CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)

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Project Title: Improving the diagnostic capabilities for detecting molybdenum deficiency in alfalfa and avoiding toxic concentrations for animals.

Project Location: Shasta and Siskiyou Counties

Project Duration: 3 years (2001-03)

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Problem and Objectives:

During the mid 1980's molybdenum deficiency in alfalfa was identified in several intermountain valleys of Northern California by plant tissue analysis and the generally recommended pound of sodium or ammonium molybdate per acre (0.4 lbs Mo/A) based on earlier research gave adequate growth and high yields of alfalfa. Since the mid 1990's numerous samples of alfalfa coming from the same areas have shown lower levels of molybdenum (<0.5 ppm). Over the past 10-15 years many laboratories have changed a number of analytical procedures and instruments which do not provide for reliable analyses of molybdenum at concentrations in the range of 0.1 - 2 ppm. Several surveys of alfalfa and other forage species as well as animal blood samples have indicated that copper concentrations are minimally adequate to deficient in many of the same locations where molybdenum is deficient. Hence if repeated applications of molybdenum were made even at the low rate of just 1 lb/A sodium molybdate (0.4 lb Mo/ A) the higher molybdenum would cause severe animal nutrition problems. The objectives of the project were:

1) To characterize the relationship between plant tissue molybdenum, boron and copper concentrations and alfalfa yield response where molybdenum and boron are applied at several rates.
2) To develop a broader ranged diagnostic capability by assessing plant tissue molybdenum concentrations at different stages of alfalfa growth where several rates of molybdenum have been applied.
3) To provide standard forage samples for distribution to analytical laboratories by collecting large quantities (20-25 lbs) of two alfalfa samples having molybdenum concentrations in the range of 0.1-0.3 ppm and 0.5-0.7 ppm.

Abstract:

Yields of alfalfa are often limited by inadequate supplies of molybdenum (Mo) and boron (B) in the intermountain valleys of Northern California. The period of time during which plant tissue samples should be taken for diagnosing nutrient deficiencies for many plants is usually rather short. The upper 6 inch section of the alfalfa plant is usually sampled at 1/10th bloom growth stage for the micronutrients molybdenum (Mo) and boron (B). To insure higher forage quality, growers often harvest before the 1/10th growth stage. The first objective of this research was to characterize the relationship between plant tissue molybdenum, boron and copper concentrations and alfalfa yield response where molybdenum and boron are applied at several rates. A second objective was to develop a broader ranged diagnostic capability by assessing plant tissue molybdenum concentrations at different stages of alfalfa growth where several rates of molybdenum have been applied. A third objective was to provide standard forage samples for distribution to analytical laboratories by collecting large quantities (20-25 lbs) of two alfalfa samples having molybdenum concentrations in the range of 0.1-0.3 ppm and 0.5-0.7 ppm. Top 6 inch samples of alfalfa plants were collected to locate two field sites, one deficient in

Mo (<0.2 ppm) and another in B (<10 ppm) as well as Mo (<0.2 ppm). At the Mo deficient site; 0, 0.2, 0.3, 0.4, 0.6, 0.8, and 1.2 lb Mo/A plus a 2 ton/A lime treatment were applied on March 30, 2000. The second site was established March 9-10, 2001 with Mo alone at 0.4 and 0.8 lb/A, B alone at 2 and 4 lb/A and the 4 lb/A rate along with the 6 rates of Mo above. Lime alone and in combination with two rates of Mo (0.2 and 0.4 lb/A) plus B (4 lb/A) were also included. Alfalfa was harvested either 3 or 4 times each year at site # 1 during the four years 2000-2003 and 3 or 4 times each year at site # 2 during the three years 2001-2003. Early plant growth stage samples were taken at 6 inches height, at 12 inches height, and pre-bud (when only 2 - 5% of the plants have a small ball that can just be detected between the thumb and forefinger indicating the bud is developing) growth stage prior to each harvest as well as sampling at harvest. In some cases, growers harvested prior to 1 / 101h bloom so samples taken at harvest were characterized as to stage of growth. All of the plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high, pre-bud plants and at harvest plants were analyzed for molybdenum, boron and copper concentrations to develop the relationships between growth stage, alfalfa yield and molybdenum and boron concentrations. Alfalfa was harvested either 3 or 4 times in 2000-2003. Significant yield responses to Mo at site one were 1 out of 4 harvests in 2000, none of 4 in 2001, one of 3 in 2002, and one of 3 in 2003. Yield responses to Mo were generally of the magnitude of 0.15-0.4 ton/A with lime alone giving among the highest yields in the second and third years. At site two significant yield responses were recorded in none out of 4 harvests in 2001, 3 out of 4 during 2002 and 3 out of 3 during 2003. Boron alone gave slightly higher yield responses than Mo alone with the greatest yields when both were applied. Lime in combination with Mo and B also gave among the highest yields. Lime alone resulted in yields seldom better than the control. Both Mo and B concentrations remained nearly constant throughout each growth cycle and throughout the growing season when these nutrients are in the deficient range. Higher concentrations resulting from applied nutrients declined during the growth cycle and later years. To achieve objective three, large bulk sized samples of top 1/3 of alfalfa plants were collected at or just prior to harvest from selected plots to acquire sufficient quantities for standard samples with known molybdenum and boron concentrations. Four samples have been prepared with the following concentrations: 1). Low Mo (0.1-0.4 ppm)-low B (9-11 ppm)-about 12 lbs, 2). Low Mo (0.1-0.4 ppm)-intermediate B (15-25 ppm)-about 8 lbs, 3). Low Mo (0.1-0.4 ppm)-high B (35+ ppm)-about 4 lbs, and 4). Intermediate Mo (0.5-0.7 ppm)-intermediate B (15-25 ppm)-about 16 lbs.

Growers, advisors and researchers alike often raise the question of whether fertilizer nutrient additions influence the forage quality of alfalfa. One may suspect that molybdenum (Mo) an element closely associated with nitrogen fixation might influence the protein content of alfalfa. The objective of this research was to evaluate the influence that applied molybdenum (Mo) and boron (B) have upon the forage quality of alfalfa. Whole plant alfalfa samples were collected at each harvest either 3 or 4 times in 2000-2003 at the two sites. Crude protein (CP), acid detergent fiber (ADF) and neutral detergent fiber (NDF) analysis were conducted to assess forage quality from three replications of each treatment. No statistically significant differences in any of the three parameters were observed at site # 1 over the four years or at site # 2 over the three years. In general there was a slight trend of increased crude protein with increasing rates of applied Mo.

Introduction

Molybdenum has two important roles or functions to establish it's essentiality in the growth of crop plants, nitrate reduction and biological nitrogen fixation'. Enzymes containing molybdenum needed by higher plants are nitrate reductase and sulfite oxidase, and in nodulated legumes, nitrogenase and xanthine dehydrogenase.

Arnon and Stout[2] first demonstrated the essentiality of molybdenum for higher plants in 1939 by growing tomatoes in six successive experiments. Recent reviews by Romheld and Marscher[1] and Srivastava[3] indicate a more complete picture of our knowledge of molybdenum and its various biochemical and physiological functions. Much of the early attention on molybdenum was focused on alfalfa and other legumes and the interaction with nodulation along with the increases in nitrogen content of the plant [(4,5,6)]. From early on the effect of lime applications to acid soils where alfalfa was growing has been difficult to understand. Separating the effect of the improved growing environment for the rhizobia and the increased plant availability of molybdenum in the soil both contribute to make more nitrogen available to the alfalfa plant to improve its growth and yield[(4'5'7'8,9,10)]

Visual symptoms of molybdenum deficiency in alfalfa appear as a general yellowing of the whole plant similar to that of nitrogen in a number of plant species (4,11) The deficient plants are stunted and show chlorotic spots in the interveinal tissue; these spread to include the entire leaf, which then dies and drops off.

Applications of fertilizer molybdenum in the field have resulted in good yield and nitrogen content increases in alfalfa but usually not until the soil pH has been raised to 6.0-6.3 with lime additions(4'7'10). Unfortunately, if acid soils are limed and even moderate rates of molybdenum (>I lb Mo/A) are applied the molybdenum concentrations in alfalfa and other legumes can exceed 10 ppm. Molybdenum concentrations of greater than 10 ppm or even less, particularly if the copper concentration is not twice that of molybdenum may cause molybdenosis in ruminant animals or result in unthrifty performance(12'13'I4) Many ranchers, dairymen and animal nutritionists currently deal with the excessively high molybdenum (and sometimes low copper) concentrations in the San Joaquin Valley south of about Stockton and in Southern California.

Since the geographical area where molybdenum deficiency may occur extends from the northern part of the Sacramento Valley north to the Oregon border and east to within 75-100 miles of the Nevada border, one site was located north of Burney, CA, and the second in Scott Valley. These two sites represent different soils and climatic regions. At each location treatments will be chosen with a range of applied molybdenum to result in forage concentrations from deficiency to toxicity (for animals). One of the sites has sufficiently acid soil so a lime treatment will be included to assess the increase in molybdenum availability as the result of raising the soil pH. Each experiment will be established so that alfalfa forage yields can be collected throughout the season as well as sufficient treatment area to collect `stage of growth' plant tissue samples. Forage and plant tissue samples will be analyzed for molybdenum, copper, boron and other nutrients to ensure that only molybdenum is the nutrient limiting alfalfa growth. Data will be collected from the experiments for three years to measure molybdenum responses over time under different seasonal climatic and other environmental effects on crop growth.

The current University of California guidelines for molybdenum concentrations in alfalfa are: deficient -- <0.3 ppm, critical - 0.3-0.9 ppm, adequate - 1-5 ppm, and high - 5-10 ppm with the comment that concentrations in excess of 10 ppm may result in molybdenosis in ruminant animals. These are suitable for the 1/10th growth stage or when %2 to 1" regrowth from the crown appears. It has been observed on a number of occasions that alfalfa is severely stunted after the 1St, 2nd or even 3rd cutting has been harvested. Sampling this very short regrowth usually indicates very low molybdenum concentrations but foliar applications of molybdenum without rainfall or sprinkler irrigation may easily result in toxic forage. Plant concentrations are likely to be well in excess of 10 ppm even if considerable regrowth occurs. Our second objective is focused on this problem. When the first growth occurs in the spring and it begins to appear chlorotic or generally yellow in color at an early growth stage, the most likely nutrient deficiency is either sulfur or molybdenum. Sampling every 8 to 10 days during the development of the alfalfa plant prior to each harvest of the growing season will either substantiate current guideline concentrations or suggest new deficient and adequate levels be adopted for different growth stages.

Results:

Two sites were laid out in conjunction with this project, one in Shasta County several miles north of Burney, CA, and a second in Siskiyou County several miles northwest of Fort Jones, CA, in Scott Valley. The work description including the project activities identified by tasks and subtasks is incorporated into the presentation of the results.

Shasta County Site**-2000**-Site # 1

The Shasta County Site was initiated on March 31, 2000 when the treatments listed in Table 1 were applied. Individual plots were 10 ft by 25 ft in size and the field trial design was a randomized complete block with 3 blocks or replications. Several alfalfa fields on the ranch were sampled in August 1999 and indicated top 1/3 of plant concentrations of molybdenum were in the 0.1 - 0.3 ppm range. Plant tissue samples also indicated that phosphorus, potassium, sulfur, and boron were in the adequate range.

Early plant growth stage samples were taken at 6 inches height, at 12 inches height as well as at harvest. All of the plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high or taller plants were analyzed for molybdenum concentrations to develop the relationships between growth stage, yield and molybdenum concentration. The first harvest was collected at the early bud stage of plant development on May 25, 2000. Yield results given in Table 1 indicate a small but significant yield increase in response to molybdenum additions for the first harvest with slight trends for response in the second and third harvests. Normally there would not be a response expected from a lime application during the first year after it is applied on the soil surface.

