

**Fertilizer Research and Education Program (FREP)  
FINAL REPORT project #11-0469-SA**

**A. Project Information:**

**Title: Improved Methods for Nutrient Tissue Testing in Alfalfa**

**Time Period: 2010-2012**

**FREP Grant Number: 11-0469-SA**

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**B. OBJECTIVES**

- 1 Evaluate the feasibility of using a whole-plant sample (simulated cored-bale hay sample) to determine the nutrient status of alfalfa fields and to guide fertilization practices
- 2 Compare 3 different plant tissue sampling methods for nutrient monitoring (top 6 inches, fractionated plant, and whole-plant sample) as to their ability to reflect the nutritional status of fields
- 3 Quantify the phosphorus, potassium and sulfur tissue concentration in alfalfa plant tissue over time as the crop matures from early bud growth stage to 10% bloom
- 4 Determine alfalfa yield response from phosphorus, potassium and sulfur fertilization
- 5 Evaluate the accuracy of NIRS analysis to determine, phosphorus, potassium, sulfur, boron and molybdenum concentrations

## C. ABSTRACT

Field research was conducted to examine different plant tissue testing protocols to better manage nutrients in alfalfa. The standard plant sampling method in California has been to collect 40 to 60 stems when the alfalfa is at the 10 percent bloom growth stage and fractionate the shoots into three different parts for analysis. The bottom third is discarded while the mid-stem portion is analyzed of PO<sub>4</sub>-P and K, the mid-stem leaves for S, and the top third for B and Mo. This technique is time consuming, tedious and people get confused on which plant part to analyze. In addition, to meet the forage quality demands of the dairy industry, alfalfa is commonly harvested before the 10 percent bloom stage. A simplified sampling protocol would encourage broader adaptation of plant tissue testing in alfalfa. In addition, information was needed to determine the degree to which nutrient concentrations are affected by plant maturity to enable producers and consultants to interpret analyses from alfalfa sampled prior to 10 percent bloom.

We compared the traditional UC plant sampling technique using the fractionated samples described above to two alternative sampling techniques: whole plant samples (which would be analogous to a cored bale sample) and sampling just the top 6 inches (15 cm.), which is a common technique in some other alfalfa-producing states. We sampled fields from the Intermountain Region, the Sacramento Valley and the High Desert over three different growth periods or times of the year. The nutrient deficiencies that occur in California alfalfa fields in order of importance are P, K, S, B and Mo. We analyzed the alfalfa samples collected using the different protocols for all five of these nutrients.

Plant stage of development was found to have a large influence on nutrient concentrations for all three sampling protocols (fractionated plant parts, whole tops, or top 6 inches). In general, nutrient concentrations decreased significantly with advancing maturity for all five nutrients except for B. There was little change in B concentration with advancing maturity, and unlike the other nutrients, the B concentration was actually found to increase slightly over time. Phosphorus, K, and Mo concentration were most affected by alfalfa maturity level while S was less affected. Therefore, it is essential to recognize the maturity of the alfalfa when interpreting plant tissue analysis values. If critical values developed for 10 percent bloom alfalfa were used to evaluate less mature alfalfa, one could be misled to believe the concentration was adequate while in actuality it might be deficient.

There was a strong correlation in nutrient concentrations between whole plant samples and fractionated plant samples and between whole plant samples and top 6 inch samples. The strength of the correlation varied somewhat depending on the location, year and the nutrient being analyzed. In general, the strongest correlation between the different plant tissues occurred for the micro nutrients B and Mo, then the primary nutrients P and K, and then the secondary nutrient S. Our research demonstrated that it is likely that NIRS methods can be useful for early detection of nutrient deficiencies, especially phosphorus and potassium. Since many growers routinely analyze their

alfalfa hay for nutritional quality using NIRS, this may be a simple method to evaluate the need for supplemental fertilizer. However, an initial NIRS analysis should likely be followed up with more vigorous field testing to confirm the nutritional status of the field. It was apparent that alfalfa tissue testing protocols using whole tops or cored bale samples are simple to use and sufficiently accurate so that nutrient analysis can become a routine component of forage quality testing.

#### **D. INTRODUCTION**

Alfalfa is the largest acreage crop in California with typically about a million acres. Because of its acreage and nutrient requirements, alfalfa represents an important component of California's fertilizer and agricultural footprint. The most limiting nutrients for alfalfa production in California are phosphorus followed by potassium, sulfur, and occasionally the micronutrients boron and molybdenum. Despite the importance of fertility management, many alfalfa growers do not assess the fertility status of their fields and do not know whether their fields are deficient, in excess, or adequate. Fertilizer practices are often based primarily on past practices or habit with little knowledge of the current nutrient status of fields. This approach can be costly in terms of lost production or high fertilizer costs. Without knowledge of the fertility status of a field, the producer cannot determine the appropriate fertilizer to apply or the proper rate.

Soil tests are effective to determine the pH of a field, assess the salinity status, and to detect some nutrient deficiencies such as P and K. They are especially useful before planting, as this is when corrective action can be taken to resolve pH and salinity problems and is the only time when nutrients can be mechanically incorporated without physically damaging the alfalfa stand. For these reasons, a preplant soil analysis is a standard recommendation. However, after the alfalfa stand is established, plant tissue tests are believed to be more accurate. This is particularly true for sulfur and many micronutrients, where soil tests are generally not believed to be reliable. The plant itself is a better indicator of the nutritional status of a field due to soil sampling and laboratory nutrient extraction limitations. Nutrient concentrations vary with depth, yet standard protocol is to only sample the top 6 to 8 inches of soil in alfalfa fields. With a typical alfalfa rooting depth of 5 feet or more, shallow soil sampling may not be indicative of the crop's access to essential nutrients. Additionally, the level of plant-available nutrients in soil using laboratory nutrient extraction techniques may differ from the nutrients actually available to the alfalfa plant. Plant analysis is an indicator of actual nutrient uptake, and therefore a better measure of nutrient availability.

In spite of its generally-recognized utility, unfortunately, most alfalfa growers currently do not utilize tissue testing. There is a need to encourage better management of nutrients in general (deficiencies and excesses), but in particular to more widely adapt soil and tissue testing protocols to guide fertilization practices. However, there are practical limitations to tissue testing. The overall purpose of this research was to develop the supporting data to assist growers in better utilizing tissue testing to improve fertilizer management practices.

## E. WORK DESCRIPTION

The established alfalfa tissue testing protocol in California involves collecting stems at the time of cutting (ideally 10 percent bloom) and fractionating the plant into 3 parts and analyzing each part for a distinct nutrient(s). For alfalfa producers and consultants, this process can be time consuming, tedious and confusing. In addition, there is no way to sample after the crop has already been harvested. This sampling procedure is unique to California and other states have different protocols with no universal nationwide sampling method. Typically, either whole plant or the top 6" (15 cm) of the plant is used, and the samples taken at early or 10% bloom (Kelling, 2000, Koenig et al., 1999, Koenig et al., 2009, Flynn et al., 1999).

Many alfalfa crops in California, especially those destined for the dairy market, are routinely tested for forage quality (e.g. fiber, protein and calculated digestibility values) to determine their nutritional value for feeding purposes by coring the hay bales after harvest. If these same cored samples used for forage quality analysis could also be used for nutrient management purposes, it would greatly simplify the process, promote the practice of tissue sampling to guide fertilizer applications and encourage more careful nutrient management.

**Sampling Commercial Alfalfa Fields to Compare Tissue Testing Protocols.** Twelve commercial alfalfa fields were sampled over the season in three different alfalfa production regions (5 fields in the Intermountain area, 4 in the Sacramento Valley and 3 in the high desert). Each field was sampled three times over the season—each of the three cuts in the Intermountain area, and cuts 2, 3 and the second to the last cutting (5th or 6th) in the Sacramento Valley and High Desert. Fields were selected to represent a range of nutrient levels. Plant samples were collected at the early-bud, late-bud, and 10 percent bloom growth stages at each of the three cuttings. Plant samples were collected and processed using the following sampling protocols: **1) Fractionated plant samples** according to the standard UC protocol. Samples were divided into thirds. The stems from the mid-third portion were analyzed for PO<sub>4</sub>-P and K. The leaf portion of the middle third was analyzed for SO<sub>4</sub>-S, and the top third portion for boron and molybdenum. **2) The top 6 inches of the alfalfa plant** (method used in other alfalfa-producing states) were analyzed for total P, K, total S, boron and molybdenum. **3) Whole plant samples** (used in some states and comparable to cored bale samples) were analyzed for the same nutrients as the top 6-inch samples as well as N.



