Management of Phosphorus and Potassium Fertilization in Alfalfa[1]

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INTRODUCTION

Alfalfa (*Medicago sativa* L.) represents a significant component of California's fertilizer footprint, especially for potassium and phosphorus due to its acreage and uptake levels. Greater than 800,000 acres of alfalfa were grown in California in 2017, producing 5.35 million tons of hay and haylage, largest of any state in the US. It is the most critical feed for the state's #1 agricultural enterprise, dairy. Yields in California are among the highest in the US – mostly averaging 6 to 9 tons/acre, but ranging from 4 to 15 tons/acre depending upon location (statewide average is 6.7 t/a = 15 MT/ha, USDA-NASS, 2017).

Figure 1. Strip without fertilizer indicates yield response to P. It's always useful to include non-fertilized controls to determine whether a fertilizer application is effective. Photo: Intermountain region.

Phosphorus (P) is typically the most limiting fertility factor for alfalfa in California (Figure 1), followed by potassium (K). The high yields of alfalfa have important implications for nutrient management (Table 1). Since the entire above-ground crop is harvested, soils may become deficient after several years of production, unlike grains or fruits when only a portion of the crop is removed.

Nitrogen. While alfalfa also has very high levels of nitrogen uptake, it is also a vigorous N_2 fixer (biological), and so normally N is not considered a limiting

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nutrient for alfalfa production and N fertilizers are not generally recommended (Long and Putnam, 2013). However, alfalfa can contribute significant N to cropping systems in rotation and alfalfa can play a role mitigating excess N (See Putnam and Lin, 2015 for a more complete discussion of the role N in alfalfa cropping systems).

Table 1. P & K Nutrients removed in an alfalfa crop at various yield levels.

	Forage Yield Level					
	4 t/a	6 t/a	8 t/a	10 t/a	12 t/a	14 t/a
Nutrient	Nutrient Removal (lbs./acre)					
Phosphorus (P_2O_5)	21(47)	31 (71)	42(95)	52 (119)	62 (143)	72 (165)
Potassium (K_20)	160(192)	240(288)	320(384)	400(480)	480(576)	560(672)

Adapted from: Meyer et al., 2007.

PHOSPHORUS & POTASSIUM MANAGEMENT

In general an integrated approach which includes soil testing and plant sampling is recommended. The range on a specific soil will indicate whether P is likely to be an important limiting factor or not (Table 2). However, soil testing alone is likely not typically adequate, since this is a multi-year crop with high uptake levels, and a combination of soil and plant sampling is recommended. Deficient soils typically require long-term approaches to build up P supplies for alfalfa. Since P is generally not lost from most CA alfalfa fields by soil erosion in

Table 2. Interpretation of soil test results for alfalfa production. An economic yield response to fertilizer application is very likely for values below the deficient level, somewhat likely for values in the marginal range, and unlikely for values significantly over the adequate range.

		Soil Value (ppm)			
Nutrient	Extract	Deficient	Marginal	Adequate	High
Phosphorus	Bicarbonate (Olsen P)	<5	5-10	10-20	>20
Potassium	Ammonium acetate	<40	40-80	80-125	>125

Adapted from: Meyer et al., 2007.

alfalfa, growers can attempt to build P in anticipation of long-term productivity. Phosphorus is particularly challenging for organic producers, since inexpensive P organic fertilizers are not readily available. Manures are often excellent sources, but may require long-distance transport and/or high expenditures. Typically, inexpensive sources of P are recommended, and foliar applications are not generally very useful, due to their short-term impacts, costs, and the multiple harvests of this crop.

Yield Response to Phosphorus. On P-deficient soils, alfalfa responds readily to additions of P fertilizers (Figure 1 and 2). The most dramatic increases in yield due to fertilizers are seen in the first additions (e.g. the first 50-100 lbs. P_2O_5/acre) in many studies done over the years. As Figure 2 indicates, there was a significant gain of up to 1.5 t/a hay up with fertilizer applications up to 150 lbs. P_2O_5, but responses were modest after this point: only ½ ton (if at all) above that rate (depending upon the data point chosen- Figure 2). It's important to determine the economic worth of the crop in relationship to the cost of fertilizers. In addition, contributing P fertilizers to long-term build-up must be considered. If the economic value of the crop is low in a given year, applications can be perhaps moderated or postponed, but as we have reported elsewhere, scrimping on P fertilization does not make sense, especially the first increment of applications (Orloff & Putnam, 2016). The typical yield response to P on depleted soils of 50-100 lb. P_2O_5/acre of about 1 ton/acre is very likely to be cost effective even with low hay prices.