Table 1. Alfalfa yield during 2000 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo lbs/A	Lime tons/A	May 25 Yield tons DM/A	July 8 Yield tons DM/A	Aug 11 Yield tons DM/A	Sept 29 Yield tons DM/A
1. Control	0	0	2.27 cd	1.45	2.00	1.02
2. Mo	0.2	0	2.53ab	1.49	2.01	0.98
3. Mo	0.3	0	2.44 be	1.49	2.19	1.03
4. Mo	0.4	0	2.48abc	1.46	2.14	1.08
5. Mo	0.6	0	2.60ab	1.57	2.23	1.04
6. Mo	0.8	0	2.68a	1.53	2.12	1.09
7. Mo	1.2	0	2.50ab	1.57	2.15	1.03
8. Lime	0	2	2.21 d	1.57	1.97	0.97
$LSD_{0.05}$			0.222	0.120(NS)	0.386(NS)	0.154(NS)

The molybdenum concentrations of the top 1/3 of plant samples taken at harvest (equivalent to the top 6 inches of the plant) are given for the four harvests in 2000 in Table 2. It can be noted that there is a significant increase in alfalfa yield (1st harvest-May 25th in Table 1) and molybdenum concentration (Mo concentration-May 25th in Table 2) with the increase in the rate of molybdenum application but no response to lime. Maximum yield was achieved with 0.6 - 0.8 lbs Mo/A (Table 1). The 1.2 lbs Mo/A rate resulted in a rather high molybdenum concentration of just over 5 ppm in the plant (Table 2) which is well above the desired plant level for maximum yield and approaches the problem range for animals, particularly if copper concentrations are below the 8 - 10 ppm range. Copper concentration in the top 1/3 of plant samples is given in Table 3. Note that all were in the normal range (8.3-15.1 ppm) and there were no significant differences in copper concentrations in the top 1/3 of the plant in response to either the molybdenum or lime treatments.

Table 2. Alfalfa molybdenum concentration in the top 1/3 of plant samples taken at harvest during 2000 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo lbs/A	Lime tons/A	May 25 Mo Conc. ppm	July 8 Mo Conc. m	Aug 11 Mo Conc. m	Sept 29 Mo Conc. ppm
1. Control	0	0	0.23 e	0.20 d	0.17 c	0.17 c
2. Mo	0.2	0	0.67 de	0.43 cd	0.23 c	0.30 be
3. Mo	0.3	0	0.87 cd	0.47 cd	0.30 c	0.30 be
4. Mo	0.4	0	1.40 c	0.60 bed	0.33 c	0.43 be
5. Mo	0.6	0	2.43 b	1.13 b	0.70 b	0.57 b
6. Mo	0.8	0	2.33 b	0.97 be	0.70 b	0.67 b
7. Mo	1.2	0	5.07a	2.07a	1.17a	1.37a
8. Lime	0	2	0.47 de	0.23 d	0.20 c	0.30 be
LSDo.os			0.63	0.58	0.18	0.38

Table 3. Alfalfa copper concentration in the top 1/3 of plant samples taken at harvest during 2000 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo lbs/A	Lime tons/A	May 25 Cu Conc. ppm	July 8 Cu Conc. ppm	Aug 11 Cu Conc. ppm	Sept 29 Cu Cone. ppm
1. Control	0	0	9.4	12.7	12.6	11.8
2. Mo	0.2	0	8.8	15.1	12.5	11.5
3. Mo	0.3	0	8.3	13.9	12.7	11.1
4. Mo	0.4	0	8.3	13.8	12.5	11.4
5. Mo	0.6	0	8.5	13.4	13.6	11.3
6. Mo	0.8	0	9.0	13.3	12.2	11.4
7. Mo	1.2	0	8.3	13.4	10.9	11.1
8. Lime	0	2	9.5	11.1	12.8	10.8
LSDo.os			1.3 (NS)	3.9 (NS)	5.2 (NS)	1.2 (NS)

The plant tissue samples taken at harvest (May 25, 2000) indicated that phosphorus (P04- P), potassium, sulfur and boron were all in the adequate range. Zinc (19-33 ppm), manganese (24-47 ppm), iron (62-104 ppm), copper (6.1-10.2 ppm) and cobalt (0.1-0.2 ppm) would be considered to be adequate while selenium for animals would be slightly in the deficient range, 0.023 - 0.145 ppm.

Shasta County Site-2001

Early plant growth stage samples were taken at 6 inches height, at 12 inches height, and pre-bud (when only 2 - 5% of the plants have a small ball that can just be detected between the thumb and forefinger indicating the bud is developing) growth stage prior to each harvest as well as sampling at harvest. In some cases, growers harvest prior to 1/10 bloom so samples taken at harvest will be characterized as to stage of growth. All of the plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high, pre-bud plants and at harvest plants were analyzed for molybdenum, boron and copper concentrations to develop the relationships between growth stage, alfalfa yield and molybdenum and boron concentrations.

The first harvest for the second year of this trial was collected at the early bud stage of plant development on May 25, 2001. Yield results given in Table 4 indicate a small but significant yield increase in response to molybdenum additions for the first and fourth harvests but growth responses were inconsistent for both the 2'd and 3rd harvests . As is often the case during the second year, the application of lime at the rate of 2 tons/A gave a slightly higher alfalfa yield response to that of most of the applied molybdenum treatments for the four harvests. The plant tissue samples taken at the 1st and 3rd harvests (May 25th and August 13th) indicated that phosphorus (P04-P), potassium, sulfur and boron were all in the adequate range while selenium for animals would be slightly in the deficient range, all below 0.10 ppm.

Table 4. Alfalfa yield during 2001 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo lbs/A	Lime tons/A	May 25 Yield tons DM/A	July 6 Yield tons DM/A	August 13 Yield tons DM/A	October 1 Yield tons DM/A
1. Control	0	0	1.76 b	1.54ab	0.93	0.97ab
2. Mo	**0.2**	**0**	**1.91ab**	**1.52ab**	**1.02**	**0.94ab**
3. Mo	**0.3**	**0**	**1.88ab**	**1.64a**	**1.06**	**1.00ab**
4. Mo	**0.4**	**0**	**1.89ab**	**1.37 b**	**0.99**	**0.97ab**
5. Mo	0.6	0	1.96ab	1.51ab	0.97	1.04ab
6. Mo	**0.8**	**0**	**2.00a**	**1.64a**	**0.94**	**0.96ab**
7. Mo	1.2	0	1.89ab	1.43ab	1.01	0.85 b
8. Lime	**0**	**2**	**1.92ab**	**1.67a**	**1.12**	**1.11a**
LSD0.05			**0.228**	**0.260**	**0.260 (NS)**	**0.215**

The molybdenum concentrations in the top 1/3 of plant samples (equivalent to the top 6 inches of the plant) are given for the four harvests in 2001 in Table 5. The yields during 2001 reached near maximum with 0.3 to 0.6 lbs applied Mo per acre. This is also where the molybdenum concentration in the top 1/3 of the plant reaches approximately 0.5 to slightly over 1 ppm. It is interesting to note that the molybdenum concentration decreased throughout the season, particularly for the treatments having the higher rates of applied Mo. As is often the case during the second year, the application of lime gave a higher molybdenum concentration than the control. The 1.2 lbs Mo/A rate resulted in a molybdenum concentration of 2.47 ppm compared to just over 5 ppm in the plant last year.

Table 5. Alfalfa molybdenum concentration in the top 1/3 of plant samples taken at harvest during 2001 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo Lbs/A	Lime tons/A	May 25 Mo Conc. m	July 6 Mo Conc. m	Aug 13 Mo Conc. m	Oct 1 Mo Conc. m
1. Control	0	0	0.27 d	0.23 b	0.17 c	0.20 e
2. Mo	0.2	0	0.50 cd	0.47 b	0.23 c	0.33 de
3. Mo	0.3	0	0.70 cd	0.60 b	0.43 be	0.50 cd
4. Mo	0.4	0	0.70 cd	0.50 b	0.33 c	0.37 de
5. Mo	0.6	0	1.37 b	1.13a	0.63 b	0.57 c
6. Mo	0.8	0	1.30 b	1.23a	0.63 b	0.90 b
7. Mo	1.2	0	2.47a	1.50a	1.13a	1.17a
8. Lime	0	2	0.97 be	0.60 b	0.33 c	0.47 cd
LSD0.05			0.505	0.508	0.298	0.200

Table 6. Alfalfa copper concentration in the top 1/3 of plant samples taken at harvest during 2001 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo Lbs/A	Lime tons/A	May 25 Cu Conc. ppm	July 6 Cu Conc. Win	Aug 13 Cu Conc. ppm	Oct 1 Cu Conc. Ppm
1. Control	0	0	12.9	9.8	12.0	10.6
2. Mo	0.2	0	15.3	11.2	13.4	10.9
3. Mo	0.3	0	13.7	10.2	12.4	11.2
4. Mo	0.4	0	13.2	10.2	12.4	10.6
5. Mo	0.6	0	12.9	10.5	11.6	9.9
6. Mo	0.8	0	13.0	11.6	12.8	10.1
7. Mo	1.2	0	12.9	11.2	11.8	10.2
8. Lime	0	2	12.7	10.4	11.0	10.6
LSD0.05			2.56 (NS)	2.37 (NS)	1.97 (NS)	1.0 (NS)

Copper concentrations in the top 1/3 of plant samples taken at harvest for the four harvests in 2001 are given in Table 6. Note that all were in the normal range of 10-13 ppm. Note as well that there were no significant differences in copper concentrations in the top 1/3 of the plant in response to either the molybdenum or lime treatments.

Shasta County Site-2002

To reduce the number of samples and thus the cost of laboratory analyses, early plant growth stage samples were only taken prior to the first and third cuttings of alfalfa during 2002 and 2003. They were taken at 6 inches height, at 12 inches height, prebud and at harvest. All of the plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high plants, prebud and harvest time samples were analyzed for molybdenum, boron and copper concentrations to develop the relationships between growth stage, alfalfa yield and molybdenum and boron concentrations.

The first harvest for 2002 was collected at 1/10th bloom stage of plant development on June 14th. The considerably later harvest was a result of herbicide damage to early season growth of the alfalfa. No significant yield responses were observed from the application of molybdenum in the first harvest results (Table 7). Alfalfa yield responses to molybdenum and lime applications in the second harvest on July 19th were significant but somewhat erratic. As in the first harvest, there were no significant yield responses to molybdenum or lime treatments in the 3rd harvest on September 3rd. There is a trend for increased yield as the rate of applied molybdenum increases in all three cuttings. Note as well that the lime alone treatment resulted in equally as high a yield as the molybdenum treatments. This is often the case since raising the soil pH increases the availability of molybdenum to plants. Maximum yield was often achieved with as little as 0.2 lbs Mo/A up to the higher rates of 0.8 lbs Mo/A. Phosphorus (P04-P), potassium, sulfate-sulfur (S04-S) and boron were all in the adequate range based on midstem, midstem leaf and top 1/3 of plant samples taken on June 14th and September 3, 2002.