**Figure 1.** Collecting plant tissue samples from a commercial alfalfa field in the Intermountain area.

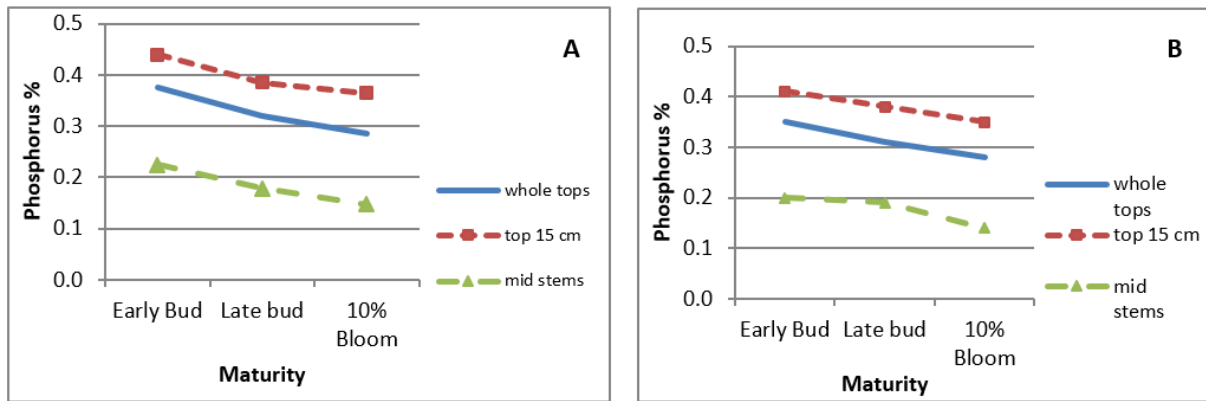
**NIRS and Wet Chemistry Validation and Calibration.** In addition to the wet chemistry methods mentioned above, all the whole plant samples were also analyzed using Near-infrared spectroscopy (NIRS) by UC Forage Specialist Dan Putnam's laboratory at UC Davis and at a commercial laboratory experienced with NIRS (JL Analytical Services, Inc).

**Fertilizer Rate Studies.** Fertilizer response trials were conducted in the Sacramento Valley for phosphorus and in the Intermountain area for potassium (phosphorus rate studies were conducted previously). The purpose was to correlate alfalfa yield with plant tissue nutrient concentration. Each trial had at least five different rates (unfertilized and four increasing fertilizer rates) with four replications. The trials were harvested for three cuttings spaced throughout the season in the Sacramento Valley and all three cuttings in the Intermountain area. Plant tissue samples were collected and the whole tops analyzed. Yield data were collected to determine the response to applied P and K and to correlate those yield levels with plant nutrient concentration. The purpose is to provide the data necessary to develop critical tissue levels for whole plant analysis, which can be used to interpret results from cored bale samples.

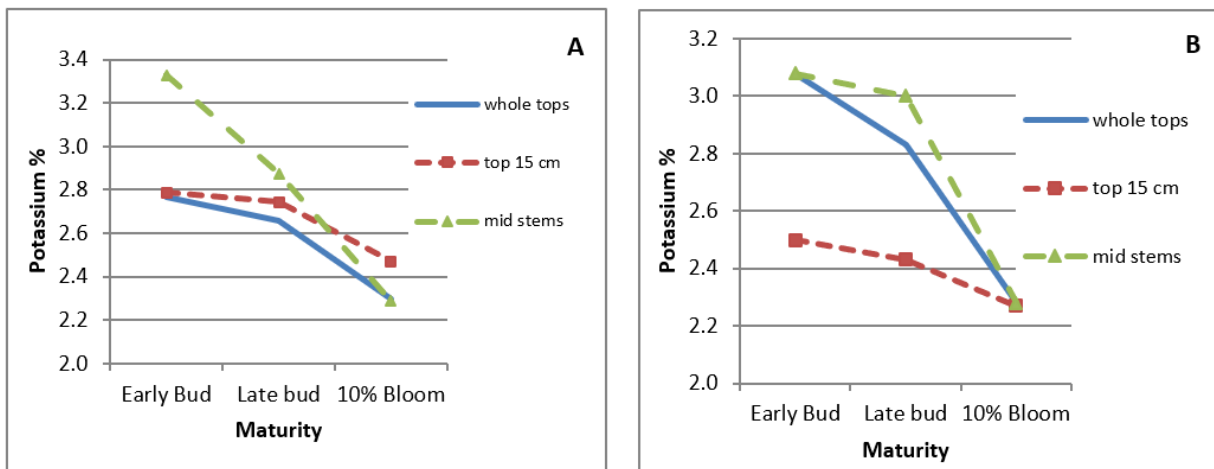
## **F. DATA/RESULTS**

Phosphorus concentration, expressed as total P for whole tops and top 6 inches and  $\text{PO}_4\text{-P}$  for midstems, varied with the different plant parts (Figure 2). Nutrient concentrations were significantly affected by alfalfa growth stage at all sites and for all cuttings. All three plant parts (whole tops, top 6 inches and midstems) showed a similar decline in phosphorus concentration with advancing maturity (Figure 2). Potassium concentration also decreased with advancing maturity, but the decline was more precipitous (Figure 3). In addition, the decline in potassium concentration with advancing alfalfa maturity was not as linear as it appeared for phosphorus. In general,

the potassium concentration declined more dramatically when alfalfa matured from the late bud stage to the 10 percent bloom stage than it did from the early to late bud stage.



**Figure 2.** Influence of plant maturity on phosphorus concentrations in alfalfa, average of 10 farms, and all cuttings, (A) 2010 and (B) 2011. Note: Whole tops and top 15 cm are expressed as total P, whereas mid-stem phosphorus is expressed as PO<sub>4</sub>-P.



**Figure 3.** Influence of plant maturity on potassium concentrations in alfalfa, average of 10 farms, and all cuttings, (A) 2010 and (B) 2011.

Another way to consider the effect of maturity on nutrient concentration is to calculate the percentage change from 10% bloom (the current standard used to evaluate nutrient concentration in plant tissue). These results (Table 1) clearly demonstrate that alfalfa maturity must be considered when interpreting alfalfa plant tissue levels. Previous guidelines (Meyer *et al*, 1997) suggested that nutrient concentrations were only 10 percent higher in bud stage than in 10 percent bloom alfalfa. However, our research indicates that the difference can be far greater. For whole tops (averaged over the 2 years), there was approximately a 12 percent increase in phosphorus concentration for late bud alfalfa and a 30 percent increase in phosphorus concentration for early-bud alfalfa compared with the nutrient concentration of 10 percent bloom alfalfa. When the

top 6 inches were sampled, there was about an 8 percent change in P concentration when comparing late bud to 10 percent bloom and a 20 percent change between early bud and 10 percent bloom (Table 1). The difference in percent change is a reflection of a higher total P concentration in the upper 6 inches compared with the whole tops; not that the top 6 inches is less sensitive to maturity effects. Similarly, there was about a 20 percent change in potassium concentration between 10 percent bloom and early bud alfalfa for the whole tops and about a 12 percent change for the top 6 inches. Sulfur concentration was somewhat less affected with about 15 percent higher levels in early-bud alfalfa and about 5 percent higher in late-bud alfalfa compared with the standard 10 percent bloom sampling period. It is interesting to note that boron concentration was only slightly affected and in contrast to the other nutrients, boron concentration actually tending to increase rather than decrease with advancing maturity. Boron was about 4 percent lower in early bud alfalfa than it was in 10 percent bloom alfalfa. Molybdenum concentration was highly influenced by growth stage with up to around a 50 percent higher value for early-bud alfalfa compared with 10 percent bloom alfalfa.

**Table 1.** Changes in nutrient concentrations from 10 percent bloom to earlier growth stages, all California locations, 2010-2011

<b>2010 Whole tops. Statewide averages</b>					
Percent increase in concentration from 10% bloom to earlier growth stage					
	<b>P % (Total)</b>	<b>K % (Total)</b>	<b>S ppm (Total)</b>	<b>B ppm (Total)</b>	<b>Mo ppm</b>
Late bud	12	16	5	1	19
Early Bud	31	20	17	-4	28
<b>2010 Top 6 inches. Statewide averages</b>					
Percent increase in concentration from 10% bloom to earlier growth stage					
	<b>P % (Total)</b>	<b>K % (Total)</b>	<b>S ppm (Total)</b>	<b>B ppm (Total)</b>	<b>Mo ppm</b>
Late bud	6	11	4	2	26
Early Bud	20	14	7	-7	44
<b>2011 Whole tops. Statewide averages</b>					
Percent increase in concentration from 10% bloom to earlier growth stage					
	<b>P % (Total)</b>	<b>K % (Total)</b>	<b>S ppm (Total)</b>	<b>B ppm (Total)</b>	<b>Mo ppm</b>
Late bud	13	6	6	-2	18
Early Bud	27	17	12	-4	46
<b>2011 Top 6 inches. Statewide averages</b>					
Percent increase in concentration from 10% bloom to earlier growth stage					
	<b>P % (Total)</b>	<b>K % (Total)</b>	<b>S ppm (Total)</b>	<b>B ppm (Total)</b>	<b>Mo ppm</b>
Late bud	10	7	5	-3	28
Early Bud	19	10	8	-7	51

Whole plant total P was strongly correlated with the total P concentration of the top 6 inches (top 15 cm.) in both years (Figure 4). Similarly, whole plant P was correlated with the PO<sub>4</sub>-P concentration of the midstems (the standard sampling method recommended by UC in the past but not used in other states). The R<sup>2</sup> value was approximately 0.6 for the comparison of whole plant and top 6 inch total P concentration and 0.5 when comparing whole plant total P and mid-stem PO<sub>4</sub>-P (Figure 5), indicating that much of the variability when comparing the two sampling methods was unexplained.