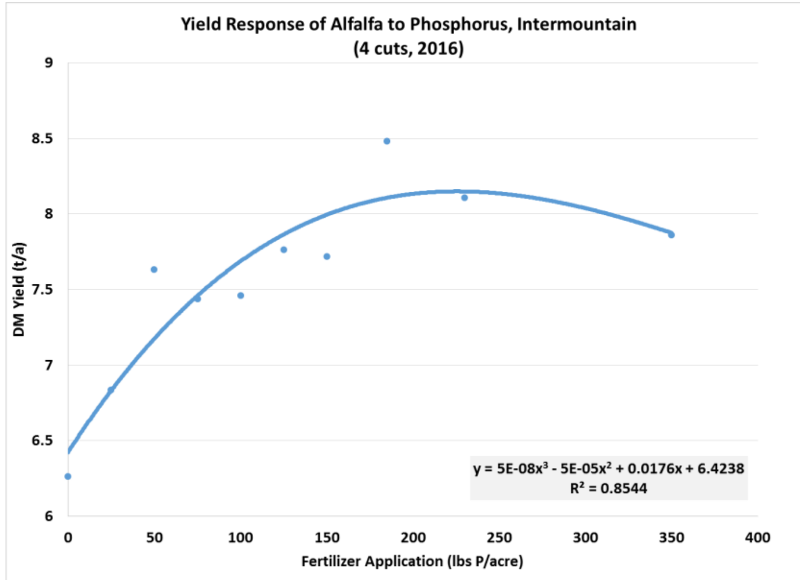

Figure 2. Yield response of alfalfa to phosphorus fertilizer (P_2O_5), Siskiyou Co., CA, 2016. First year data (Steve Orloff, UCCE Farm Advisor, Siskiyou County).

Response of alfalfa to P fertilization on P-depleted soils in the Sacramento Valley were also significant but less dramatic (Figure 3). This was a difficult, poorly drained clay-loam soil, so it had other limitations as well as low soil P levels. Both the sites for P experimentation were considered deficient soils (P< 5 ppm) using the Olsen test.

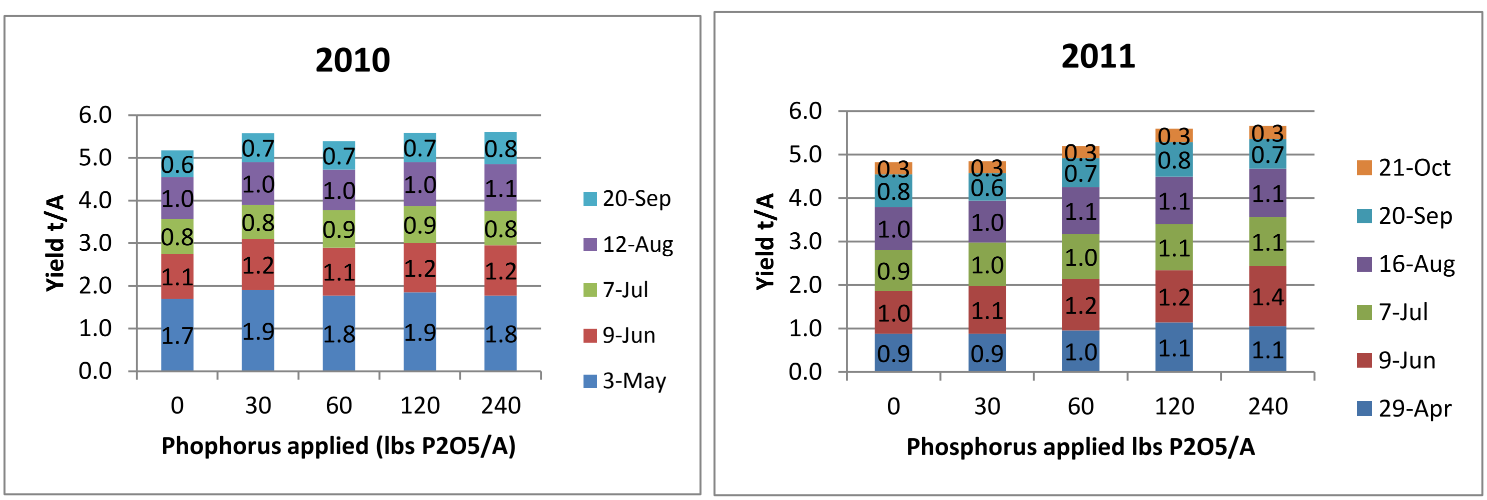

Figure3. Yield response of alfalfa to P application on a phosphorus deficient soil, Sacramento Valley, 2010-2011

