AN ABSTRACT OF THE THESIS OF

PAUL OWEN KRESGE for the degree MASTER OF SCIENCE
(Name of student) (degree)

in Soil Science presented on February 18, 1975
(Major department) (Date)

Title: IDENTIFICATION OF POTENTIAL COPPER AND MOLYBDENUM LIVESTOCK NUTRITION PROBLEMS WITH FORAGE ANALYSIS

Abstract approved: (Dr. Thomas L. Jackson)

Copper deficiency and Mo-induced Cu deficiency are nutrition problems of ruminant livestock in the Burns and Klamath Falls area of Oregon. Chemical analysis of plant and soil samples was used to survey Cu and Mo levels in forage in these areas. The objectives were to assess the possibility of animal nutrition problems and to study the relationship between forage levels of Cu and Mo and plant species, stage of plant maturity, time of growing season, management factors, and soil characteristics.

A total of approximately 400 plant samples was collected during the 1972 grazing season. The samples from Burns were taken from an alfalfa maturity experiment, improved pastures, native meadows, and a forage nursery. The legumes sampled were alfalfa (Medicago sativa), Ladino clover (Trifolium repens), and sainfoin (Onobrychis

viciaefolia). Grasses sampled were Fawn tall fescue (Festuca arundinacea), Manchar brome (Bromus inermis), Greenar and Oahe intermediate wheatgrass (Agropyron intermedium), wildrye (Elymus triticoides), Rush (Juncus sp.), and Sedge (Carex sp.). The Klamath samples were from an Alta tall fescue (Festuca arundinacea) - quack-grass (Agropyron repens) comparison and from 13 sites on a variety of pastures throughout the area. In addition to alfalfa, clover, sedge, rush, Alta fescue and quackgrass, the species sampled were Kentucky bluegrass (Poa pratensis), orchardgrass (Dactylis glomerata), and meadow foxtail (Alopecuris pratensis). Most of the sites were clipped periodically to simulate grazing and were sampled at two week intervals from May through August.

Plant analysis was valuable for indicating the type of livestock nutrition problem encountered in a particular area. The Burns forage contained high levels of Mo and a Mo-induced Cu deficiency is probable. The survey in the Klamath area identified two sites on muck soils with potentially toxic Mo levels. Several sites had such low Cu levels that uncomplicated Cu deficiency may be a problem in livestock. A wide range of values was encountered and forage analysis would be valuable for identifying problems on a local basis.

Large differences were found in Cu and Mo levels between plant species. Legumes contained much higher levels of Cu and Mo than did grasses. Changes in maturity, or clipping interval, had different effects on Cu and Mo content for grasses and legumes. Alfalfa was found to decrease in Cu and Mo content with increased maturity. However, legumes in pastures maintained relatively constant levels through the grazing season. Many grasses were found to decrease markedly in Cu levels, and some to increase in Mo levels as the season progressed. This may result in a reduction in the Cu/Mo ratio through the season.

Forage analysis was shown to be a valuable technique for identifying potential Cu and Mo livestock nutrition problems and for investigating environmental and management factors which may regulate Cu and Mo levels in forage plants.

Identification of Potential Copper and Molybdenum Livestock Nutrition Problems with Forage Analysis

by

Paul Owen Kresge

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1975

APPROVED:

Professor of Soils in charge of Major

Head of Department of Soils

Dean of Graduate School

Date thesis is presented February 18, 1975

Typed by Lyndalu Sikes and Ilene Anderton for Paul Owen Kresge.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the advice and assistance of Dr. T. L. Jackson throughout this investigation and preparation of the manuscript. Appreciation is also expressed to Dr. D. P. Moore for his advice and suggestions.

Acknowledgement is given for the advice and work of Drs. R. J. Raleigh and F. B. Gomm of the Squaw Butte Experiment Station and of Mr. George C. Carter of the Klamath Experiment Station. The author also wishes to thank those at the respective experiment stations and at Oregon State University who assisted during the study.