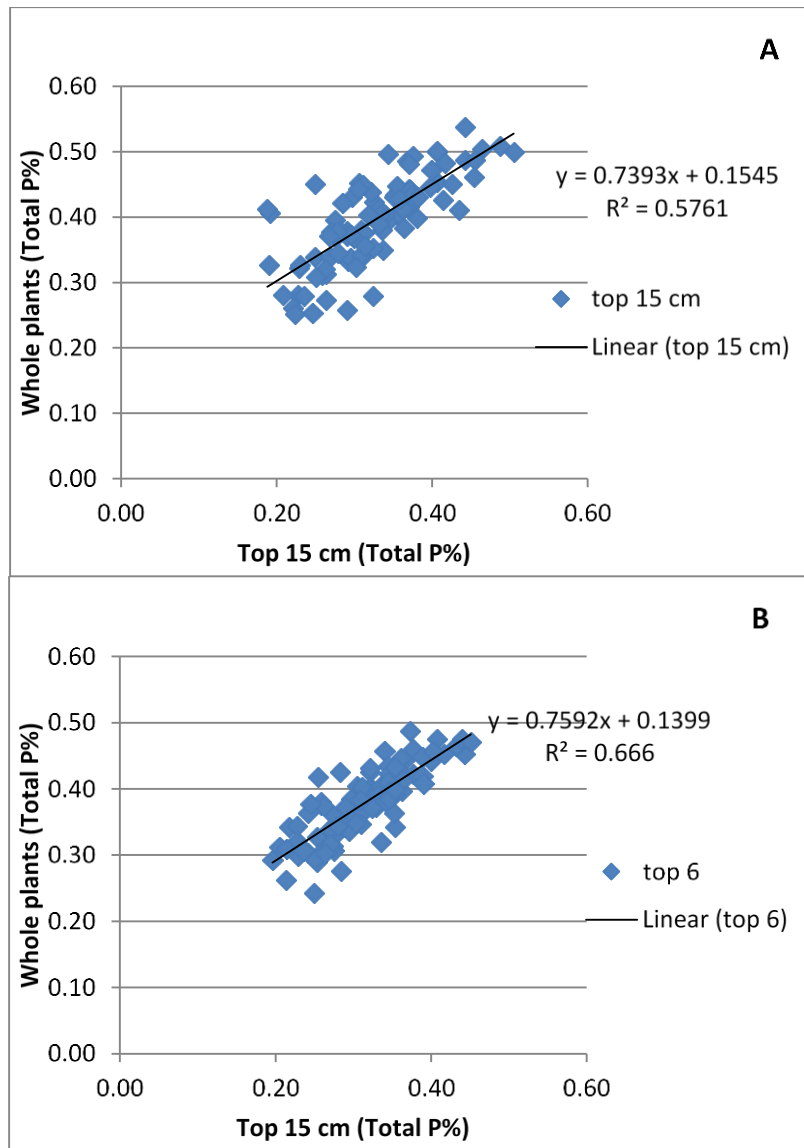
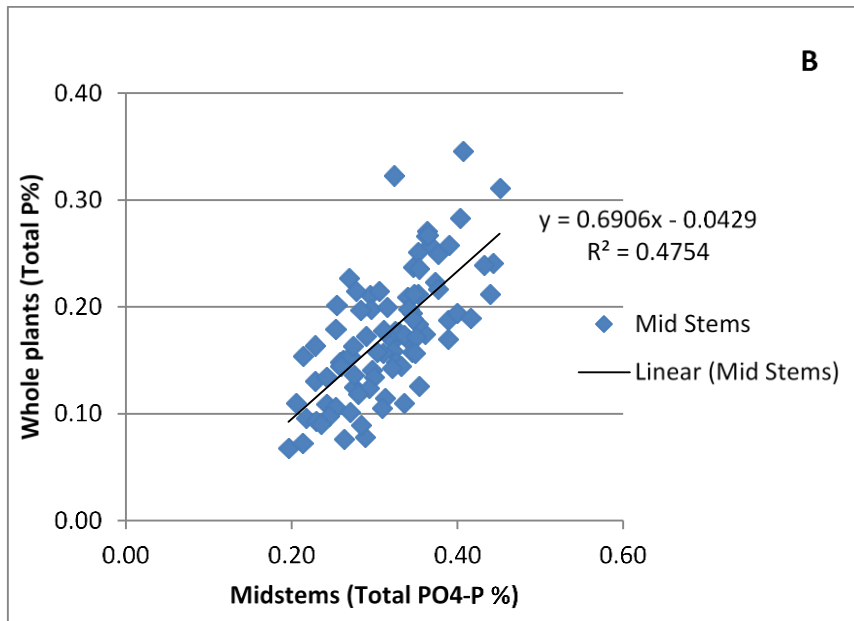
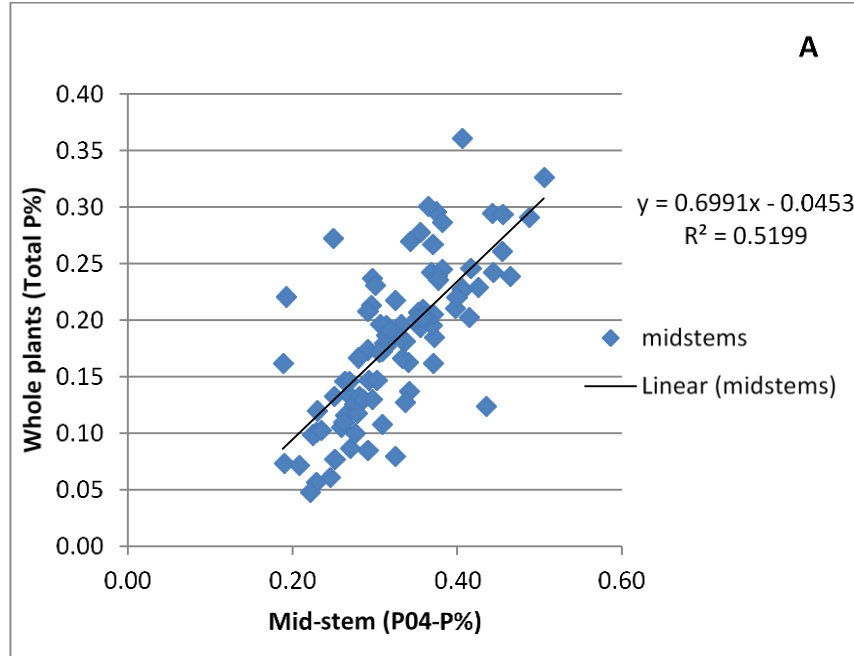


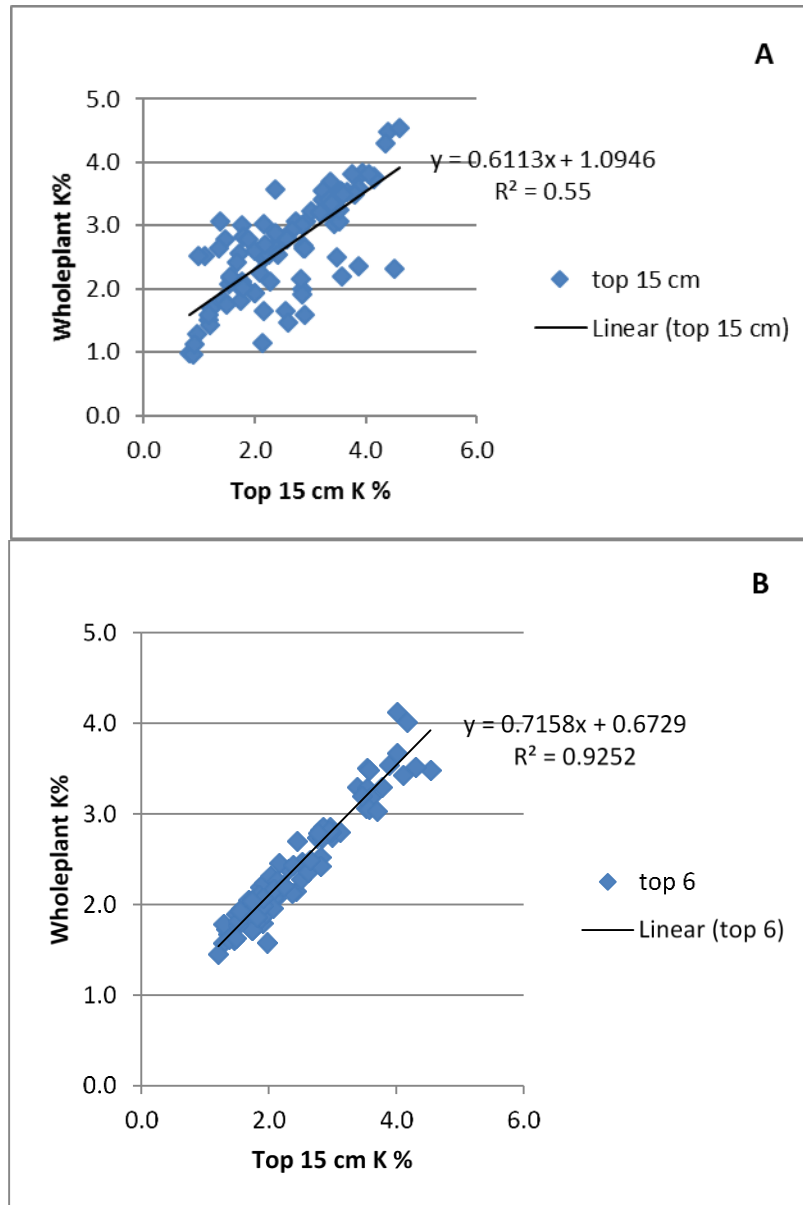
Figure 4. Relationship between whole top and top 15 cm sampling protocols for P concentration in alfalfa (All Regions). (A) 2010 and (B) 2011.