Plant Sampling for Phosphorus and Potassium. The plant is often a better indicator of the nutrient supplying capabilities of a soil due to variations in rooting depth, the nutrient supplying characteristics of specific soils, and the limitations of soil sampling regimes and lab extraction. Often, we don't understand the true root exploration of a soil (is it 2 feet or 4 feet – how many effective root hairs are in each layer?), nor the ability of the soil to release nutrients. Therefore, soil sampling is only one (but an important) way to analyze nutrient limitations. Plant tissue sampling, utilizing either whole plants or portions of plants is an important way to test for P adequacy in a standing alfalfa crop (Table 3). We have found plant sampling of either whole plants or plant portions to be diagnostic of P deficiencies (Figure 4) but threshold levels are very different for the different plant parts and at different stages – thus care should be taken to utilized thresholds for adequacy that are specific to either whole plants or plant parts.

Table 3. Interpretation of tissue test results for alfalfa production, as per recommendations given by Meyer et al., 2007 for samples taken at the 10% bloom stage.

		Plant Tissue Value			
Nutrient	Sample	Deficient	Marginal	Adequate	High
		ppm			
Phosphorus	Mid 3rd Stems	300-500	500-800	800-1500	>1500 ppm
		%			
Potassium	Mid 3rd Stems	0.40-.65	0.65-0.80	0.80-1.50	>1.5%

Adapted from: Meyer et al., 2007. Note: Growth Stage will affect concentrations, with immature plants having much higher concentrations.

Unfortunately, most alfalfa growers do not perform tissue tests and many growers fertilize (or don't fertilize) based upon habit or fertilizer company recommendations with little idea of the actual nutrient status of the field. Thus, more practical ways of obtaining plant samples utilizing bales samples (already commonly taken from hay stacks) might be useful.

Bale Sampling. Many alfalfa crops in California are routinely tested for forage quality (e.g. fiber, protein and calculated digestibility values) to determine their nutritional value for feeding purposes. If those same cored samples could also be used for nutrient management purposes, it would greatly simplify the process of tissue testing and encourage more careful nutrient management. Results from one such comparison is found in Figure 4. In this and other datasets, we've found r^2 values of greater than 75%, indicating a high degree of correlation between the two methods. Using analysis of bale samples, growers may be able to 'pick up' nutrient deficiencies that would otherwise go undetected. In addition to less work, bale sampling has the added feature of actually sampling more forage than would be possible with hand sampling for forage. Typically, in a 20-core sample, over 5,000 stems from a field might be represented, while in hand-cut samples, hundreds of stems might be represented.

