control and K content differences between cuttings (Figure 2, Figure 3.). The year affect is significant (Figure 5.) Why 2020 did not take up as much is in 2019 a good question, but it was likely do to the dropping soil test results of averaging across treatments 80 ppm K in the soil at the beginning of 2020 and 60 ppm at the end of 2020 (Table 2). Current recommendations are 1.2 – 1.5% K being adequate (Meyer et al., 2008) for baled mid-bud hay, and 2 – 2.5% for whole tops at first flower (Koenig et al., 2009). Under this low K testing field tissue testing may not be the best choice for even determining sufficiency. Although K content did not increase much the amount taken up by the crop did increase by 104, 158, and 46 lb K acre$^{-1}$ for 2018, 2019 and 2020 years, respectively. Why 2020 did not take up as much is in 2019 a good question, but it was likely do to the 80 ppm K in the soil that K was tied up in the soil.

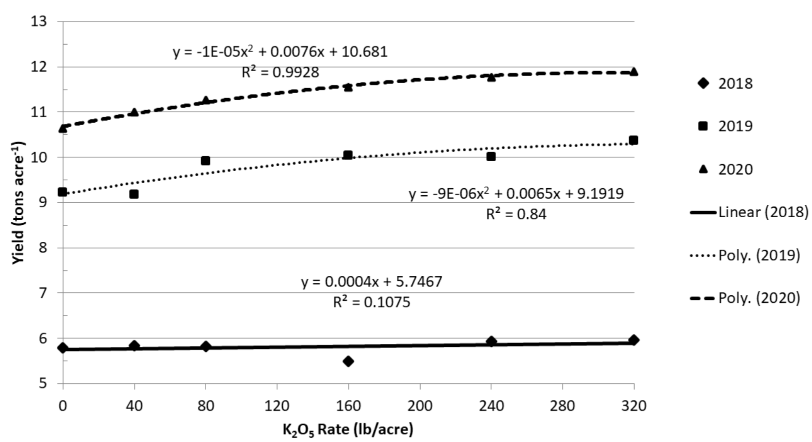


Figure 2. Influence of potassium fertilizer rate on total yield in 2018-2020 at Prosser, WA.

Table 2. Soil test values, application rates and removal rates of $K_2O$ for crop years 2018 to 2020 at Prosser, WA. Soil test in spring of 2018 was taken just prior to the experiment.

| $K_2O$ Rate Applied | Spring Soil Test K 2018 | Spring Soil Test K 2019 | Spring Soil Test K 2020 | Fall Soil Test K 2020 | 2018 $K_2O$ Removed | 2019 $K_2O$ Removed | 2020 $K_2O$ Removed |
|---|---|---|---|---|---|---|---|
| lb $K_2O$ $a^{-1}$ | ------------------------ppm------------------------ | | | | -------------lb $K_2O$ $acre^{-1}$----------- | | |
| 0 | 106.8 | 90.5 | 79.0 | 67.3 | 196.1 | 458.3 | 334.9 |
| 40 | 104.3 | 85.8 | 69.0 | 54.5 | 212.1 | 431.5 | 316.1 |
| 80 | 87.0 | 82.3 | 82.8 | 53.3 | 213.5 | 450.8 | 302.6 |
| 160 | 106.0 | 88.0 | 83.0 | 64.0 | 239.3 | 525.6 | 334.8 |
| 240 | 106.3 | 85.0 | 83.5 | 54.3 | 308.4 | 567.2 | 369.0 |
| 320 | 92.8 | 84.8 | 78.3 | 62.0 | 300.2 | 616.1 | 381.2 |

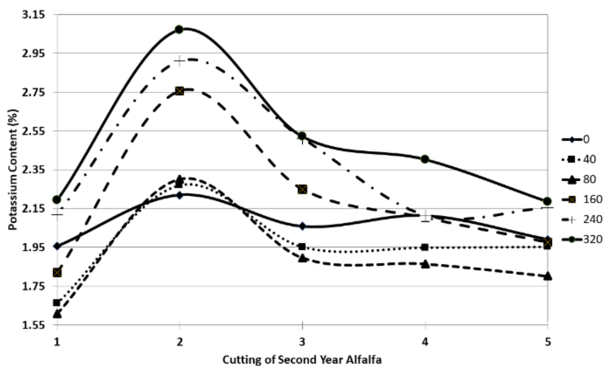


Figure 3. Potassium content of alfalfa as influenced by cutting and rate of $K_2O$ $acre^{-1}$ in 2019 at Prosser, WA.

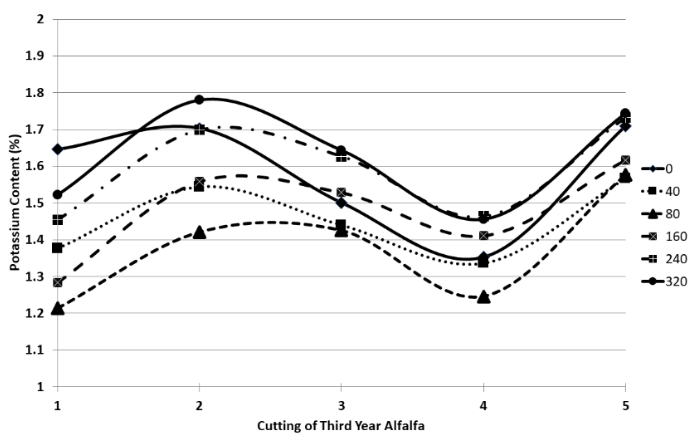


Figure 4. Potassium content of alfalfa as influenced by cutting and rate of $K_2O$ $acre^{-1}$ in 2020 at Prosser, WA.

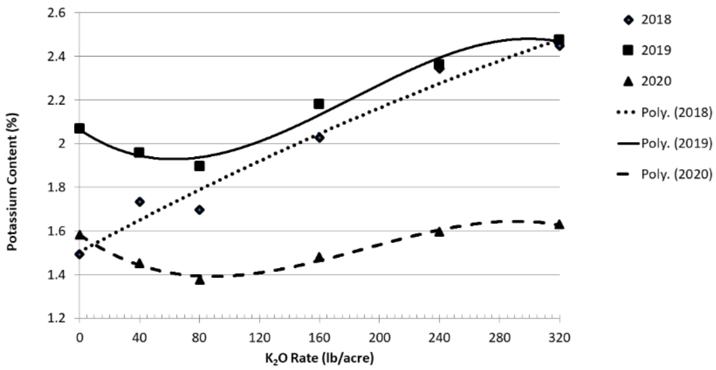


Figure 5. Potassium content of alfalfa as influenced by year and potassium rate applied to alfalfa near Prosser, WA from 2018-2020.

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