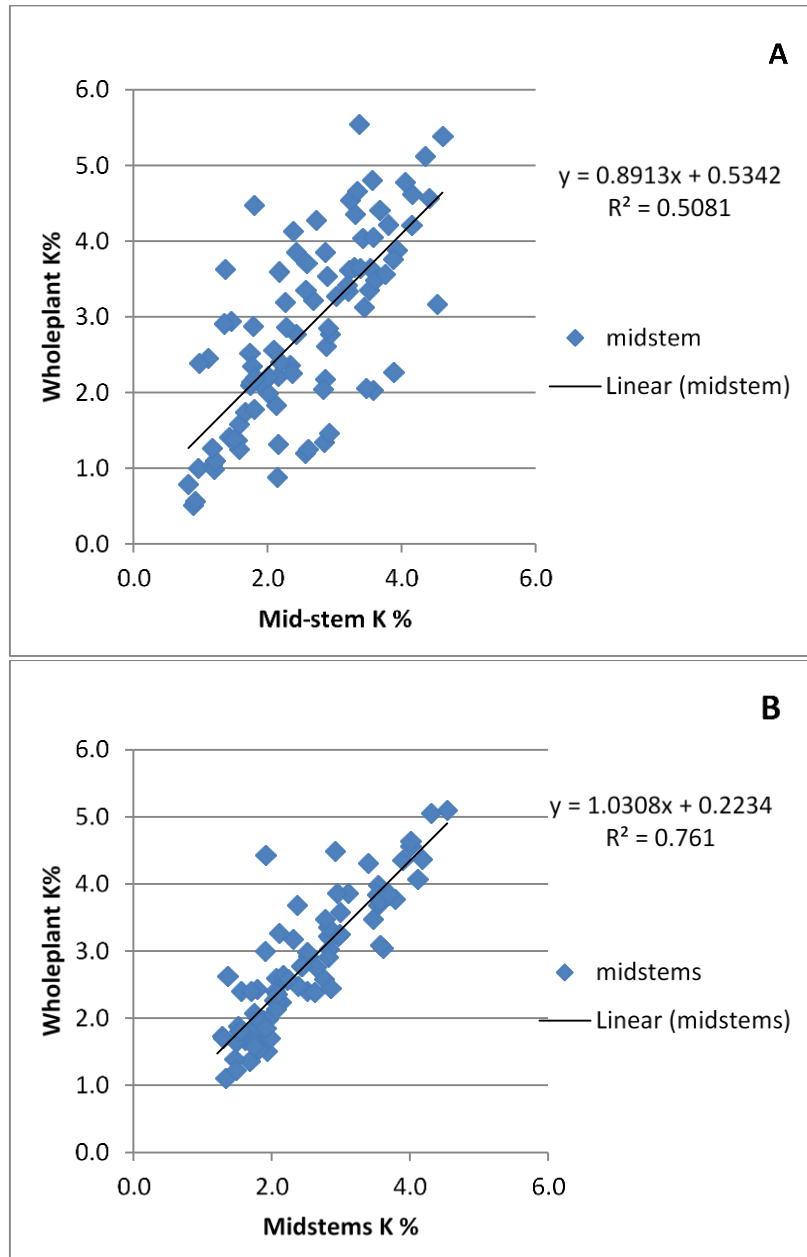


**Figure 5.** Relationship between whole top and mid-stem sampling protocols for P concentration in alfalfa (All Regions). (A) 2010 and (B) 2011.

The relationship between whole tops and top 6 inch (15 cm.) sampling protocols for K concentration was highly correlated for the samples collected in 2011 ( $R^2$  value of 0.95) but less so in 2010 (Figure 6). It is important to note that for some reason it was only the data from the Intermountain Region was not strongly correlated in 2010. When considering the results from each of the three regions separately, the intermountain Region had an  $R^2$  value of only 0.11, however; the  $R^2$  values for the Central Valley and High Desert were 0.85 and 0.95, respectively. Similarly, there was a strong correlation between whole plant K concentration and the K concentration of the mid stems. Again, for some reason the correlation was much stronger in 2011 than in 2010 (Figure 7).

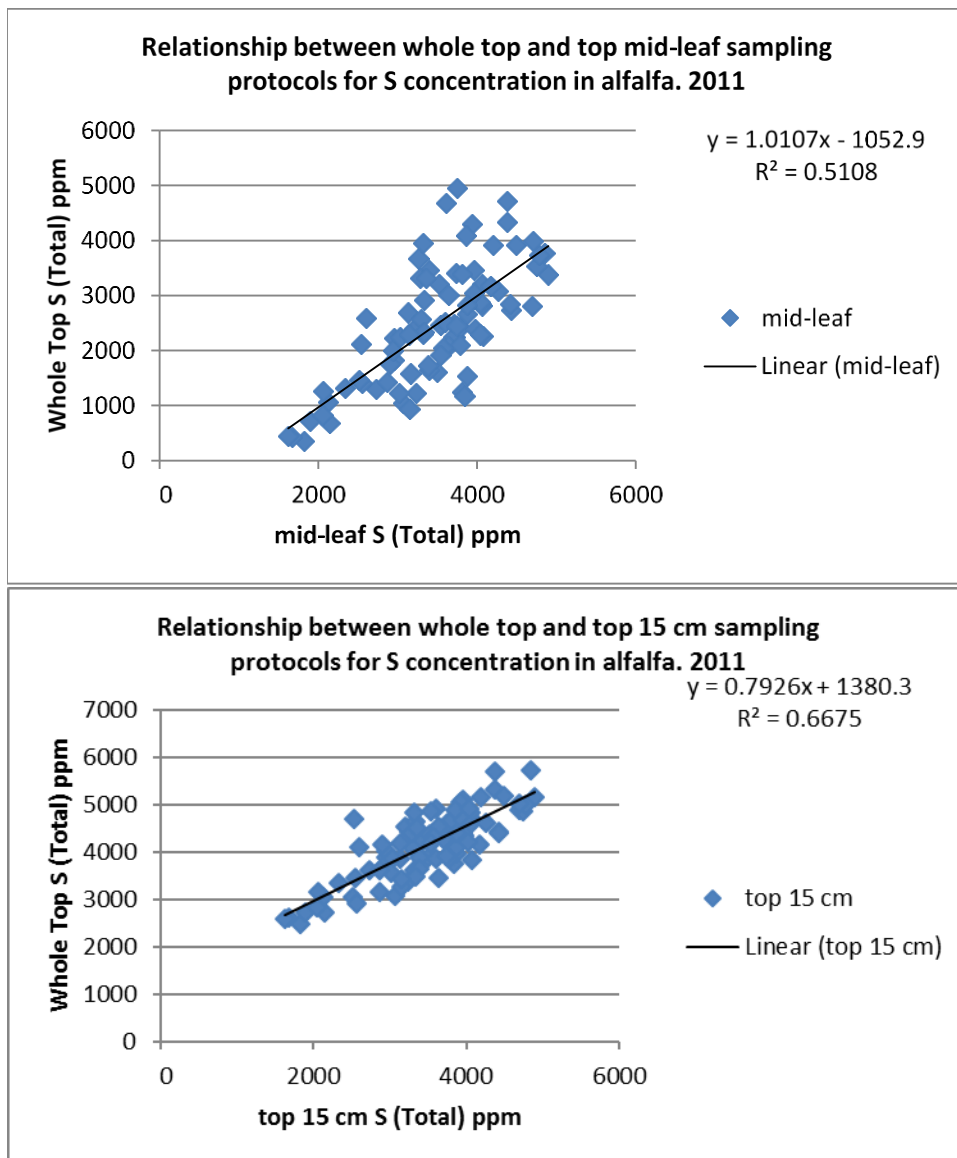


**Figure 6.** Relationship between whole top and top 15 cm sampling protocols for K concentration in alfalfa (All Regions). (A) 2010 and (B) 2011.



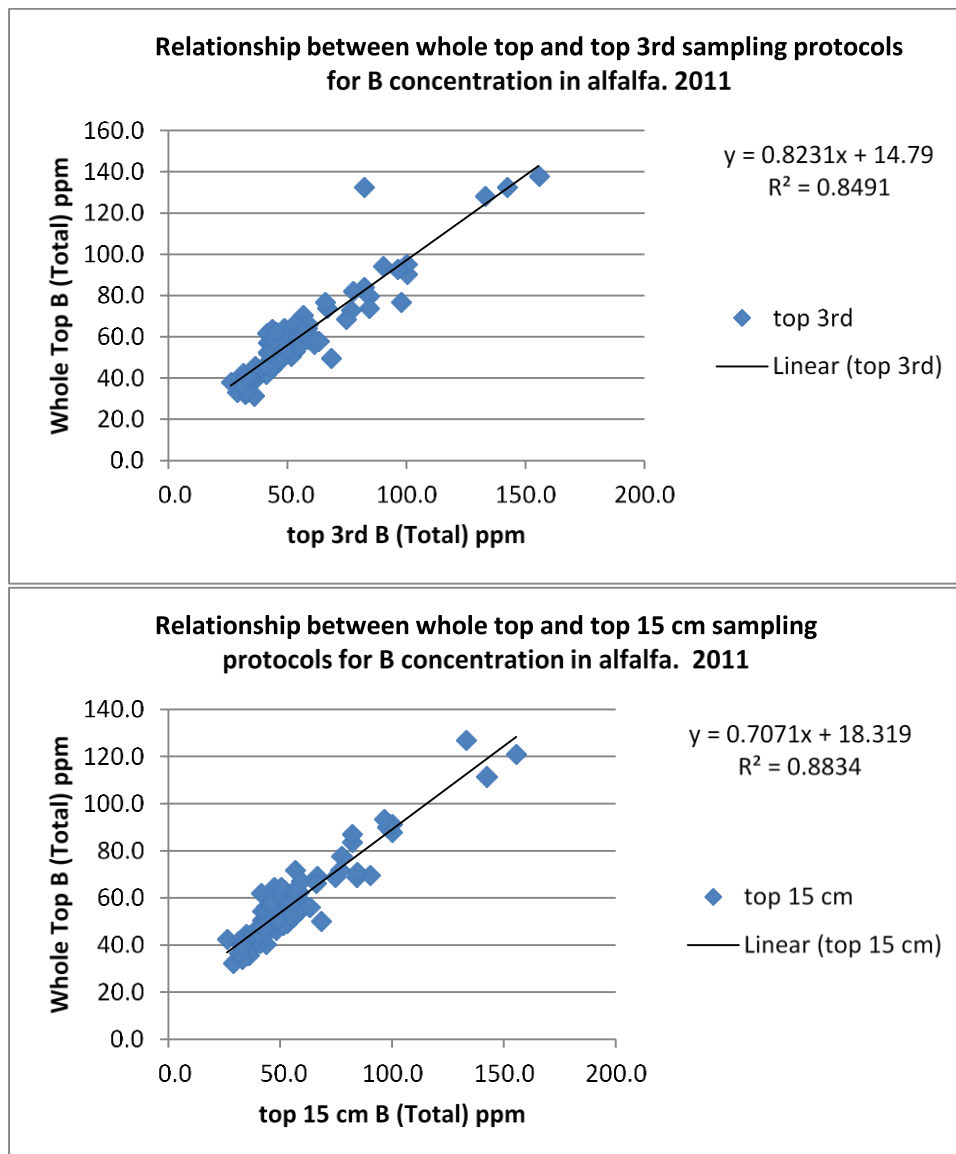
**Figure 7.** Relationship between whole top and mid-stem sampling protocols for K concentration in alfalfa (All Regions). (A) 2010 and (B) 2011.