The financial support of Tulana Farms, Klamath Falls, Oregon, is gratefully acknowledged.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

IDENTIFICATION OF POTENTIAL COPPER AND MOLYBDENUM LIVESTOCK NUTRITION PROBLEMS WITH FORAGE ANALYSIS

INTRODUCTION

The elements Cu and Mo are required at low levels for proper nutrition of plants and animals and a deficiency of either adversely affects normal growth and function. The critical level of Cu in plant tissue below which a deficiency of Cu occurs is 2 to 5 ppm. A Mo deficiency in plants occurs at a level of less than 0.5 ppm. A Cu deficiency in plants is rare but may occur in peat soil or sands. Molybdenum deficiency to plants and livestock may occur on some acid mineral soils on a local basis. At very high levels, Cu may be toxic to plants and animals. Such levels are not associated with normal soil conditions. Although Mo has not been shown to be toxic to plants, high Mo levels in feedstuffs cause a serious interaction with Cu in ruminant animals.

At levels of 3 to 5 ppm Mo, plants fed to ruminants may interfere with Cu metabolism by accelerating Cu excretion. As the level of Mo in the plant material increases above 5 ppm the effect becomes increasingly severe. This Mo induced Cu deficiency is also known as teartness and molybdenosis. Molybdenosis has been found to be a problem in certain areas of Oregon and Nevada. The effect of high Mo levels is less severe when Cu levels are also high and may be alleviated by supplementing the animals' feed with Cu. For this reason the ratio of Cu to Mo in forage is an important consideration. A Cu/Mo ratio of 2.0 is often considered adequate, below which molybdenosis may be expected. Of course if Cu levels are extremely low or Mo levels are extremely high the ratio may not be the limiting parameter.

It is important to identify areas where Cu deficiency might be a problem and to consider whether or not the deficiency is Mo-induced. A knowledge of the Cu and Mo levels present in forage and of the factors affecting these levels is necessary for effective treatment of Cu deficiency by clinical or management schemes. A suspected Cu deficiency at Burns, and Klamath Falls, Oregon, led to an investigation of these levels and factors.

In experiments on improved pasture of the Squaw Butte Experiment Station near Burns, cattle failed to gain weight at acceptable rates through the grazing season. The animals showed symptoms of molybdenosis and responded only slightly to Cu injections. Previous plant analysis had shown low to moderate Cu levels and generally high Mo levels. A pasture study in the Klamath Falls area has shown that Cu levels and the Cu/Mo ratio are inadequate in many locations. A grazing experiment of the Klamath Experiment Station has shown cattle gains to be closely correlated to blood Cu levels. Feeding or injecting additional Cu has improved or corrected the deficiency problem. Limited analysis of forage in the Klamath area has shown low Cu levels and in some cases, high Mo levels.

Because of these problems the Squaw Butte Experiment Station, the Klamath Experiment Station, and the Oregon State University Department of Soil Science began a cooperative study in 1972 of the Cu and Mo status of forage in the two areas of interest. The broad objective of the program is an extensive evaluation, by plant analysis, of the nutritional value of forage related to various factors including soil conditions, management practices, levels of fertilization, stage of forage maturity, and species grown. The first phase of study, reported in this paper, was intended to survey the Cu and Mo levels encountered on various types of improved pastures in the two areas throughout the grazing season.

More specifically, the objectives of this phase of study may be summarized as follows:

1. To survey levels of Cu and Mo in selected improved pastures in the Burns and Klamath areas of Oregon as they might relate to ruminant livestock nutrition.
2. To study the relationship between plant levels of Cu and Mo and the plant species, stage of plant maturity, and the time of growing season.

3. To review the value of plant sampling and analysis in investigating livestock nutrition problems, including the value of sampling pastures of individual ranches.

REVIEW OF LITERATURE

Copper and Molybdenum in Livestock Nutrition

Molybdenum toxicity in livestock was first identified by Ferguson, Lewis, and Watson (1938) at the Jealott's Hill Research Station in England. Cattle and sheep grazing pastures in Somerset exhibited rapid decreases in production, loss of condition including rough hair coat, severe diarrhea, and even death. These "teart" pastures were found to contain levels of Mo ranging between 20 and 100 ppm, much higher than non-teart pastures in the same area. In addition, the symptoms of teart disease could be duplicated in experimental animals by feeding comparable levels of molybdate. Because of the similarity between symptoms of cattle on teart pastures and cattle found to be Cu deficient on reclaimed Polder in Holland, it was found that a supplement of 2 g of $CuSO_4$ per animal per day was a successful treatment for the teart cattle (Ferguson, Lewis and Watson, 1943).