Table 7. Alfalfa yield during 2002 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo (lbs/A)	Lime (tons/A)	June 14 Yield (tons DM/A)	July 19 Yield (tons DM/A)	Sept 3 Yield (tons DM/A)
1. Control	0	0	1.81	1.48 cd	1.52
2. Mo	0.2	0	1.94	1.45 cd	1.65
3. Mo	0.3	0	1.93	1.57abc	1.59
4. Mo	0.4	0	1.95	1.41 d	1.58
5. Mo	0.6	0	1.91	1.63ab	1.49
6. Mo	0.8	0	2.07	1.68a	1.66
7. Mo	1.2	0	1.83	1.51 bcd	1.50
8. Lime	0	2	2.22	1.57abc	1.62
$LSD_{0.05}$			0.396(NS)	0.124	0.200(NS)

The molybdenum concentrations in the top 1/3 of plant samples taken at harvest (equivalent to the top 6 inches of the plant) are given for the three harvests in 2002 in Table 8. It can be noted that yields during 2002 (Table 7) reached near maximum with 0.2 to 0.8 lbs applied Mo per acre. This is also where the molybdenum concentration in the top 1/3 of the plant reaches approximately 0.17 to slightly over 1.7 ppm. It is interesting to note that the molybdenum concentration decreased dramatically throughout the season for most treatments. Concentrations of molybdenum may be no more than '/4 to 1 /3 in the 3rd harvest of the level observed in the 15` harvest. As is often the case during the second or later years, the application of lime gave a higher molybdenum concentration than the control. The 1.2 lbs Mo/A rate resulted in a molybdenum concentration of 2.80 ppm in the first harvest compared to just over 5 ppm in the plant two years ago. Copper concentrations in the top 1/3 of plant samples for the

Table 8. Alfalfa molybdenum concentration in the top 1/3 of plant samples taken at harvest during 2002 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo Lbs/A	Lime tons/A	June 14 Mo Conc. ppm	July 19 Mo Conc. pm	Sept 3 Mo Conc. m
1. Control	0	0	0.37 c	0.30 d	0.17 c
2. Mo	0.2	0	0.90 be	0.50 cd	0.17 c
3. Mo	0.3	0	1.00 be	0.50 cd	0.27 be
4. Mo	0.4	0	0.87 be	0.53 cd	0.33 be
5. Mo	0.6	0	1.50 a	1.07 b	0.40 be
6. Mo	0.8	0	1.77 b	1.07 b	0.50ab
7. Mo	1.2	0	2.80a	1.60a	0.70a
8. Lime	0	2	1.23 be	0.73 be	0.33 be
LSDo.os			0.927	0.388	0.254

Table 9. Alfalfa copper concentration in the top 1/3 of plant samples taken at harvest during 2002 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo Lbs/A	Lime tons/A	June 14 Cu Conc. m	July 19 Cu Conc. ppm	Sept 3 Cu Conc. ppm
1. Control	0	0	11.0	9.7	12.3
2. Mo	0.2	0	11.0	10.5	12.2
3. Mo	0.3	0	10.9	10.0	12.1
4. Mo	0.4	0	11.4	10.2	11.8
5. Mo	0.6	0	11.5	10.5	11.8
6. Mo	0.8	0	10.9	10.6	12.1
7. Mo	1.2	0	11.3	10.5	11.6
8. Lime	0	2	11.4	9.8	11.8
LSDo.os			1.60(NS)	1.53(NS)	1.05(NS)

three harvests in 2002 are given in Table 9. Note that all were in the normal range of 10-12 ppm. Note as well that there were no significant differences in copper concentrations in the top 1/3 of the plant in response to either the molybdenum or lime treatments.

Shasta County Site-2003

Alfalfa yield results for 2003 are given in Table 10. No significant yield responses to molybdenum or lime treatments were observed during the year. The strongest trend for a yield response was observed in the second harvest with little if any trend indicated in the first or third harvests. Note that the lime alone treatment resulted in equally as high a yield as the molybdenum treatments in the second and third harvest but not in the first harvest. This is often the case since raising the soil pH increases the availability of molybdenum to plants. Maximum yield was often achieved with as little as 0.2 lbs Mo/A up to the higher rates of 0.8 lbs Mo/A. Phosphorus (P04-P), potassium, sulfate-sulfur (S04-S) and boron were all in the adequate range.

Table 10. Alfalfa yield during 2003 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo (lbs/A)	Lime (tons/A)	June 3 Yield (tons DM/A)	July 14 Yield (tons DM/A)	Sept 3 Yield (tons DM/A)
1. Control	0	0	1.81	1.75	1.48ab
2. Mo	0.2	0	1.85	1.88	1.41 b
3. Mo	0.3	0	1.81	1.86	1.55ab
4. Mo	0.4	0	1.66	1.86	1.47ab
5. Mo	0.6	0	2.01	2.07	1.54ab
6. Mo	0.8	0	1.94	2.06	1.43ab
7. Mo	1.2	0	1.81	1.93	1.50ab
8. Lime	0	2	1.75	2.08 S)	1.59a
LSDo.os			0.372(NS)	0.411	0.175

Plant growth stage samples were taken at 6 inches height, 12 inches height, prebud (only a small ball was formed to indicate the new bud) and at harvest (early bud to 1/10th bloom) for the first and third harvests in 2003. All of the plant material of the samples collected at the 6- inch growth stage and only the top 6 inches of the 12-inch high or older plants were analyzed for molybdenum concentrations to develop the relationships between growth stage and molybdenum concentration.

The molybdenum concentrations in the top 1/3 of plant samples (equivalent to the top 6 inches of the plant) are given for the three harvests in 2003 in Table 11. In general, yields during 2003 (Table 10) reached near maximum with 0.2 to 0.8 lbs applied Mo per acre. This is also where the molybdenum concentration in the top 1/3 of the plant reaches approximately 0.10 to 1.7 ppm. As in pass years, the molybdenum concentration decreased dramatically throughout the season for most treatments. Concentrations of molybdenum may be no more than 1/8 to 1/3 in the 3rd harvest of the level observed in the 1St harvest. As is often the case during the second or later years, the application of lime gave a higher molybdenum concentration than the control. The 1.2 lbs Mo/A rate resulted in a molybdenum concentration of 2.63 ppm compared to just over 5 ppm in the plant three years ago. The over 5 ppm level which is well above the desired plant level for maximum alfalfa yield, approaches the problem range for animals, particularly if copper concentrations are below the 8 - 10 ppm range. Copper concentrations in the top 1/3 of plant samples for the three harvests in 2002 are given in Table 12. Note that most were in the normal range of 10-12 ppm or higher. Note as well that there were no significant differences in copper concentrations in the top 1/3 of the plant in response to either the molybdenum or lime treatments.

Table 11. Alfalfa molybdenum concentration in the top 1/3 of plant samples taken at

harvest during 2003 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo Lbs/A	Lime tons/A	June 2 Mo Conc. Ppm	July 14 Mo Conc. ppm	Sept 3 Mo Conc. m
1. Control	0	0	0.50 e	0.13 b	0.10 c
2. Mo	0.2	0	0.87 de	0.13 b	0.10 c
3. Mo	0.3	0	1.67 cd	0.20 b	0.10 c
4. Mo	0.4	0	1.23 cd	0.20 b	0.13 c
5. Mo	0.6	0	1.53 be	0.50ab	0.20 be
6. Mo	0.8	0	1.67 be	0.53ab	0.27ab
7. Mo	1.2	0	2.63a	0.67a	0.33a
8. Lime	0	2	1.87 b	0.43ab	0.17 be
LSDo.os			0.144	0.375	0.111

Table 12. Alfalfa copper concentration in the top 1/3 of plant samples taken at harvest during 2003 as influenced by molybdenum and lime treatments applied on March 31, 2000.

Treatment	Mo Lbs/A	Lime tons/A	June 2 Cu Conc. Ppm	July 14 Cu Conc. ppm	Sept 3 Cu Conc. ppm
1. Control	0	0	13.3	11.4	9.4
2. Mo	0.2	0	13.9	12.1	9.5
3. Mo	0.3	0	14.1	12.2	9.2
4. Mo	0.4	0	14.0	12.2	11.2
5. Mo	0.6	0	13.6	11.9	9.9
6. Mo	0.8	0	13.8	11.6	9.7
7. Mo	1.2	0	13.2	11.0	9.7
8. Lime	0	2	13.9	11.5	9.4
$LSD_{0.05}$			1.06(NS)	1.76(NS)	1.59(NS)

Shasta County Site-2000-2003-Four Year Yield Totals for Site # 1

Yield results for the four-year period 2000-2003 are given in Table 13. Even though there were no significant yield responses to molybdenum or lime treatments, slight trends did exist during 2000 (Probability=13.8%), 2002 (Probability=11.9%), and for the four year total yields (Probability=21.3%). One individual harvest in 2000 and one in 2002 had highly significant yield responses to molybdenum. Note that the lime alone treatment resulted in equally as high a yield as the molybdenum treatments in the second, third and fourth years but not in the first year. This is often the case since raising the soil pH increases the availability of molybdenum to plants but some period of time is necessary to effect yields if no incorporation of the lime occurs. Maximum yield was often achieved with as little as 0.2 lbs Mo/A up to the higher rates of 0.8 lbs Mo/A. Rates greater than 0.6 - 0.8 lbs Mo/A however often increase molybdenum concentrations in the forage to undesirable levels the first year or two after application considering the needs of animals, particularly if copper concentrations are below the 8 - 10 ppm range (See Figure 4). Phosphorus (midstem PO_4-P), potassium (midstem K), and sulfate-sulfur (midstem leaf SO_4-S) and boron were all maintained in the adequate range.

Table 13. Alfalfa yields (100% dry matter basis) during the four-year period 2000-2003 as influenced by molybdenum and lime treatments applied on March 31, 2000. Four harvests were made in 2000 and 2001 while three were made in 2002 and 2003.

Treatment	Mo **lbs/** A	Lime **tons/** A	2000 Yield **tons** DM/A	2001 Yield **tons** DM/A	2002 Yield **tons** DM/A	2003 Yield **tons** DM/A	Total Yield **tons** DM/A
1. Control	0	0	6.74	5.39	4.81	5.17	22.10
2. Mo	0.2	0	7.01	5.60	5.04	5.25	22.90
3. Mo	0.3	0	7.15	5.79	5.08	5.38	23.41
4. Mo	0.4	0	7.16	5.42	4.93	5.12	22.63
5. Mo	0.6	0	7.45	5.68	5.02	5.72	23.87
6. Mo	0.8	0	7.42	5.73	5.41	5.60	24.15
7. Mo	1.2	0	7.25	5.38	4.83	5.35	22.81
8. Lime	0	2	6.72	6.06	5.41	5.58	23.77
Probability			0.138	0.400	0.119	0.633	0.213

Plant growth stage samples were taken at 6 inches height, 12 inches height, prebud (only a small ball was formed to indicate the new bud) and at harvest (early bud to 1/10th bloom) for three harvests in 2001 and one each in 2000, 2002 and 2003. All of the plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high or older plants were analyzed for molybdenum, boron and copper concentrations to develop the relationships between growth stage and molybdenum, boron and copper concentrations.

Shasta County Site-2001-Site # 1-Forage Quality

To evaluate the effect of molybdenum and lime upon alfalfa forage quality during 2001, the analysis for crude protein was conducted. Table 14 gives the changes in crude protein (total N x 6.25) associated with the increased rate of applied molybdenum and lime. There were no statistically significant differences in crude protein as a result of the treatments. There seems to be a rather consistent trend for the crude protein to be slightly higher for most of the molybdenum and lime treatments. Acid detergent fiber (ADF) analysis was also conducted on all whole plant samples during 2001 to determine total digestible nutrient (TDN) levels. No statistically significant differences in total digestible nutrient (TDN) levels were observed in any of the four harvests as a result of the molybdenum, boron or lime treatments.

Table 14. Alfalfa crude protein during 2001 as influenced by molybdenum and lime treatments applied on March 31, 2000.