Similar results were found for sulfur concentration (Figure 8). Whole top S concentration was highly correlated with both top 6 inch (15 cm.) and with mid-leaf S concentration but the relationship was stronger between the whole tops and top 6 inches than it was for whole tops and the mid-stem leaves.



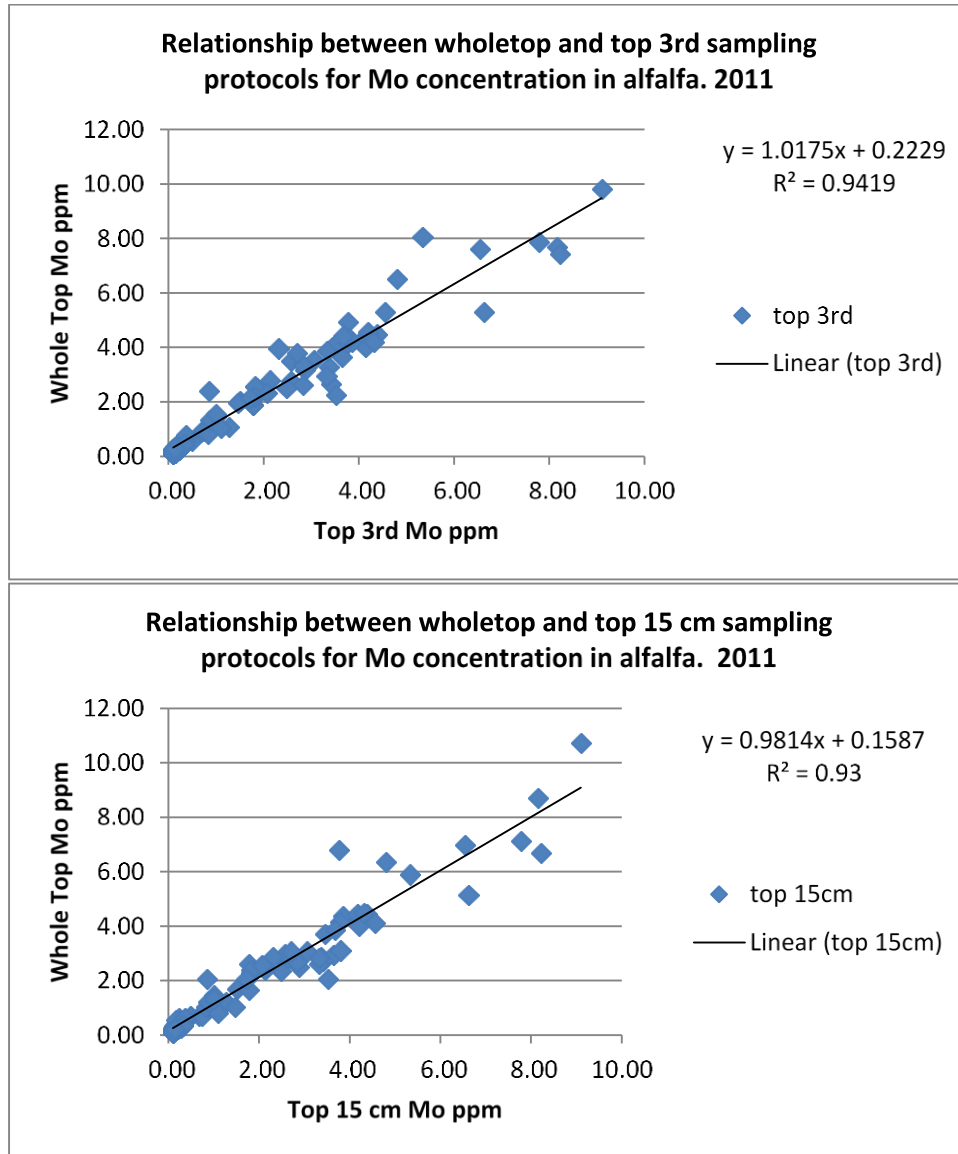
**Figure 8.** Relationship between whole top and top 15 cm and mid-leaf sampling protocols for S concentration in alfalfa (All Regions). (2011).

The plant part analyzed for boron concentration in California has been the upper one-third of the plant. We compared the upper-one third to the whole tops and the whole tops to the upper 6 inches (15 cm.). Whole top B content was very highly correlated with the top one-third ( $R^2 = 0.85$ ) and with the top 6 inches ( $R^2 = 0.88$ ) It is logical that the relationship between whole tops would be similar for both the top one-third and for the top 6 inches because the top one-third and the top 6 inches are nearly the same, especially at the early bud stage of the alfalfa. At the 10 percent bloom stage, the top 6 inches is less plant material than the top one-third. The relationships between the nutrient concentrations with the different plant parts were greater for boron than for the macro nutrients tested.



**Figure 9.** Relationship between whole top and top 15 cm, and top 1/3 protocols for B concentration in alfalfa (All Regions). (2011).

The relationship between whole tops and top one-third or whole tops and top 6 inches was stronger for boron than for any of the other nutrients tested (Figure 10) with an R2 value of 0.94 and 0.95 for the top one-third and top 6 inches, respectively. In addition, there was nearly a one to one relationship between the plant parts indicating that the values from the different plant parts could likely be used interchangeably.



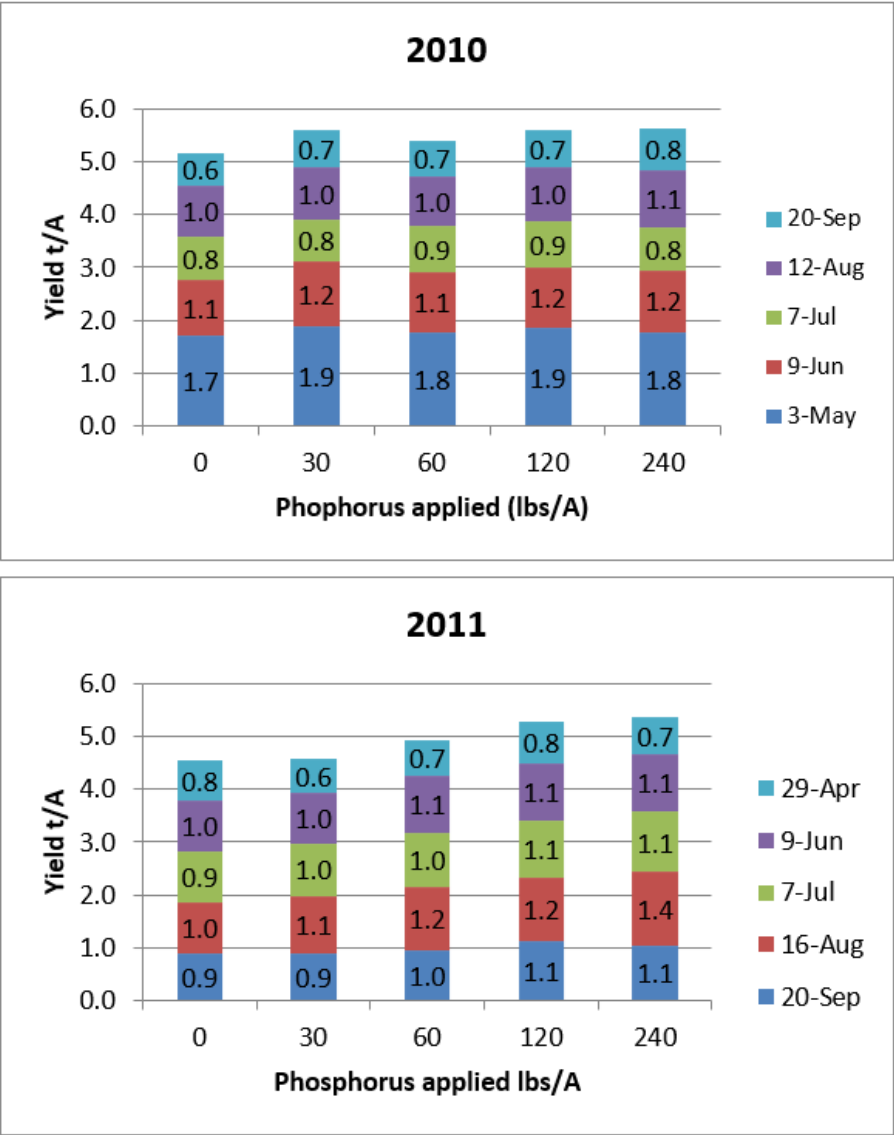
**Figure 10.** Relationship between whole top and top 15 cm, and top 1/3 protocols for Mo concentration in alfalfa (All Regions). (2011).