Ruminant disorders due to Mo-induced Cu deficiency or "molybdenosis" have since been reported from Australia, New Zealand, Holland, Sweden, Canada, and the United States. The areas of Canada where molybdenosis has been diagnosed include Eastern Ontario (Brannion, 1960), Northern Ontario (Hideroglou et al., 1970), the Swan River Valley of Manitoba (Cunningham, Brown and Edie, 1953) and British Columbia (Miltimore et al., 1964). Cases of molybdenosis in the United States have been reported in the San Joaquin Valley of California (Britton and Goss, 1946), Florida (Comar, Singer and Davis, 1949), Nevada (Kubota et al., 1961), and Oregon (Kubota et al., 1967).

The effect of Cu and Mo on ruminant diseases in New Zealand was reviewed by Cunningham (1950). He distinguished between Cu deficiency and Mo-induced Cu deficiency on the basis of symptoms. Cattle grazing peat soils with high levels of Mo exhibited "peat scours" in addition to the general unthriftiness associated with uncomplicated Cu deficiency. In a recent review, Scott (1972) noted that while anemia is a general symptom of Cu deficiency, a variety of other clinical syndromes exist. He listed these syndromes as follows:

1. Bone disorders similar to rickets and osteoporosis
2. Demyelination of the nervous system or ataxia causing spastic paralysis, incoordination of the hind legs, a stiff and staggering gait, and exaggerated swaying of the hindquarters
3. Effect of pigmentation of hair and wool including bleaching and roughening of hair and the loss of crimp in wool

4. Fibrosis of the myocardium characterized by sudden death usually without any preliminary signs

5. Diarrhea in cattle which is accentuated with high levels of Mo.

The importance of Cu in animal nutrition was discovered by Hart et al. (1928) who showed that Cu was necessary for hemoglobin formation in anemic rats. It has since been found that Cu is also an essential constituent of several enzymes with oxidase functions and of butyryl CoA dehydrogenase (Scott, 1972). The essentiality of Mo to animals was shown by Richert and Westerfield (1953) who developed a bioassay procedure for xanthine oxidase, a molybdoflavoprotein. The interaction between Cu and Mo has been shown by Halverson, Phifer and Monty (1960) to be an interference of Mo with the enzyme sulfide oxidase. Copper is made unavailable by the resulting buildup of sulfides. Molybdenum may also interfere with P metabolism. Davis (1950) reported that high levels of Mo altered the pathway of ^{32}P excretion from the urine to the feces.

A large amount of research into the physiology of molybdenosis has been done by workers in Australia and New Zealand. Dick and Bull (1945) had experimentally shown that Mo added to the diet significantly reduced Cu storage in the liver. In a subsequent paper Dick (1952) confirmed this result and suggested that another factor or factors in the feed affected the Cu-Mo interaction. He later isolated inorganic sulfate as this moderating factor (Dick, 1953 and 1954) and suggested that Mo limited Cu storage in the liver only in the presence of sufficient sulfate S. At an intake of 2g sulfate S per day as little as 0.5 mg Mo per day significantly reduced liver storage of Cu. He also attributed a lesion of wool associated with Cu deficiency in sheep to a high level of Mo and sulfate. The lesion appeared with sulfate at 8g per day and 80 mg Mo but disappeared when Mo was reduced to 20 mg per day. These studies also indicated that Mn blocked the effect of Mo on Cu retention in sheep on a high protein diet Dick (1956b). Mylrea (1958) reported however, that feeding up to 391 ppm Mn had no effect on liver Cu levels. The role of sulfate S in Cu metabolism was confirmed by Wynne and McClymont (1955) in New South Wales. They noted that at low levels of Mo (0.7 ppm) in forage, sulfate caused a significant depletion of liver Cu in ewes. They also found a depression of liver Cu levels with 5 ppm Mo in the forage. Wynne and McClymont also suggested a critical level of sulfate in forage of 0.6% to 0.9%, above which depression of liver Cu could be expected. These levels are supported by data of Miltimore et al. (1964) from a 1957 survey of farms with similar levels of Mo averaging 9 ppm. Farms where scouring occured averaged 0.65% sulfate in the forage as total S by the AOAC method. Feeding studies further verifying the effects of sulfate have been conducted by Mylrea (1958) and Vanderveen and

Keener (1964). Work on the effects of sulfate has been reviewed by Dick (1956a) and by Allcroft and Lewis (1957).