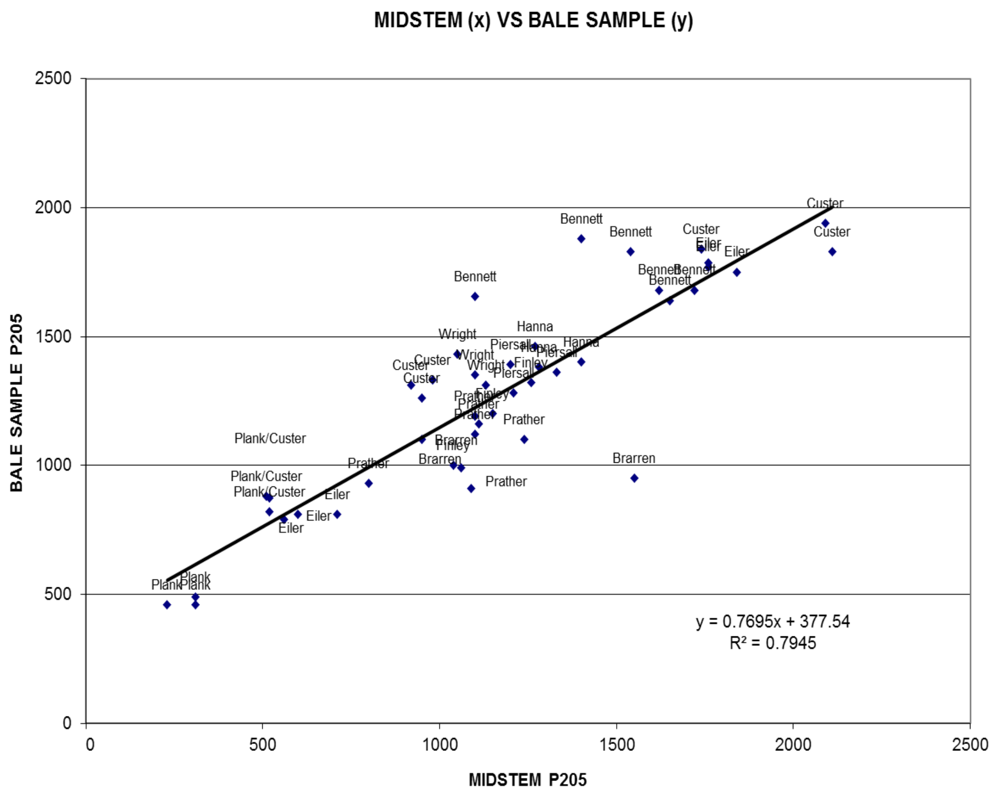

Figure 4. Phosphorus concentrations of Mid-stem samples compared with sampling from bales, data from a range of Intermountain alfalfa fields, 2007 (S. Orloff, data).

Potassium (K) Response. Although K deficiencies are less common than P deficiencies, the crop will sill respond to K fertilization when deficiencies are present. We have seen K deficiencies especially on sandy soils. Alfalfa yield has responded dramatically to K rates at the Intermountain sites and in San Joaquin Valley sites (Figure 5).

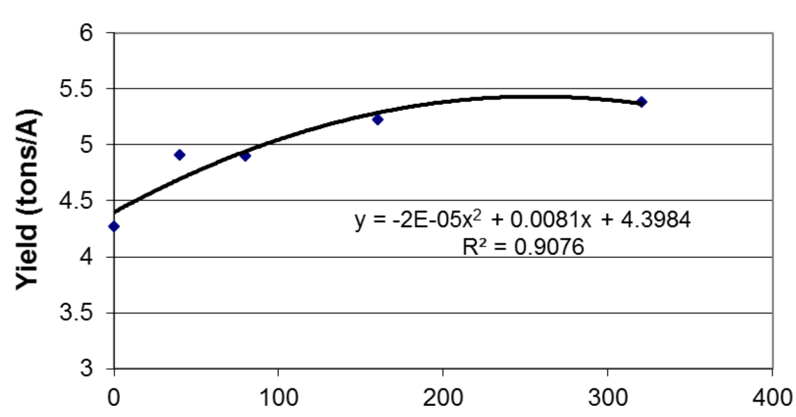

Figure 5. Typical potassium response, Intermountain soil, 2010.

Effect of Growth Stage and Sampling Method. Stage of growth and sampling method (whole plant, mid stems or top 15 cm) both have a large effect on concentration of P and K in alfalfa samples (Figure 6). Concentration of P and K in plants declines significantly with plant maturity, ranging from bud through 10% bloom stage. For P analysis, all three methods (whole plant, top 6" and stem) provide similar (parallel) results, but with different average concentrations for each method (Figure 6). Average levels of potassium concentrations were similar for whole plant and top 15 cm at all maturities, but concentrations in stems were much greater during early growth periods vs. late maturities (Figure 6).

CONCLUSIONS

For alfalfa, the importance of P and K fertilizers on deficient soils cannot be overemphasized. Due to high uptake levels, lack of a soil fertility management plan for alfalfa will lead to a 'mining' of soils, depletion of soil nutrient supply over time, and lower yields. We recommend a combination of preliminary P and K testing of soils and applications at stand establishment to meet the needs of approximately 2 years of crop growth, followed by plant sample monitoring to determine ongoing P needs of the crop for subsequent applications. Deficient soils require long-term strategies. Plant or bale sampling may be useful to determine relative status of soils, followed by more detailed monitoring. Stage of growth and sampling method should be considered when determining the threshold levels for whole plant and plant part tissue P and K concentrations. Sampling at earlier growth stages (vs. 10% bloom) is feasible, but different thresholds will be required. Alfalfa tissue testing protocols are simple to use and sufficiently accurate so that nutrient analysis can become a routine component of forage quality testing.