			Crude Protein			
Treatment	Mo (lbs/A)	Lime (tons/A)	May 25 %	July 6 %	Aug 13 %	Oct 1 %
1. Control	0	0	22.13	21.33	23.10	26.47
2. Mo	0.2	0	23.37	22.80	24.67	27.70
3. Mo	0.3	0	23.53	21.10	24.13	26.97
4. Mo	0.4	0	22.77	20.77	24.40	27.00
5. Mo	0.6	0	22.70	21.90	23.93	27.67
6. Mo	0.8	0	23.53	20.93	24.70	27.70
7. Mo	1.2	0	22.77	20.17	26.10	26.37
8. Lime	0	2	22.70	21.93	24.67	26.97
$LSD_{0.05}$			1.632(NS)	3.037(NS)	3.086(NS)	1.774(NS)

Shasta County Site-2000-2003- Four Year Forage Quality Summary -Site # 1

To evaluate the effect of molybdenum and lime treatments on alfalfa forage quality, chemical analyses for crude protein and acid detergent fiber (ADF) to determine total digestible nutrients (TDN) were conducted on four harvests in 2001 and three harvests in 2002 and 2003. There were no statistically significant differences in crude protein as a result of the treatments. There did seem to be a rather consistent trend for the crude protein to be slightly higher for most of the molybdenum and lime treatments however. Acid detergent fiber (ADF) analysis on whole plant samples to determine total digestible nutrient (TDN) levels also showed no statistically significant differences in total digestible nutrient (TDN) levels as a result of the molybdenum or lime treatments.

Siskiyou County Site-2001-Site # 2

The Siskiyou County site was initiated when the treatments given in Table 15 were applied, lime on March 9, 2001 and boron and molybdenum on March 10, 2001. Individual plots were 10 ft by 25 ft in size and the field trial design was a randomized complete block with 3 blocks or replications. The alfalfa field proposed for a trial was sampled on June 21, 2000 and found to have low concentrations of molybdenum (0.2 - 0.3 ppm) and boron (6 ppm). Plant tissue samples also indicated that phosphorus (>2700 ppm midstem P04-P), potassium (>4.5 % midstem total K), and sulfur (>1250 ppm midstem leaf S04-S) were in the above adequate range.

Early plant growth stage samples were taken at 6 inches height (May 4, 2001), at 12 inches height (May 14, 2001), and pre-bud (when only 2 - 5% of the plants have a small ball that can just be detected between the thumb and forefinger indicating the bud is developing) growth stage prior to each harvest as well as sampling at harvest. In some cases, growers harvest prior to 1/10 bloom so samples taken at harvest were characterized as to stage of growth. All of the
plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high, pre-bud plants and at harvest plants were analyzed for molybdenum, boron and copper concentrations to develop the relationships between growth stage, alfalfa yield and molybdenum and boron concentrations.

Table 15. Alfalfa yield during 2001 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/ A	B lbs/ A	Lime tons/ A	May 18 Yield tons DM/A	July 2 Yield tons DM/A	Aug 13 Yield tons DM/A	Sept 28 Yield tons DM/A
1. Control	0		0	1.56ab	2.34 c	2.04	1.30 b
2. Mo plus B	0.2	4	0	1.57ab	2.75a	2.19	1.38ab
3. Mo plus B	0.3	4	0	1.65ab	2.55abc	2.16	1.39ab
4. Mo plus B	0.4	4	0	1.76a	2.50abc	2.06	1.39ab
5. Mo plus B	0.6	4	0	1.71 ab	2.70ab	2.15	1.40ab
6. Mo plus B	0.8	4	0	1.66ab	2.50abc	2.18	1.36ab
7. Mo plus B	1.2	4	0	1.68ab	2.51abc	2.21	1.47a
8. Mo	0.4	0	0	1.65ab	2.40 c	2.12	1.35ab
9. Mo	0.8	0	0	1.60ab	2.49abc	2.07	1.35ab
10. B	0	2	0	1.68ab	2.36 c	2.12	1.31 b
11. B	0	4	0	1.72a	2.39 c	2.13	1.39ab
12. Lime	0		2	1.46 b	2.37 c	2.16	1.35ab
13. Mo + B + Lime	0.2	4	2	1.61 ab	2.43 be	2.14	1.40ab
14. Mo + B + Lime	0.4	4	2	1.69ab	2.48abc	2.18	1.38ab
LSD0.05				0.260	0.281	0.184 (NS)	0.150

The first harvest was collected at the pre-bud stage of plant development on May 18, 2001. The yield results are given in Table 15. It can be noted that there is a slight trend for molybdenum, boron or a combination of molybdenum and boron to increase the first harvest alfalfa yields. Observations of the trial just prior to harvest indicated the control plots as well as those receiving molybdenum alone had slightly chlorotic tops of the plants because of boron deficiency. This slightly chlorotic appearance of the tops of the plants caused by boron deficiency seldom results in vegetative yield decreases but could reduce seed yields by 25 to 50% or more. Second harvest (July 2) yields show a somewhat similar trend but with slightly less response from boron or lime alone treatments. Third harvest (August 13) yields show only a slight trend for improvement from applied treatments. Fourth harvest (September 28) yields also show a slight trend but significant increase to molybdenum and boron at the higher rates of application.

The molybdenum concentrations in the top 1/3 of plant samples taken at harvest (equivalent to the top 6 inches of the plant) are given for the four harvests in 2001 in Table 16. Note first of all that molybdenum concentrations in the top 1/3 of the plant were much higher than in site #1, reaching well over 1 ppm and up to 3 ppm or above (7.17 ppm in the first harvest at the 0.6 lbs applied Mo per acre). As was the case at site #1, yields during 2001 reached near maximum with 0.3 to 0.6 lbs applied Mo per acre and this is also where the molybdenum concentration in the top 1/3 of the plant reaches approximately 0.5 to well over 1 ppm. Similar to site #1, the molybdenum concentrations decreased throughout the season, particularly for the treatments receiving the higher rates of applied Mo. The application of lime resulted in no change in the molybdenum concentration as compared to the control.

Table 16. Alfalfa molybdenum concentration in the top 1/3 of plant samples taken at harvest during 2001 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/ A	B lbs /A	Lime tons/ A	May 18 Mo Conc. pm	July 2 Mo Conc. ppm	Aug 13 Mo Conc. ppm	Sept 28 Mo Conc. ppm
1. Control	0		0	0.37	0.13	0.17	0.17
2. Mo plus B	0.2	4	0	1.77	1.13	1.00	0.77
3. Mo plus B	0.3	4	0	4.67	1.93	1.53	1.57
4. Mo plus B	0.4	4	0	5.00	2.07	1.90	1.73
5. Mo plus B	0.6	4	0	7.17	3.27	2.87	2.90
6. Mo plus B	0.8	4	0	8.30	4.07	3.17	3.20
7. Mo plus B	1.2	4	0	14.73	6.50	3.70	5.50
8. Mo	0.4	0	0	4.37	1.67	1.43	1.57
9. Mo	0.8	0	0	8.93	3.73	2.93	3.07
10. B	0	2	0	0.83	0.37	0.33	0.33
11. B	0	4	0	0.33	0.27	0.20	0.17
12. Lime	0		2	0.27	0.23	0.17	0.17
13. Mo + B + Lime	0.2	4	2	3.87	1.40	1.07	1.10
14. Mo + B + Lime	0.4	4	2	6.47	2.80	1.83	2.00
LSD0.05				2.124	1.015	0.800	0.948

The 1.2 lbs Mo/A rate resulted in a molybdenum concentration of nearly 15 ppm compared to 3.70 and 5.50 ppm in the 3rd and 4th harvests. The 3 to over 5 ppm level and certainly the 15 ppm concentration is well above the desired plant level for maximum alfalfa yield, and the 15 ppm level is in the problem range for animals, particularly if copper concentrations are below the 8 - 10 ppm range. Note that all were in the low range of 5 -7 ppm (Table 17).

Copper concentrations in the top 1/3 of plant samples for the four harvests in 2001 are given in Table 17. Note that all concentrations are well below the levels observed in site #1 and could therefore become more of an animal health problem if molybdenum concentrations exceed 5 ppm. Note that there were no significant differences in copper concentrations in the top 1/3 of the plant in response to either the molybdenum, boron or lime treatments.

Table 17. Alfalfa copper concentration in the top 1/3 of plant samples taken at harvest during 2001 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/A	B lbs/A	Lime tons/A	May 18 Cu Conc. ppm	July 2 Cu Conc. ppm	Aug 13 Cu Conc. ppm	Sept 28 Cu Conc. ppm
1. Control	0		0	6.47	5.93	5.63	5.40
2. Mo plus B	0.2	4	0	5.63	5.93	5.63	5.57
3. Mo plus B	0.3	4	0	5.80	6.20	5.67	5.27
4. Mo plus B	0.4	4	0	5.97	6.07	5.80	5.70
5. Mo plus B	0.6	4	0	5.80	6.23	6.27	5.83
6. Mo plus B	0.8	4	0	6.13	6.37	6.27	5.53
7. Mo plus B	1.2	4	0	6.13	6.10	5.97	5.97
8. Mo	0.4	0	0	6.13	5.93	5.67	5.40
9. Mo	0.8	0	0	5.97	5.47	5.97	5.67
10. B	0	2	0	6.30	5.80	5.93	6.50
11. B	0	4	0	5.63	5.63	5.83	5.27
12. Lime	0		2	6.13	5.93	5.50	5.57
13. Mo + B + Lime	0.2	4	2	6.13	6.07	6.27	5.83
14. Mo + B + Lime	0.4	4	2	5.97	6.40	5.80	6.10
$LSD_{0.05}$				0.80(NS)	0.70(NS)	0.81(NS)	0.91(NS)

Boron concentrations in the top 1/3 of plant samples for the four harvests in 2001 are given in Table 18. Boron concentrations are significantly higher in all of the treatments receiving boron. The control and all treatments not receiving applied boron had concentration in the 11-16 ppm range throughout 2001. Treatment #10 which received 2 lbs B/A had concentrations in the 36 to 42 ppm range while treatments receiving 4 lbs B/A were somewhat higher, 40-60 ppm. The first harvest had somewhat lower boron concentrations (40-47 ppm) than the 2n' through 4th harvests (52-60 ppm) in 2001.

The plant tissue samples taken at the 1st and 3`a harvests (May 18th and August 13th) indicated that phosphorus (PO4-P), potassium and sulfate - sulfur (S04-S) were all in the adequate range while selenium for animals would be slightly in the deficient range, all below 0.10 ppm.