**Fertilizer Rate Studies.** We conducted fertilizer response trials in the Sacramento Valley for phosphorus and in the Intermountain area for potassium (phosphorus rate studies have been conducted previously in the Intermountain Region). The purpose was to correlate alfalfa yield with plant tissue nutrient concentration. This research will provide information needed to develop critical tissue levels for whole plant analysis, which can be used to interpret results from cored bale samples.



**Figure 11.** Potassium study, Siskiyou County, CA, 2011. The light-colored unfertilized field is in the background.

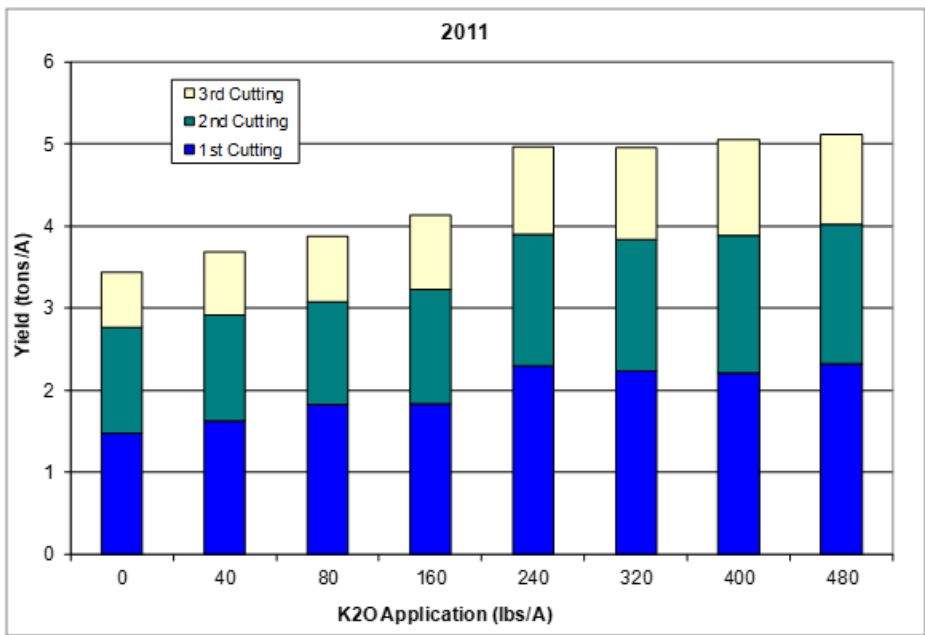
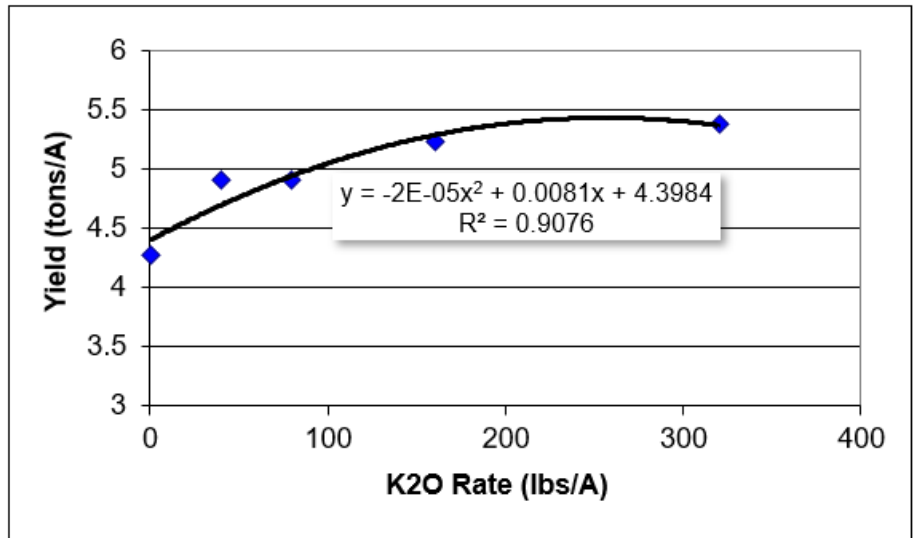
**P Response.** A phosphorus rate study was established in the Sacramento Valley in 2010 and continued on the same farm in 2011. The same rates were applied to the same plots in 2011 as 2010. In spite of very low initial soil P levels (Olsen P values 2.5 or less) we saw little yield response to P applications the first year (Figure 12), but second year response was statistically significant. Overall yield levels at this site were low, suggesting additional soil limiting factors such as drainage and aeration on the heavy clay soils in Western Yolo County.



**Figure 12.** Yield response of alfalfa to P application on a phosphorus deficient soil, Sacramento Valley, 2010-2011 (additional yield data pending for 2011).



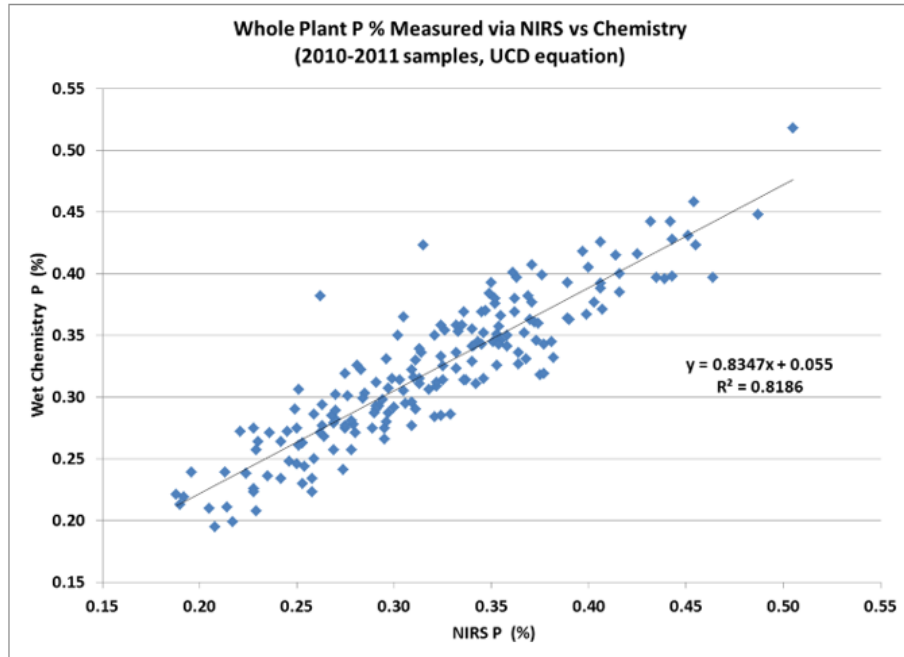
**K Response.** Alfalfa yield responded dramatically to K applications at both Intermountain sites in 2010 and 2011. The total yield increase for the season was greater than 1.5 tons per acre from the untreated control plots to 240 lbs of K<sub>2</sub>O per acre. No additional increase in yield was observed at rates over 240 lbs/a K<sub>2</sub>O (Figure 13). This is a typical yield response curve for applied fertilizer. These data together with plant tissue values and subsequent field trails will be used to establish critical values for whole plant tissue levels.



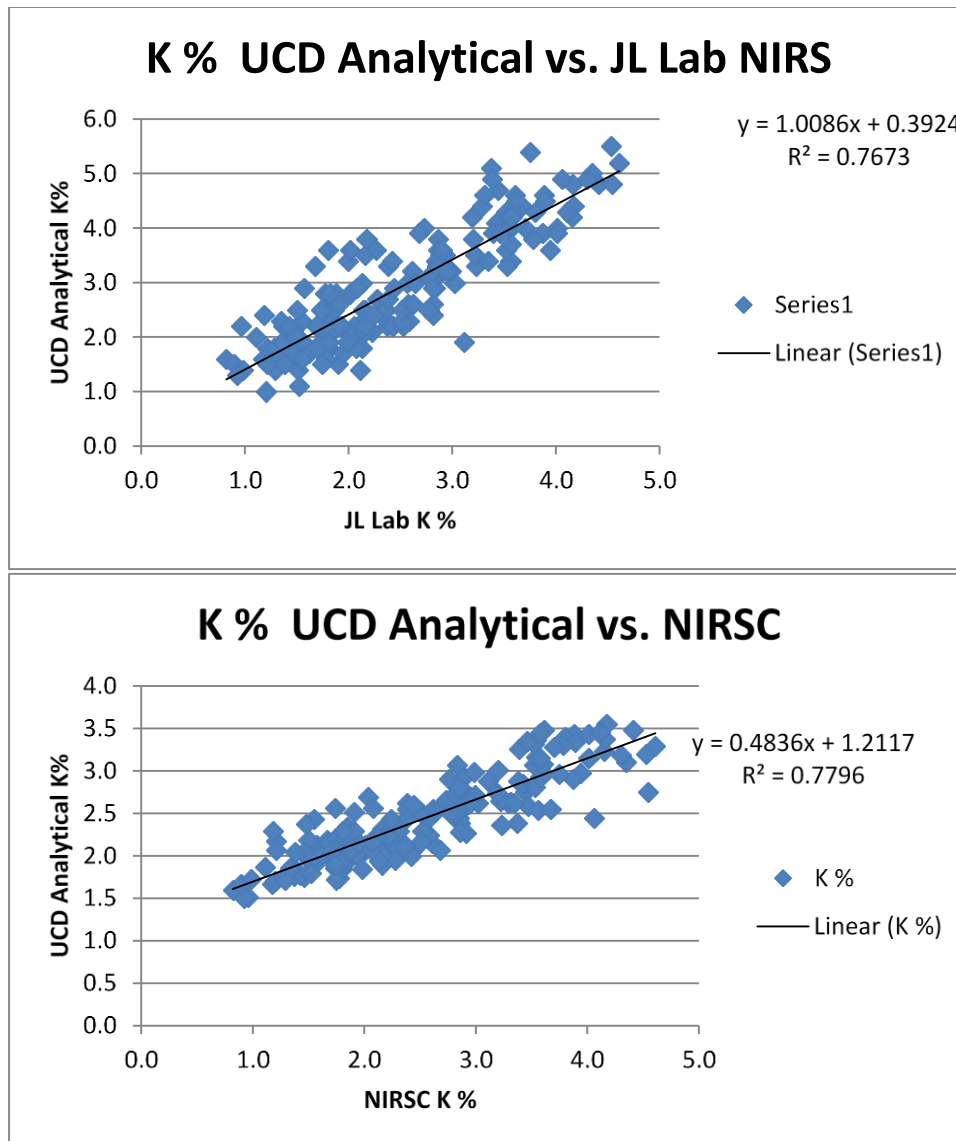
**Figure 13.** Alfalfa Response to Potassium Applications, Siskiyou County Trial, 2010 and 2011.