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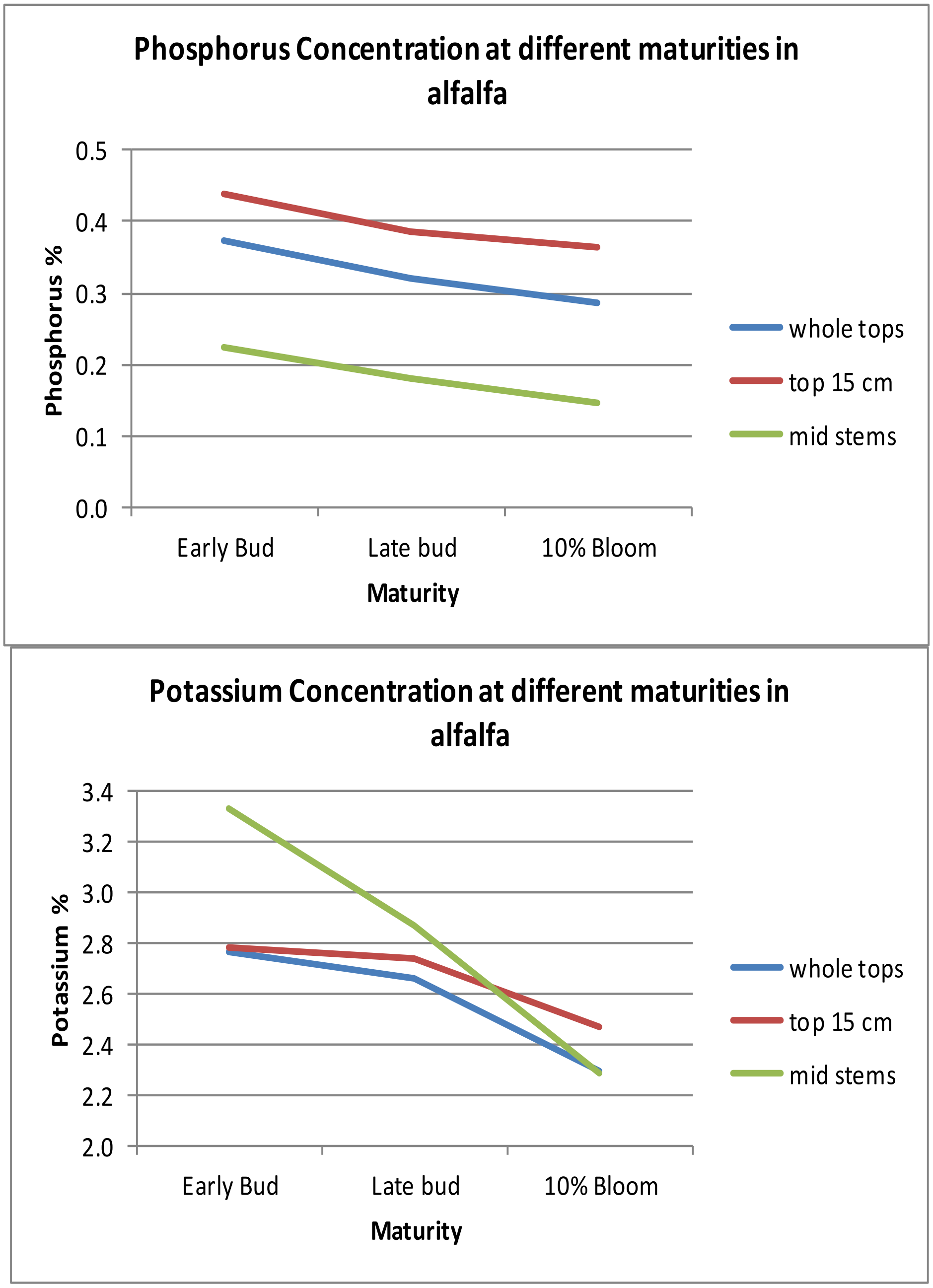

Figure 6. Influence of plant maturity on Phosphorus and Potassium concentrations in alfalfa, average of 10 farms, and all cuttings, 2010.