Table 18. Alfalfa boron concentration in the top 1/3 of plant samples taken at harvest during 2001 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/ A	B lbs /A	Lime tons/ A	May 18 B Conc. ppm	July 2 B Conc. ppm	Aug 13 B Conc. ppm	Sept 28 B Conc. ppm
1. Control	0		0	14 d	12 c	14 e	11 e
2. Mo plus B	0.2	4	0	41 b	52a	57abc	57 be
3. Mo plus B	**0.3**	**4**	**0**	**42ab**	**53a**	**52 c**	**60abc**
4. Mo plus B	**0.4**	**4**	**0**	**40 be**	**59a**	**53 be**	**57 c**
5. Mo plus B	**0.6**	**4**	**0**	**41 be**	**57a**	**56abc**	**59abc**
6. Mo plus B	**0.8**	**4**	**0**	**47a**	**59a**	**56abc**	**64ab**
7. Mo plus B	**1.2**	**4**	**0**	**42ab**	**59a**	**60a**	**65a**
8. Mo	**0.4**	**0**	**0**	**12 d**	**12 c**	**14 e**	**11 e**
9. Mo	**0.8**	**0**	**0**	**16 d**	**15 c**	**15 e**	**12 e**
10. B	0	2	0	36 c	42 b	42 d	38 d
11. B	0	4	0	44ab	56a	58ab	65a
12. Lime	0		2	13 d	16 c	13 e	12 e
13. Mo + B + Lime	**0.2**	**4**	**2**	**41 b**	**57a**	**60a**	**64abc**
14. Mo + B + Lime	**0.4**	**4**	**2**	**43ab**	**57a**	**52 c**	**64abc**
LSDo.os				4.75	8.54	5.63	7.40

Siskiyou County Site-2002

To reduce the number of samples and thus the cost of laboratory analyses early plant growth stage samples were only taken prior to the first and third cuttings of alfalfa during 2002 and 2003. They were taken at 6 inches height, at 12 inches height , prebud and at harvest. All of the plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high plants , prebud and harvest time samples were analyzed for molybdenum, boron and copper concentrations to develop the relationships between growth stage and molybdenum and boron concentration

Yield results for the four harvests for 2002 are given in Table 19. Molybdenum and boron in combination or with lime usually resulted in higher yields than the control . Selected treatments resulted in significantly higher yields over the control in the first and second harvests. It can be noted that neither molybdenum, boron nor lime alone resulted in as consistently high yields as when

at least molybdenum and boron were applied. As was observed in site 1, near maximum yield was often achieved with as little as 0.2 to 0.4 lbs Mo/A. Observations of the trial just prior to harvest (all four harvests) indicated the control plots as well as those receiving molybdenum alone had slightly chlorotic tops of the plants because of boron deficiency. This slightly chlorotic appearance of the tops of the plants caused by boron deficiency usually does not result in vegetative yield decreases but could reduce seed yields by 25 to 50% or more. Phosphorus
(P04-P), potassium and sulfate-sulfur (S04-S) were all in the adequate range based on midstem, midstem leaf and top 1/3 of plant samples taken on May 28th and August 8, 2002.

Table 19. Alfalfa yield during 2002 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/ A	B lbs/ A	Lime tons/ A	May 28 Yield tons DM/A	July 3 Yield tons DM/A	Aug 8 Yield tons DM/A	Sept 20 Yield tons DM/A
1. Control	0		0	1.83 e	1.80 d	1.90	1.36
2. Mo plus B	0.2	4	0	2.09abcde	2.22ab	2.16	1.58
3. Mo plus B	0.3	4	0	2.16ab	2.26a	2.04	1.51
4. Mo plus B	0.4	4	0	2.24a	2.12abc	2.07	1.48
5. Mo plus B	0.6	4	0	2.24a	2.13abc	2.09	1.52
6. Mo plus B	0.8	4	0	2.08abcde	2.22ab	1.94	1.43
7. Mo plus B	1.2	4	0	2.12abc	2.20ab	2.09	1.52
8. Mo	0.4	0	0	1.88 cde	1.88 cd	1.87	1.39
9. Mo	0.8	0	0	1.96 bcde	1.89 cd	1.96	1.38
10. B	0	2	0	**2.11abcd**	2.00abcd	1.95	1.39
11. B	0	4	0	2.14abc	2.10abc	1.99	1.44
12. Lime	0		2	1.85 de	1.99abcd	1.97	1.37
13. Mo + B + Lime	0.2	4	2	2.21 ab	1.97 bcd	2.00	1.48
14. Mo + B + Lime	0.4	4	2	2.20ab	2.08abc	1.91	1.42
$LSD_{0.05}$				0.271	0.276	0.23(NS)	0.14(NS)

The molybdenum concentrations in the top 1/3 of plant samples taken at harvest (equivalent to the top 6 inches of the plant) are given for the four harvests in 2002 in Table 20. Molybdenum concentration in alfalfa was increased significantly with applied molybdenum. As was the case at site #1, yields during 2002 reached near maximum with 0.3 to 0.8 lbs applied Mo per acre. Molybdenum concentrations in the top 1/3 of the plant were much higher than in site #1, reaching well over 1 ppm and up to 3 ppm or above (4.67 ppm in the second harvest).
Similar to site #1, the molybdenum concentrations decreased throughout the season after the 2nd harvest, with the 1st and 3rd harvests having similar concentrations. The application of lime resulted in no change in the molybdenum concentration as

compared to the control. The 1.2 lbs Mo/A rate resulted in a molybdenum concentration of 3 to 5 ppm which is well above the desired plant level for maximum alfalfa yield, and levels above 5 ppm may present increasing problems for animals, particularly if copper concentrations are below the 8 - 10 ppm range.

Table 20. Alfalfa molybdenum concentration in the top 1/3 of plant samples taken at harvest during 2002 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/ A	B lbs /A	Lime tons/ A	May 28 Mo Conc. ppm	July 3 Mo Conc. ppm	Aug 8 Mo Conc. ppm	Sept 20 Mo Conc. ppm
1. Control	0		0	0.60	0.23	0.13	0.17
2. Mo plus B	0.2	4	0	0.83	1.07	0.80	0.57
3. Mo plus B	0.3	4	0	1.60	1.63	1.30	1.07
4. Mo plus B	0.4	4	0	1.70	2.13	1.90	1.37
5. Mo plus B	0.6	4	0	2.47	3.40	2.60	1.80
6. Mo plus B	0.8	4	0	2.73	4.57	3.43	2.07
7. Mo plus B	1.2	4	0	3.77	4.67	3.70	3.10
8. Mo	0.4	0	0	1.33	2.30	1.47	1.23
9. Mo	0.8	0	0	2.73	3.60	2.57	2.23
10. B	0	2	0	0.40	0.47	0.43	0.23
11. B	0	4	0	0.27	0.20	0.20	0.13
12. Lime	0		2	0.30	0.30	0.13	0.13
13. Mo + B + Lime	0.2	4	2	1.33	1.63	0.97	0.77
14. Mo + B + Lime	0.4	4	2	2.10	2.60	1.83	1.57
LSD0.05				0.836	0.764	0.447	0.360

Copper concentrations in the top 1/3 of plant samples for the four harvests in 2002 are given in Table 21. Note that all concentrations are well below the desired levels of 10-12 ppm and those observed in site #1. These low concentrations and therefore become more of an animal health problem if molybdenum concentrations exceed 5 ppm. Note that there were no significant differences in copper concentrations in the top 1/3 of the plant in response to either the molybdenum, boron or lime treatments.

Boron concentrations in the top 1/3 of plant samples for the four harvests in 2002 are given in Table 22. Boron concentrations are significantly higher in all of the treatments receiving boron. The control and all treatments not receiving applied boron had concentration in the 7-12 ppm range throughout 2002. Treatment #10 which received 2 lbs B/A had concentrations in the 20 to 26 ppm range while treatments receiving 4 lbs B/A were somewhat higher, 39-49 ppm. Boron concentrations during 2002 were somewhat below those in 2001 when first harvest concentrations were between 40-47 ppm and 2nd through 4th harvests were 52- 60 ppm.

Table 21. Alfalfa copper concentration in the top 1/3 of plant samples taken at harvest during 2002 as influenced by molybdenum, boron and lime treatments applied on March 9- 10, 2001.

Treatment	Mo lbs/ A	B lbs /A	Lime tons/ A	May 28 Cu Conc. ppm	July 3 Cu Conc. ppm	Aug 8 Cu Conc. ppm	Sept 20 Cu Conc. ppm
1. Control	0		0	5.0	8.1	5.0	5.1
2. Mo plus B	0.2	4	0	5.2	8.4	5.1	5.0
3. Mo plus B	0.3	4	0	4.9	7.7	4.9	4.8
4. Mo plus B	0.4	4	0	5.2	8.0	5.7	5.2
5. Mo plus B	0.6	4	0	4.9	7.9	5.6	4.8
6. Mo plus B	0.8	4	0	4.9	8.2	5.2	5.9
7. Mo plus B	1.2	4	0	4.9	8.2	4.7	5.0
8. Mo	0.4	0	0	4.8	7.5	5.6	4.8
9. Mo	0.8	0	0	4.9	7.8	5.6	4.7
10. B	0	2	0	5.4	8.5	5.9	5.4
11. B	0	4	0	4.9	7.3	5.0	4.3
12. Lime	0		2	4.8	7.1	4.3	4.0
13. Mo + B + Lime	0.2	4	2	5.0	7.5	4.6	4.5
14. Mo+B+Lime	0.4	4	2	5.0	7.8	5.2	4.6
$LSD_{0.05}$				0.36(NS)	1.54(NS)	1.02(NS)	1.30(NS)

Table 22. Alfalfa boron concentration in the top 1/3 of plant samples taken at harvest during 2002 as influenced by molybdenum, boron and lime treatments applied on March 9- 10, 2001.

Treatment	Mo lbs/ A	B lbs /A	Lime tons/ A	May 28 B Conc. ppm	July 3 B Conc. pm	Aug 8 B Conc. ppm	Sept 20 B Conc. ppm
1. Control	0		0	10 e	10 c	10 c	7 c
2. Mo plus B	0.2	4	0	34 c	44a	38a	40a
3. Mo plus B	0.3	4	0	37abc	45a	38a	38a
4. Mo plus B	0.4	4	0	35 be	44a	39a	38a
5. Mo plus B	0.6	4	0	39ab	47a	41a	39a
6. Mo plus B	0.8	4	0	39a	50a	40a	37a
7. Mo plus B	1.2	4	0	37abc	46a	38a	37a
8. Mo	0.4	0	0	10 e	9 c	9 c	7 c
9. Mo	0.8	0	0	11 e	11 c	12 c	9 c
10. B	0	2	0	23 d	26 b	23 b	20 b
11. B	0	4	0	40a	49a	40a	39a
12. Lime	0		2	10 e	9 c	9 c	8 c
13. Mo + B + Lime	0.2	4	2	37abc	44a	38a	39a
14. Mo + B + Lime	0.4	4	2	38abc	47a	39a	36a
$LSD_{0.05}$				4.04	6.75	5.16	4.85

Siskiyou County Site-2003

Yield results of the three harvests for 2003 are given in Table 23. Selected treatments of molybdenum and boron resulted in significantly higher yields over the control in the three harvests. It can be noted that neither molybdenum, boron nor lime alone resulted in as consistently high yields as when at least molybdenum and boron were applied. As was observed at site # 1, near maximum yield was often achieved with as little as 0.2 lbs Mo/A. Visual observations of the trial just prior to harvest (all three harvests) indicated the control plots as well as those receiving molybdenum alone had slightly chlorotic tops of the plants because of boron deficiency. This slightly chlorotic appearance of the tops of the plants caused by boron deficiency seldom results in large vegetative yield decreases but could reduce seed yields by 25 to 50% or more.