**Utilizing NIRS for Detection of Deficiencies in Alfalfa.** A large percentage of alfalfa hay in California is analyzed with either wet chemistry or near-infrared spectroscopy (NIRS) methods to assess its nutritional value. This technique is used primarily for the evaluation of typical forage quality parameters (Dry Matter, Acid Detergent Fiber, Neutral Detergent Fiber, Crude Protein), but some commercial labs also report values for minerals. NIRS technology, which uses light reflectance and calibration equations to estimate hay quality parameters, has become widely accepted because it is faster, highly repeatable and usually less expensive. Although wet chemistry techniques are ordinarily preferred for mineral analysis, some labs have proposed utilizing NIRS (an indirect method) for estimating nutrient concentrations. This may become especially useful with the monitoring of nutrients in crops for the purposes of nutrient management plans. The use of NIRS methodology could greatly simplify alfalfa plant tissue testing if reliable calibration equations exist, or could be developed, for routine prediction of the nutrient status of fields. Note: nitrogen is a very reliable parameter to measure utilizing NIRS – Crude protein values are calculated from %N in plant tissue utilizing robust NIRS equations. However, P, K and S analyses have not been as widely accepted.

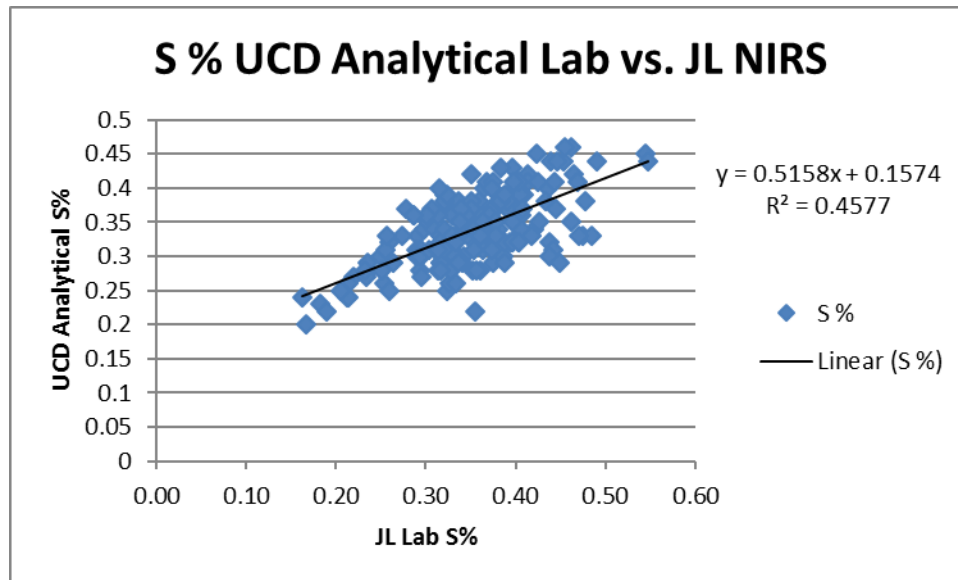
NIRS scans were performed on samples from 2010 and 2011, in both the UC Davis lab and a cooperating commercial lab (JL Analytical Services). We used a large set of samples to compare NIRS methodology for prediction of minerals with wet chemistry (standard) procedures. Correlations with NIRS-predicted values compared with wet chemistry values for a range of samples from our studies found relatively high  $R^2$  values. Correlations were 81% (Putnam lab equation, Figure 14) for phosphorus. Additionally,  $R^2$  values of 76% to 78% for K were observed using a commercial lab equation and the NIRS Consortium equation (Figure 15). Sulfur correlations (NIRS vs. chemistry) were lower so it is questionable at this point whether NIRS can be used to estimate the sulfur status of an alfalfa field. There currently are not equations at JL Analytical or NIRS Consortium for Mo or B so we could not evaluate the correlation between wet chemistry and NIRS for these nutrients at this time. We tentatively conclude that NIRS can be used for early routine detections of phosphorus and potassium nutrient deficiencies (and perhaps for uptake analysis), but caution should be exercised on this issue, since the mechanism for response of NIRS to different nutrient concentrations is not fully understood.



**Figure 14.** Relationship between whole plant sample P concentration utilizing NIRS vs. chemistry methods.



**Figure 15.** Relationship between whole plant sample K concentration utilizing wet chemistry (UCD Analytical) vs. NIRS method using the commercial lab equation from JL Analytical (top) and the NIRS Consortium equation (bottom).



**Figure 16.** Relationship between whole plant sample S concentration utilizing wet chemistry (UCD Analytical) vs. NIRS method using the commercial lab equation from JL Analytical.

## G. DISCUSSION AND CONCLUSIONS

Current plant tissue interpretation guidelines for California (Meyer et al., 2007) and other states throughout the US (Koenig et al., 2009) are based on alfalfa at the one-tenth bloom growth stage. However, to produce highly digestible alfalfa for the dairy industry, growers will frequently harvest alfalfa in the bud stage and many fields never reach one-tenth bloom before harvest.

One of the key impediments to the standardization of sampling methods in alfalfa is the influence of plant maturity on nutrient concentrations. This is important for any plant sampling protocol (standing crop sampling of the top 6 inches, plant fractions, whole tops or bale sampling). The change in nutrient concentration with crop maturity stage has not been adequately accounted for in previous guidelines developed for alfalfa tissue testing. Most guidelines simply state that they are based on alfalfa at the 10 percent bloom stage without indicating how to evaluate less mature alfalfa samples.

In agreement with previous research (Schmierer et al, 2005), we found that the change in phosphorus concentration was greater than the 10 percent it has been assumed to be. In fact, we found that critical values for whole tops (same as cored bale samples) sampled at the early-bud stage should be 30 percent higher than values for 10 percent bloom alfalfa. Similarly, critical values for alfalfa sampled at the late bud stage should be 12 percent higher than alfalfa sampled at the 10 percent bloom stage. A similar effect was found for K. Critical values for early-bud stage alfalfa and late-bud stage alfalfa should be about 20 and 12 percent higher than for 10 percent bloom alfalfa, respectively. Sulfur concentration was less affected by maturity and critical values should be about 15 percent higher in early-bud alfalfa and about 5 percent higher in

late-bud alfalfa compared with 10 percent bloom alfalfa. Boron concentration was only slightly affected by maturity and the effect was the opposite of that seen for other nutrients. Critical values for B should be about 4 percent lower in early-bud alfalfa than 10 percent bloom alfalfa. Molybdenum was more affected by maturity than the other elements. Our results suggest that early-bud alfalfa should have approximately 50 percent higher values than 10 percent bloom alfalfa. The differences due to maturity has likely led to considerable interpretation errors in the past when evaluating plant tissue test results from samples taken prior to the 10 percent bloom stage. For example, a sample collected at early bud stage may appear to have adequate P, K, S, or Mo but if the same plants were sampled at one-tenth bloom they might indicate they are deficient.

NIRS is not traditionally used to analyze mineral elements, which is what would be needed to assess the nutritional status of alfalfa fields. NIRS is based upon the infrared light reflectance characteristics of OH, CH, and NH bonds and is typically used to estimate the concentration of organic compounds. However, our results in agreement with Halgerson *et al* 2004, demonstrated that NIRS accurately predicted the P and K content of the whole tops of alfalfa but was less consistent in prediction S. Therefore, it is likely that NIRS methods can be useful for early detection of nutrient deficiencies, especially P and K, the two most commonly deficient nutrients in California alfalfa. Since many growers routinely analyze their alfalfa hay for nutritional quality using NIRS, this may be a simple method to evaluate the need for supplemental fertilizer. However, an initial NIRS analysis should likely be followed up with more vigorous field testing to confirm the nutritional status of the field.