Table 23. Alfalfa yield during 2003 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/A	B lbs/A	Lime tons/A	June 9 Yield tons DM/A	July 16 Yield tons DM/A	Aug 27 Yield tons DM/A
1. Control	0		0	1.66abc	1.35 cd	1.07ab
2. Mo plus B	0.2	4	0	1.68abc	1.73a	1.13ab
3. Mo plus B	0.3	4	0	1.86abc	1.49abcd	1.07ab
4. Mo plus B	0.4	4	0	2.03a	1.58abc	1.05ab
5. Mo plus B	0.6	4	0	1.78abc	1.64ab	1.12ab
6. Mo plus B	0.8	4	0	1.83abc	1.54abc	1.02 b
7. Mo plus B	1.2	4	0	1.72abc	1.64ab	1.06ab
8. Mo	0.4	0	0	1.55 be	1.25 d	1.09ab
9. Mo	0.8	0	0	1.50 c	1.39 bcd	0.99 b
10. B	0	2	0	1.49 c	1.26 d	0.97 b
11. B	0	4	0	1.70abc	1.51abcd	1.12ab
12. Lime	0		2	1.52 c	1.35 cd	1.06ab
13. Mo + B + Lime	0.2	4	2	1.55 be	1.53abcd	1.28a
14. Mo + B + Lime	0.4	4	2	1.91 ab	1.62abc	1.16ab
LSDo.os				0.379	0.281	0.255

The molybdenum concentrations in the top 1/3 of plant samples taken at harvest (equivalent to the top 6 inches of the plant) are given for the four harvests in 2003 in Table 24. Molybdenum concentration in alfalfa was increased significantly with applied molybdenum. As was the case at site #1 , yields during 2003 reached near maximum with 0.3 to 0.8 lbs applied Mo per acre. Molybdenum concentrations in the top 1/3 of the plant were much higher than in site # 1, reaching well over 1 ppm and up to 3 ppm or above (4.67 ppm in the first harvest). Molybdenum concentrations were highest in the 2d harvest , second highest in the 1St and lowest in the 3rd harvest. The application of lime resulted in only small changes in the molybdenum concentration as compared to the control. The 1.2 lbs Mo/A rate resulted in a molybdenum concentration of 3 to 5 ppm which is well above the desired plant level for maximum alfalfa yield, and levels above 5 ppm may present increasing problems for animals, particularly if copper concentrations are below the 8 - 10 ppm range.

Table 24. Alfalfa molybdenum concentration in the top 1/3 of plant samples taken at harvest during 2003 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/A	B lbs/A	Lime tons/A	June 9 Mo Conc ppm	July 16 Mo Conc m	Aug 27 Mo Conc ppm
1. Control	0		0	0.17 e	0.23 e	0.10 f
2. Mo plus B	0.2	4	0	0.83 cde	0.90 de	0.53 def
3. Mo plus B	0.3	4	0	1.63 cde	1.70 cd	1.10 bed
4. Mo plus B	0.4	4	0	1.93 cd	1.77 cd	1.03 bcde
5. Mo plus B	0.6	4	0	2.07 c	2.47 be	1.63 b
6. Mo plus B	0.8	4	0	3.47 b	4.30a	2.53a
7. Mo plus B	1.2	4	0	4.67a	3.83a	2.70a
8. Mo	0.4	0	0	1.50 cde	1.47 d	0.90 cde
9. Mo	0.8	0	0	3.37 b	2.97 b	2.17a
10. B	0	2	0	0.47 de	0.57 e	0.33 of
11. B	0	4	0	0.33 e	0.17 e	0.13 f
12. Lime	0		2	0.27 e	0.27 e	0.17 f
13. Mo + B + Lime	0.2	4	2	1.23 cde	1.57 cd	0.80 cdef
14. Mo + B + Lime	0.4	4	2	2.07 c	2.43 be	1.50 be
LSDo.os				0.340	0.227	0.173

Copper concentrations in the top 1/3 of plant samples for the three harvests in 2003 are given in Table 25. Note that all concentrations are similar to those during 2002 (4-8 ppm) and could therefore become more of an animal health problem if molybdenum concentrations exceed 5 ppm. Note that there were no significant differences in copper concentrations in the top 1/3 of the plant in response to either the molybdenum, boron or lime treatments.

Boron concentrations in the top 1/3 of plant samples for the three harvests in 2003 are given in Table 26. Boron concentrations are significantly higher in all of the treatments receiving boron. The control and all treatments not receiving applied boron had concentrations in the 6-9 ppm range throughout 2003. Treatment #10 which received 2 lbs B/A had concentrations in the 12 to 17 ppm range while treatments receiving 4 lbs B/A were somewhat higher, 21-32 ppm. Boron concentrations during 2003 were considerably below those in 2002 and 2001 when first harvest concentrations were between 40-47 ppm and 2 nd through 4`h harvests were 52-60 ppm.

Table 25. Alfalfa copper concentration in the top 1/3 of plant samples taken at harvest during 2003 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo lbs/A	B lbs/A	Lime tons/A	June 9 Cu Conc ppm	July 16 Cu Conc ppm	Aug 27 Cu Conc ppm
1. Control	0		0	4.7	8.2	7.3
2. Mo plus B	0.2	4	0	4.9	9.6	7.1
3. Mo plus B	0.3	4	0	4.4	8.2	7.1
4. Mo plus B	0.4	4	0	4.8	8.1	6.8
5. Mo plus B	0.6	4	0	4.8	8.1	7.3
6. Mo plus B	0.8	4	0	4.8	8.0	7.5
7. Mo plus B	1.2	4	0	5.0	7.5	6.8
8. Mo	0.4	0	0	4.3	7.6	7.1
9. Mo	0.8	0	0	4.4	7.6	7.2
10. B	0	2	0	4.7	8.2	7.2
11. B	0	4	0	4.1	7.8	6.8
12. Lime	0		2	3.9	7.3	5.8
13. Mo + B + Lime	0.2	4	2	4.0	7.6	6.6
14. Mo + B + Lime	0.4	4	2	3.9	7.4	7.0
$LSD_{0.05}$				1.00 (NS)	1.87 (NS)	1.02 (NS)

Table 26. Alfalfa boron concentration in the top 1/3 of plant samples taken at harvest during 2003 as influenced by molybdenum, boron and lime treatments applied on March 9- 10, 2001.

Treatment	Mo lbs/A	B lbs/A	Lime tons/A	June 9 B Conc. ppm	July 16 B Conc. ppm	Aug 27 B Conc. ppm
1. Control	0		0	6 c	7 c	8 c
2. Mo plus B	0.2	4	0	21a	32a	30a
3. Mo plus B	0.3	4	0	21a	28a	26a
4. Mo plus B	0.4	4	0	20a	25a	27a
5. Mo plus B	0.6	4	0	21a	26a	32a
6. Mo plus B	0.8	4	0	21a	31a	31a
7. Mo plus B	1.2	4	0	23a	28a	28a
8. Mo	0.4	0	0	5 c	7 c	8 c
9. Mo	0.8	0	0	6 c	8 bc	9 c
10. B	0	2	0	12 b	15 b	17 b
11. B	0	4	0	24a	30a	35a
12. Lime	0		2	6 c	9 bc	7 c
13. Mo + B + Lime	0.2	4	2	24a	30a	30a
14. Mo + B + Lime	0.4	4	2	21a	30a	29a
$LSD_{0.05}$				1.39	2.13	1.89

Siskiyou County Site-2001-2003-Three Year Yield Totals for Site # 2

Yield results of the three year period 2001-2003 are given in Table 27. Selected treatments of molybdenum and boron resulted in significantly higher yields over the control during 2002 and for the three-year totals. Three individual harvests, two in 2002 and one in 2003, showed significant yield responses to molybdenum plus boron treatments. It can be noted that neither molybdenum, boron nor lime alone resulted in as consistently high yields as when at least molybdenum and boron were applied. As was observed at site # 1, near maximum yield was often achieved with as little as 0.2 lbs Mo/A. Visual observations of the trial just prior to most harvests indicated the control plots as well as those receiving molybdenum alone had slightly chlorotic tops of the plants because of boron deficiency. This slightly chlorotic appearance of the tops of the plants caused by boron deficiency generally does not result in large vegetative yield decreases but could reduce seed yields by 25 to 50% or more.

Table 27. Alfalfa yield (100% dry matter basis) during the three-year period 2001-2003 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

Treatment	Mo (lbs/A)	B (lbs/A)	Lime (tons/A)	2001 Yield (tons DM/A)	2002 Yield (tons DM/A	2003 Yield (tons DM/A	Total Yield (tons DM/A
1. Control	0		0	7.24	6.89 d	4.08	18.21 e
2. Mo plus B	0.2	4	0	7.89	8.05a	4.54	20.47a
3. Mo plus B	0.3	4	0	7.76	7.98a	4.42	20.15abc
4. Mo plus B	0.4	4	0	7.71	7.90a	4.66	20.27ab
5. Mo plus B	0.6	4	0	7.95	7.99a	4.53	20.48a
6. Mo plus B	0.8	4	0	7.71	7.67ab	4.40	19.78abcde
7. Mo plus B	1.2	4	0	7.87	7.92a	4.42	20.21 abc
8. Mo	0.4	0	0	7.52	7.02 cd	3.89	18.43 de
9. Mo	0.8	0	0	7.51	7.19 bcd	3.88	18.58 cde
10. B	0	2	0	7.47	7.45abcd	3.72	18.64 bcde
11. B	0	4	0	7.64	7.67ab	4.33	19.64abcde
12. Lime	0		2	7.34	7.17 bcd	3.93	18.45 de
13. Mo+B+Lime	0.2	4	2	7.58	7.65ab	4.35	19.58abcde
14. Mo+B+Lime	0.4	4	2	7.73	7.62abc	4.69	20.04abcd
Probability				0.592	0.006	0.052	0.037

Siskiyou County Site-2001-Site # 2-Forage Quality

Alfalfa forage quality analysis for crude protein was conducted on all samples from all four harvests during 2001. Table 28 gives the changes in crude protein (total N x 6.25) associated with the increased rate of applied molybdenum, boron and lime. There were not statistically significant differences in crude protein as a result of the treatments. There was a trend for crude protein to be slightly higher in the l st, 2nd and 4th harvests as a result of combinations of molybdenum and boron treatments. Acid detergent fiber (ADF) analysis was also conducted on all whole plant samples to determine total digestible nutrient (TDN) levels. No statistically significant differences in total digestible nutrient (TDN) levels were observed in any of the four harvests as a result of the molybdenum, boron or lime treatments.

Table 28. Alfalfa crude protein during 2001 as influenced by molybdenum, boron and lime treatments applied on March 9-10, 2001.

				Crude Protein			
Treatment	Mo (lbs /A)	B (lbs /A)	Lime (tons/ A)	May 18 %	July 2 %	Aug 13 %	Sept 28 %
1. Control	0		0	25.83	20.53	19.47	21.47
2. Mo plus B	0.2	4	0	25.50	20.87	19.00	21.50
3. Mo plus B	0.3	4	0	26.67	21.13	19.27	21.33
4. Mo plus B	0.4	4	0	26.00	20.90	19.70	21.80
5. Mo plus B	0.6	4	0	26.23	20.63	18.87	21.80
6. Mo plus B	0.8	4	0	25.63	21.80	19.37	21.57
7. Mo plus B	1.2	4	0	26.83	20.93	18.80	21.43
8. Mo	0.4	0	0	26.83	21.20	18.87	22.30
9. Mo	0.8	0	0	27.43	20.60	19.30	21.17
10. B	0	2	0	26.53	20.57	19.63	22.23
11. B	0	4	0	25.27	21.53	18.80	21.80
12. Lime	0		2	25.97	21.00	19.30	21.37
13. Mo + B + Lime	0.2	4	2	25.97	20.47	19.03	21.33
14. Mo + B + Lime	0.4	4	2	25.63	21.50	19.23	21.23
LSD $0_{.05}$				1.42(NS)	1.31(NS)	1.15(NS)	1.20(NS)

Siskiyou County Site-2001-2003- Three Year Forage Quality Summary-Site # 2

Alfalfa forage quality was evaluated by conducting chemical analyses for crude protein and acid detergent fiber (ADF) on whole plant samples to determine total digestible nutrients (TDN). These analyses were conducted on all samples from four harvests in 2001 and 2002 as well as the three harvests in 2003. There were no statistically significant differences in crude protein as a result of the molybdenum, boron and lime treatments. There appeared to be a trend for crude protein to be slightly higher in several harvests as a result of combinations of molybdenum and boron treatments. No statistically significant differences in total digestible nutrient (TDN) levels were observed in any of the harvests as a result of the molybdenum, boron or lime treatments.

To achieve objective three, the residual plant material from each plot for each harvest resulting after samples were submitted to the laboratory for chemical analyses was retained. After the results of chemical analysis of the samples were known, the residual plant materials from these samples were grouped into four bulk samples having the following concentrations: 1). low Mo (0.1-0.4 ppm)-low B (9-11 ppm), 2). low Mo (0.1-0.4 ppm)-intermediate B (15-25 ppm), 3). low Mo (0.1-0.4 ppm)-high B (35+ ppm), and 4). intermediate Mo (0.5-0.7 ppm)- intermediate B (15-25 ppm). Even after combining the plant material from selected plots for all of the alfalfa harvests there was less than 2-3 pounds of total material in each of the four samples and unfortunately, nearly all of the sample material was destroyed by a fire. Therefore, several large bulk sized samples of the top 1/3 of alfalfa plants were collected at or just prior to harvest from selected plots to acquire sufficient quantities for the standard samples with known molybdenum and boron concentrations. After the large bulk samples were dried and ground, subsamples were taken from each to submit to the laboratory for chemical analysis to learn the Mo and B concentrations. The total amounts of the four samples that have been prepared are as follows: 1). Low Mo (0.1-0.4 ppm)-low B (9-11 ppm)-about 12 lbs, 2). Low Mo (0.1-0.4 ppm)- intermediate B (15-25 ppm)-about 8 ibs, 3). Low Mo (0.1-0.4 ppm)-high B (35+ ppm)-about 4 lbs, and 4). Intermediate Mo (0.5-0.7 ppm)-intermediate B (15-25 ppm)-about 16 lbs.

Discussion and Conclusions

The results of the chemical analyses of early plant growth stage samples that were taken at 6 inches height, at 12 inches height, and pre-bud (when only 2 - 5% of the plants have a small ball that can just be detected between the thumb and forefinger indicating the bud is developing) growth stage prior to each harvest as well as sampling at harvest are presented in Figures 1-4. These figures include only the results from site or experiment # 2 for the year 2001 since samples were taken 2-3 times prior to each of the four harvests. During 2002 and 2003 sampling prior to only the 1st and 3rd harvests was carried out at both sites and the results have similar trends. In some cases, the growers harvested prior to 1/10 bloom so samples taken at harvest were characterized as to stage of growth but plotted on the calendar day basis. All of the plant material of the samples collected at the 6-inch growth stage and only the top 6 inches of the 12-inch high, pre-bud plants and at harvest plants were analyzed for molybdenum, boron and copper concentrations to develop the relationships between growth stage, alfalfa yield and molybdenum and boron concentrations.

Figure 1 gives the molybdenum concentration in the top 1/3 of the plant samples taken two times prior to the first harvest and three times prior to the 2nd, 3rd and 4th harvests as well as at each harvest at site or experiment # 2 during 2001. These data indicate that molybdenum concentrations in the top 1/3 of the plant,

when they are in the deficient range (<0.9 ppm), remain fairly constant during the early growth stages through the harvest growth period for each of the four harvests during the year. This becomes particularly desirable for diagnostic purposes
if plant samples can be taken anytime during the growth of the crop, not just at a defined stage of growth such as 1/10th bloom stage. Of particular interest is the fact that if the molybdenum concentration is in the adequate range, that is above 1 ppm, it generally decreased as the alfalfa matured and was harvested. Note as well that the 0.2 lb/A rate of molybdenum plus the 4 lbs/A rate of boron had approximately one-half the concentration of molybdenum as did the 0.4 lb/A rate of molybdenum plus the 4 lbs/A rate of boron. Also note that the 0.4 lb/A rate of molybdenum plus the 4 lbs/A rate of boron had a higher molybdenum concentration than did the 0.4 lb/A rate of molybdenum alone for much of the first year after application. The control, boron alone at the 4 lbs/A rate and the lime alone treatments had nearly the same low molybdenum concentration of 0.2 to 0.9 ppm throughout the year. A single application of the 0.4 lb/A rate of molybdenum is expected to last approximately 10 years based on a number of fields that have been sampled over time. Fields having a history of molybdenum concentrations less than 1 ppm should be resampled at least every 3 years at the early bud to 1/10th bloom growth stage to monitor the molybdenum status for maintaining high alfalfa yields.

The boron concentration in the top 1/3 of the alfalfa plant for several treatments during the 2001 growing season at site or experiment # 2 is given in Figure 2. The boron concentrations are fairly consistent when no boron is applied (control and molybdenum alone treatment) but vary considerably when boron is applied at either the 2 or 4 pound per acre rates. The 2-pound rate of boron had only slightly lower boron concentration in the top 1/3 of the plant than the 4- pound rate. The top 1/3 of the plant samples from the second and third harvests in 2003 have approximately half the boron concentrations for the 2 and 4-pound rates as compared to the 2001 results. This would suggest that the 2-pound rate of boron should be applied every other year and the 4-pound rate should be applied every 4 years. Fields having a history of boron concentrations less than 15 ppm should be resampled at least every 2 years to monitor the boron status for maintaining high alfalfa yields. Fields used for alfalfa seed production should be maintained at a somewhat higher boron concentration of 20-25 ppm and sampled annually to adjust the rate of boron application to maintain the >25 ppm concentration in the top 1/3 of plant samples at the early bud to 1/10th bloom growth stage.

The same samples collected during 2001 for molybdenum and boron analyses were also analyzed for copper concentrations. Figure 3 illustrates the copper concentrations for the same treatments that are given in Figure 1 for molybdenum treatments. The copper concentrations decrease to nearly one-half from the early growth to the harvest time sampling. This is nearly the same pattern exhibited for the molybdenum concentrations. Since the harvest concentrations of copper are only slightly above 5 ppm, to maintain the desired ratio of 2:1 for copper: molybdenum, the molybdenum concentration should not exceed 2.5 ppm. Figure 1 indicates that the first harvest molybdenum concentration at approximately 5 ppm is well in excess of the desired 2.5 ppm but the 2°d, 3rd and 4th harvests are in the desired range of 2-2.5 ppm. This would certainly suggest that when molybdenum is applied it should not be applied in excess of the 0.4 lb/A rate of molybdenum or 1 lb/A rate of sodium molybdate.

Figure 4 gives a comparison between the whole plant (harvested hay) molybdenum concentrations and the top 1/3 of the alfalfa plant concentrations for four harvests in 2001 and 2002. It can be observed that even though these two plant parts are much different they have the same molybdenum concentrations and can therefore be used equally well for diagnosing molybdenum deficiencies. Since this procedure has not been tested on very many locations and production seasons, use of the top 1/3 of the alfalfa plant concentrations would still be the preferred sampling and monitoring approach.

Recommendations

Molybdenum: Plant tissue testing was confirmed by this research study to be the most desirable way of diagnosing molybdenum and boron deficiency and copper analysis to diagnose potential animal health problems. The current University of California guidelines for molybdenum concentrations in alfalfa are: deficient -- <0.3 ppm, critical - 0.3-0.9 ppm, adequate - 1-5 ppm, and high - 5-10 ppm with the comment that concentrations in excess of 10 ppm may result in molybdenosis in ruminant animals. These are suitable for the 1/10th growth stage or when V2 to 1" regrowth from the crown appears. First, these molybdenum concentrations would not be changed based on the results from the 3 to 4 years research at the two sites studied. Second, these concentrations can be extended beyond the "1/10th growth stage or when V2 to 1" regrowth from the crown appears" to include "sampling anytime when 4-6 inches of growth can be collected" and analyzed. As Figure 1 indicates, if the molybdenum concentration is below 1 ppm it will be at that level regardless of the stage of growth when the samples are taken. Concentrations greater than 1 ppm would be adequate for maximum alfalfa production. It should be kept in mind however that the molybdenum concentration will reach its lowest point just before the alfalfa is harvested.

Regarding the current recommendation for the application of one pound of sodium or ammonium molybdate to supply 0.4 lb Mo per acre applied during the dormant season or before regrowth has occurred after cutting for at least a 3-5 year time period seems realistic. It should be pointed out that the same application rate may produce greatly different molybdenum concentrations in alfalfa as indicated by the two sites on which the research was conducted in this study. Thus the caution for not applying any higher rate than the 0.4 Mo/acre is emphasized. It would be particularly important when copper concentrations are below the 10-12 ppm range not to have molybdenum concentrations any higher than V2 of the copper concentrations for animal health considerations. Fields having a history of molybdenum concentrations less than 1 ppm should be resampled at least every 3 years at the early bud to 1/10th bloom growth stage to monitor the molybdenum status for maintaining high alfalfa yields. Also, it should be emphasized that foliar applications should never be made to the leaves of alfalfa or other legume forages because most of the material would be harvested with the next cutting of hay leaving very little molybdenum for the long term benefit and even worse, the hay would have extremely high concentrations of molybdenum which would be very toxic to animals.

Boron: Plant tissue testing was confirmed by this research study to be the most desirable way of diagnosing boron and molybdenum deficiency and copper analysis to diagnose potential animal health problems. The current University of California guidelines for boron concentrations in alfalfa are: deficient -- <15 ppm, critical - 15-20 ppm, adequate - 20-40 ppm, and high - over 200 ppm with the comment that concentrations in excess of 200 ppm may result in reduced growth and vigor. Although not as reliable to detect boron deficiency, the saturated paste concentration of boron below 0.1 ppm would suggest that plant tissue samples should be taken to assess potential deficiency. Like molybdenum, boron deficiencies can be detected using the above concentrations and can be extended beyond the "1/10th growth stage or when %2 to 1" regrowth from the crown appears" to include "sampling anytime when 4-6 inches of growth can be collected" and analyzed. As Figure 2 indicates, if the boron concentration is below 15 ppm it will be at that level regardless of the stage of growth when the samples are taken. Concentrations greater than 15 ppm would be adequate for maximum alfalfa production. It should be kept in mind however that the boron concentration will reach its lowest point just after regrowth begins and increase slightly as the alfalfa matures before harvest.

The current recommendations for the application of boron seem realistic. When tissue tests indicate boron is deficient and boron-sensitive crops such as cereals are likely to be planted in the field within 12 months, apply 1 to 3 pounds boron per acre to the soil surface. Use 3.5 to 7 pounds per acre if boron-tolerant crops such as alfalfa, sugarbeets, or onions will be grown for the next 24 months. Use the lower rates on sandy soils; the higher rates are suggested for fine- textured soils. Higher rates of boron will often last 5 to 7 years. Fields having a history of boron concentrations less than 15 ppm should be resampled at least every 2 years to monitor the boron status for maintaining high alfalfa yields. Fields used for alfalfa seed production should be maintained at a somewhat higher boron concentration of 20-25 ppm and sampled annually to adjust the rate of boron application to maintain the >25 ppm concentration in the top 1/3 of plant samples at the early bud to 1/10th bloom growth stage.

Outreach Activities

The following is a listing of the meetings and conferences at which the results of the research have been presented. Many individuals present at these meetings were alfalfa growers but a number of Certified Crop Advisors, Pest Control Advisors, fertilizer dealer representatives and plant and animal nutrition consultants were present as well. If the audience was different from above it is noted.