Analysis of whole plant or cored bale samples for detection of P, K, S, B and Mo deficiencies appears to be a practical method to monitor deficiencies of these nutrients in commercial alfalfa fields. It was apparent that alfalfa tissue testing protocols using whole tops or cored bale samples are simple to use and sufficiently accurate so that nutrient analysis can become a routine component of forage quality testing. Additional evaluation is underway to establish critical plant tissue values for whole tops or cored bale samples at different sampling maturities.

## **PROJECT IMPACTS**

Growers and CCAs are now paying a lot more attention to nutrient uptake issues in alfalfa. Previous to our efforts, many alfalfa growers simply relied on routine practices for example “100 lbs of P<sub>2</sub>O<sub>5</sub> per acre per year” regardless of the actual fertility level of the field. This resulted in either over application or under-application, since it was not based upon the needs of the crop. Some growers were previously testing soils, but even then, only before planting. Tissue testing, while common for other crops, was rarely if ever, done for alfalfa. The standard recommended protocol was too complicated and tedious and misunderstood to be practically used. In addition, many labs charged for three separate samples, which made it cost prohibitive. Our findings about the impacts of plant maturing on nutrient concentrations enabled growers to

understand sufficiency levels to a more precise degree. Previously growers may not have used the correct threshold concentrations since they did not take this into consideration.

Whole plant bale sampling, which represents an easier way to obtain plant samples from fields, improves the representative nature of the sample (due to more complete sampling of the tissue), and provides a simple, straight forward mechanism for growers to quickly obtain nutrient tissue data. This sampling procedure was not done at all before this project was initiated, and now continues to gain in popularity. Several CCAs have indicated how useful this approach has been for superior management of nutrient needs.

The coupling of tissue testing with forage quality sampling by develop a whole-plant guideline enables growers to easily test for nutrient concentrations. Additionally, the finding that NIRS appears to be useful for nutrient deficiency identification enables this technique to be utilized for nutrient management. This should further increase the use of tissue testing to guide fertilization practices.

## **OUTREACH SUMMARY**

These results were extended to growers, consultants and the agricultural industry via several channels: Field Days, California Alfalfa Symposium, Arizona farmer meetings, Utah Farmer meetings, Washington State Haygrower’s conference, American Society of Agronomy annual meetings, FREP Conferences, California Plant & Soil conference, Western Alfalfa & Forage Symposium, and various local production meetings. A complete listing of presentations follows.

<b>Meeting</b>	<b>Date</b>	<b>Presentation Title</b>	<b>Location</b>	<b>Number of attendees</b>
Washington State Hay Growers Conference	1/16/08	Why You Should Tissue Test Your Alfalfa—A new technique makes it easier than ever	Kennewick, WA	200
National Alfalfa Symposium	2/5/08	The Scoop on Fertility: Fertilizing alfalfa for maximum yield	Kearney, NE	250
Siskiyou County Growers Seminar	2/12/08	Fertilizing Alfalfa for Maximum Yields: A new tissue testing procedure may help	Yreka, CA	75

Meeting	Date	Presentation Title	Location	Number of attendees
Lassen County Grower Meeting	3/4/08	New quick and easy method for determining alfalfa nutrient needs and update on Prowl H2O for summer weed control in alfalfa	Susanville, CA	65
Western Plant Health Association's Nutrient Conference Series Plant Nutrition and Physiology	11/6/08	P & K Monitoring for Fertility Management in Alfalfa	Sacramento, CA	75
Fertilizer Research and Education Program	11/13/08	Improving Phosphorus and Potassium Monitoring	Modesto, CA	200
Hay and Forage Seminar	11/22/08	Utilizing Plant Tissue Testing & Application Methods to Maximize Fertilizer Efficiency	Klamath Falls OR	60
California Alfalfa & Forage Symposium and Western Alfalfa Seed Conference	12/4/08	Maximizing Fertilizer Efficiency through Tissue Testing and Improved Application Methods	San Diego, CA	400
Washington State Hay Growers Conference	1/14/09	Is <u>it</u> worth fertilizing alfalfa with Current Fertilizer Prices? Diagnostic tools to assist with your decision.	Kennewick, WA	200
Siskiyou County Growers Seminar	2/18/09	Is <u>it</u> Worth Fertilizing Alfalfa with Current Fertilizer Prices? Diagnostic tools to assist with your decision.	Yreka, CA	75
Seminario Internacional de Manejo, Producción y Calidad de Alfalfa	8/11/09	Determinación de Requerimientos de <u>Fertilidad</u> "Análisis de Suelos y Foliar"	Santiago, Chile	110
American Society of Agronomy	11/4/09	Using Cored Bale Samples to Assess Alfalfa Nutrient Needs: Possibilities and Limits	Pittsburg, PA	45
Idaho Hay and Forage Conference	2/16/10	Recent Advances in Alfalfa Tissue Testing	Burley, ID	220
American Society of Agronomy	11/1/10	Sampling Technique and Maturity Effects <u>On</u> Nutrient Concentrations in Alfalfa	Long Beach, CA	Poster
Utah Hay Growers Conference	1/28/11	Getting the Most from Your Fertilizer Dollar	St. George Utah	250
2011 Lassen Winter Ag Seminar	3/1/11	Top 5 Alfalfa Production Tips to Maximize Your Profits	Susanville, CA	43



Meeting	Date	Presentation Title	Location	Number of attendees
Southwest Agriculture Conference	3/8/12	New Improved Methods for Nutrient Tissue Testing in Alfalfa	Yuma, AZ	45
Siskiyou Crop Production Seminar	2/21/12	Making the Best Fertilizer Decision	Yreka, CA	82
Wilbur Ellis Alfalfa Roundtable	8/13/12	Alfalfa Best Practices	Woodland, CA	26
Plant and Soil Conference	2/7/13	Improved Methods for Nutrient Tissue Testing in Alfalfa	Visalia, CA	110
Soil Fertility Short Course	3/15/13	Alfalfa Fertilization Practices	Klamath Falls, OR	40
2013 FREP Conference	10/30/13	Improved Methods for Nutrient Tissue Testing in Alfalfa	Modesto, CA	250
Hay Production & Management Workshop	11/15/13	Assessing the Nutrient Needs of Alfalfa and Grass Forages	Central Point, OR	35
World Ag Expo Seminar	2/11/14	Top 5 Production Practices to Improve Alfalfa Yield and Profitability	Tulare, CA	72

## LITERATURE CITED

- Halgerson, J., C. Sheaffer, N. Martin, P. Peterson and S. Weston. 2004. Near-Infrared Reflectance Spectroscopy Prediction of Leaf and Mineral Concentrations in Alfalfa. *Agron. J.* Vol. 96 No. 2, p. 344-351.
- Kelling, K.A. 2000. Alfalfa Fertilization. Publication A2448 University of Wisconsin Cooperative Extension . <http://learningstore.uwex.edu/assets/pdfs/A2448.pdf>
- Koenig, R. T.,D. Horneck, T. Platt, P. Petersen, R. Stevens, S. Fransen, and B. Brown. 2009. Nutrient Management Guide for Dryland and Irrigated Alfalfa in the Inland Northwest. A Pacific Northwest Extension Publication. PNW0611. Washington State University. <http://cru.cahe.wsu.edu/cepuplications/pnw0611/pnw0611.pdf>
- Koenig, R., C. Hurst, J. Barnhill, B. Kitchen, M. Winger, M. Johnson. 1999. Fertilizer Management for Alfalfa. Utah State University Publication AG-FG-01. <http://extension.usu.edu/files/publications/publication/AG-FG-01.pdf>
- Flynn, R., S. Ball, R. Baker. 1999. Sampling for Plant Tissue Analysis. Guide A-123. New Mexico State University. [http://aces.nmsu.edu/pubs/\\_a/a-123.html](http://aces.nmsu.edu/pubs/_a/a-123.html)
- Meyer, R.D., D.B. Marcum and S.B. Orloff. 1997. "Fertilization." In S.B. Orloff and H.L. Carlson (eds.), *Intermountain Alfalfa Management*. 41–49 Oakland: University of California Division of Agriculture and Natural Resources, Publication 3366.
- Meyer, R.D, D.B Marcum, S.B. Orloff and J.L. Schmierer. 2007. "Alfalfa Fertilization Strategies." In Charles G. Summers and Daniel H. Putnam (eds.), *Irrigated Alfalfa Management for Mediterranean and Desert Zones*. Oakland: University of California

Division of Agriculture and Natural Resources, Publication  
[http://alfalfa.ucdavis.edu/IrrigatedAlfalfa/pdfs/UCAlfalfa8292Fertilization\\_free.pdf](http://alfalfa.ucdavis.edu/IrrigatedAlfalfa/pdfs/UCAlfalfa8292Fertilization_free.pdf)

Orloff, S., D. Putnam, and R. Wilson. Maximizing fertilizer efficiency through tissue testing and improved application methods, 2008 California Alfalfa & Forage Symposium and Western Alfalfa Seed Conference, San Diego, CA, 2-4 December 2008 <http://alfalfa.ucdavis.edu/+symposium/proceedings/2008/08-275.pdf>

Schmierer, Jerry L., R. Meyer, and D. Putnam. 2005. Testing alfalfa for phosphorus and potassium nutrient deficiencies. Proceedings, 35th California Alfalfa and Forage Symposium, 12–14 Dec. 2005. Visalia, CA. UC Cooperative Extension. pp. 201–208. [http://alfalfa.ucdavis.edu/+symposium/proceedings/asdf/alf\\_symp/2005/05-201.pdf](http://alfalfa.ucdavis.edu/+symposium/proceedings/asdf/alf_symp/2005/05-201.pdf)