Date	Conference or meeting and location	Number attending
2000		
Nov. 14th	CDFA **FREP Conference Proceedings**, Tulare, CA	- 75
Dec 1 lth	**29th National Alfalfa Symposium** & **30th California** Alfalfa **Symposium, Las** Vegas, NV **Title: "Lagoon** Water, **Manures and Biosolids** Applied to Alfalfa: **Pros and** Cons." **and Proceedings**	- **400**
2001		
Mar 29-30th	California Alfalfa Workgroup, **Davis,** CA Presented **research plan and** objectives to Farm Advisors, Specialists and Experiment Station personnel.	- **20**
June 21St	California Waste Management Workgroup, Davis, CA Title: "Influence of biosolids application on molybdenum and copper concentrations in alfalfa, corn silage and sudan." to Farm Advisors, Specialist and Experiment Station personnel.	- 30
Aug 28th	Alfalfa Field Day, Kearney Ag Center, Parlier, CA Title: Sulfur and micronutrient fertilization of alfalfa.	- 50
Oct 5th	Alfalfa and Cereal **meeting,** Woodland, CA Title: "Alfalfa **and small grain** fertility."	- 75
Nov 14th	CDFA FREP Conference **Proceedings**, Tulare, CA	- 75
Nov 15th	Grower Alfalfa **Meeting, Los Banos**, CA Alfalfa fertilizer **needs: using plant tissue and soil testing** to help.	- **40**
2002		
May 21St	Alfalfa Field Meeting, McArthur, CA Title: "Taking soil and plant tissue samples to fertilize alfalfa."	- 20
July 31St	Report of the Thirty-Eighth North America Alfalfa Improvement Conference, Sacramento, CA Title: "Alfalfa Yield and Quality Response to Molybdenum, Boron and Lime Applications." and Proceedings presented to University and Industry Researchers.	- 100
Nov 19th	CDFA FREP Conference Proceedings, Tulare, CA	- 75
Dec 11th	Proceedings 2002 Western Alfalfa & Forage Conference, Reno, NV Title: Understanding Micronutrient Fertilization in Alfalfa	-150
Dec 12th	Second presentation at Conference	- 100

2003

Febr 5th	California Plant and Soil Conference, Modesto, CA Presentation Title: "Micronutrients in Agriculture" and Proceedings. Audience was Certified Crop Advisors, Industry & State University personnel, Farm Advisors, Specialists and Experiment Station personnel.	- 70
Febr 14th	Alfalfa Grower Meeting, McArthur, CA Title: "Micronutrients in alfalfa and other crop nutrition programs."	- 70
Febr 20th	California Alfalfa Workgroup, Davis, CA Presented preliminary research results to Farm Advisors, Specialist and Experiment Station personnel.	- 18
April 8th	Alfalfa Field Day, Desert Research & Extension Center, El Centro, CA Title: "Alfalfa Fertilization."	- 60
May 7th	Alfalfa Field Day, Davis, CA Title: "Use of soil and plant tissue testing in alfalfa fertility management."	- 50
May 9th	UC Davis Agricultural Systems and Environment-Forage Crop Ecology Class, Davis Campus Title: "Diagnosing Nutrient Deficiencies in Alfalfa."	- 15
July 3rd	UC Davis Soils 105 Class visiting Field Site # 1 near Burney, CA "Managing Nutrient Applications to Alfalfa."	- 15
Nov 3rd	American Society of Agronomy (and CSSA-SSSA) Annual Meeting, Denver, CA-gave 3 presentations to research, industry and extension personnel	
	Title: "Alfalfa Yield Response to Molybdenum and Boron Applications." Presented by Daniel B. Marcum-Abstract in Proceedings	- 50
	Title: "Alfalfa Growth Stage Sampling Effects upon Molybdenum and Boron Concentrations." Presented by Roland D. Meyer-Abstract in Proceedings	- 50
	Title: "Alfalfa Forage Quality as Influenced by Molybdenum and Boron Applications." Presented by Roland D. Meyer -Abstract in Proceedings	- 50
Nov 20th	CDFA FREP Conference Proceedings and Presentation, Tulare, CA Title: Improving the Diagnostic Capabilities for Detecting Molybdenum Deficiency in Alfalfa and Avoiding Toxic Concentrations in Animals	75

2004

Nov 91h	CDFA FREP **Conference Proceedings and Presentation**, Tulare, CA **Title: Improving the Diagnostic Capabilities for Detecting Molybdenum Deficiency in Alfalfa and** Avoiding Toxic **Concentrations in Animals**	- 75

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Figure 1. Alfalfa-top 1/3 of plant-molybdenum concentrations during the 2001 growing season as influenced by applied treatments. Expt #2

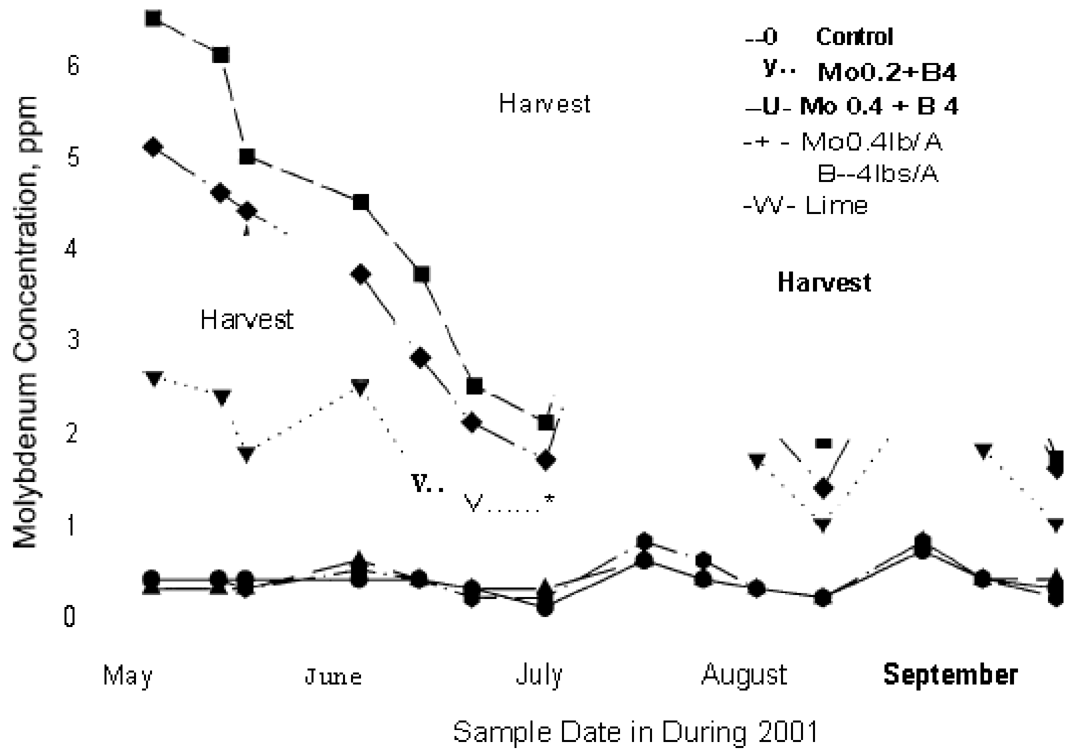

Figure 2. Alfalfa-top 1/3 of plant-boron concentrations during the 2001 growing season as influenced by applied treatments. Expt #2

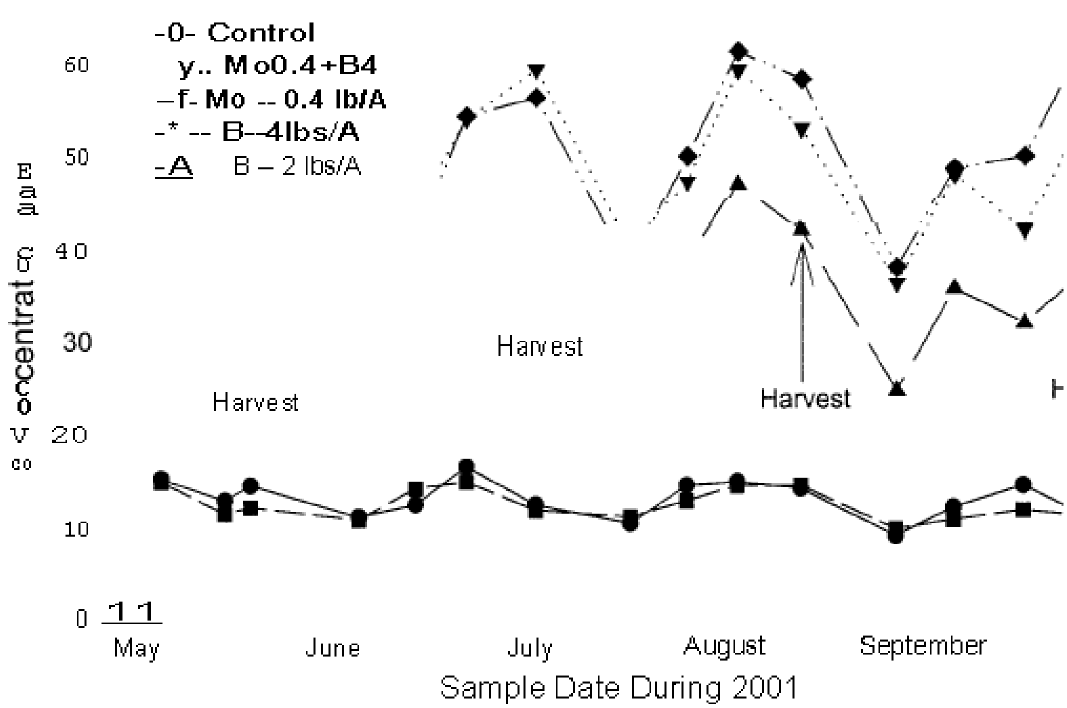

Figure 3. Alfalfa-top 1/3 of plant-copper concentrations during the 2001 growing season as influenced by applied treatments. Expt #2

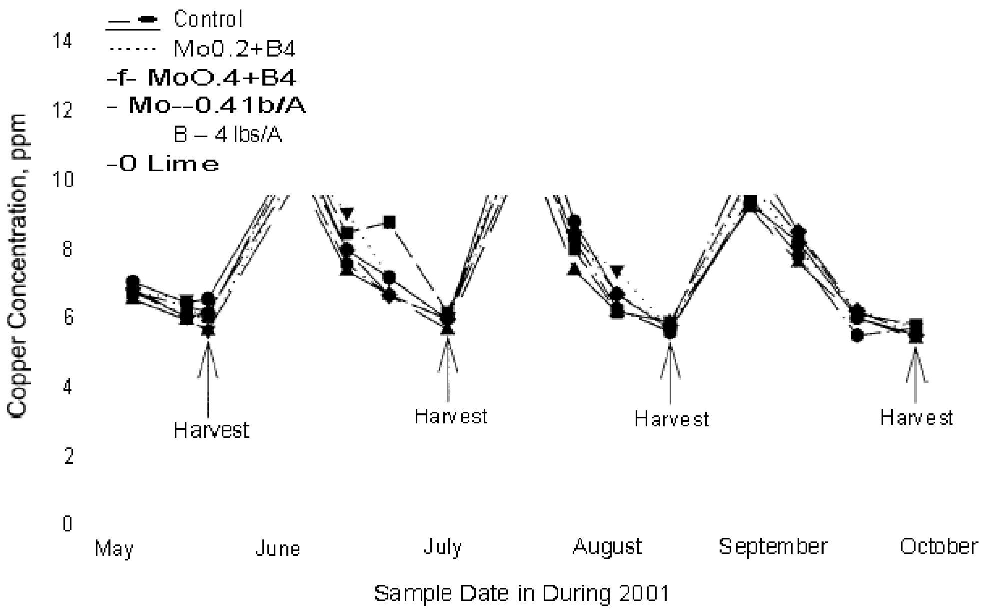

Figure 4. Alfalfa molybdenum concentrations, whole plant (WP) versus top 1/3 of plant (Top) during 2001-2002 as influenced by applied treatments. Expt #2