Marston (1950) reviewed Australian experience with Cu and Mo. He noted that although the effect of Mo was very serious with low levels of Cu in the forage, the effect was not particularly serious with adequate Cu present. The ratio of Cu to Mo in forage is also considered an important factor by Miltimore et al. (1964). After surveying Cu and Mo levels in the Okanagen Valley of British Columbia they selected the critical Cu/Mo ratio of 2.0, below which deficiency symptoms could be expected. They found the incidence of scouring to be great at a Cu/Mo ratio of 1.0, less at a ratio of 2.3, and found no scouring at a Cu/Mo ratio of 4.3. The average Cu level in the forage was 10.2 ppm and Cu levels were not related to the incidence of scouring. The Mo levels in the forage were correlated to the incidence of scouring witha high incidence at 10 ppm Mo, less scouring at 4 ppm Mo and no scouring at 2 ppm Mo.

The usual treatment for Cu deficiency is to supplement with Cu either by means of injections or as an additive to feedstuffs. As noted above, the earliest work by Ferguson, Lewis and Watson (1938) demonstrated that feeding 2g of $CuSO_4$ per animal per day corrected Molybdenosis in cattle. Cunningham, Brown and Edie (1953) also found that this Cu dosage corrected deficiency symptoms. In addition they observed that cattle grazing on toxic pastures had a craving for salt and that scouring could be halted by adding 1g to 2g of $CuSO_4$ per ounce of salt. Dye and O'Harra (1959) reviewed the preparation and use of Cu glycinate for injection into cattle. They recommend a dosage of Cu glycinate, with 60 mg Cu per ml, of 1 ml for calves and 2 ml for animals larger than 300 pounds body weight. It is possible that molybdenosis may be treated by manipulation of the levels of Cu and Mo in the forage and some significant interactions will be reviewed in the next section concerning soil and plant Cu and Mo.

Copper and Molybdenum in the Soil Plant System

In an attempt to relate soil properties with teartness, Lewis (1943) compared them with non-teart pastures. He noted that teart soils were found wherever the Lower Lias Shale formation was exposed. Alkaline calcareous soils on the Lower Lias were teart if the Mo level was about 20 ppm and were not teart at 2-3 ppm Mo. Acid soils did not cause teartness. He also found that the Mo content increased with depth in the profile. Barshad (1951a) showed that Mo uptake was closely correlated with pH and the solubility of the molybdate (MoO_4=) ion in soil. Materials which lowered the soil pH also decreased plant uptake of Mo. The addition of soluble phosphates, especially on acid soils, enhanced Mo uptake (Barshad, 1951b).

Several important soil-Mo relationships were found by Kubota et al. (1961) in Mo toxicity areas of Nevada. Mo toxicity was associated with alluvial soils derived from granitic parent material, particularly those imperfectly to poorly drained, and organic soils. Toxic Mo levels in plants from the mineral group were greater than 20 ppm whereas toxicity of plants from the organic soils began at 2-3 ppm. The difference in levels might be attributed to low Cu levels in peat and possibly differences in other nutrient elements. The Mo uptake by plants was somewhat increased with increases in pH but the relationship was not clear. Similar relationships were found in areas of Oregon (Kubota, et al., 1967) where granitic alluvium, poor drainage, and high pH were problems. Varying levels of Mo were attributed to the varying amounts supplied by basalt and shale parent materials. Plants from well drained soils did not contain large amounts of Mo regardless of pH or parent material. Soil wetness had also been found to be of great importance in greenhouse studies by Kubota, Lemon and Allaway (1963). The Mo content of clover grown in wet soil showed a highly significant increase in Mo content which was in turn correlated to the increased solubility of the molybdate ion. The Cu content was not affected.

A survey of Mo and Cu levels in forage grown on peat soil in the Everglades of Florida by Kretschmer and Allen (1956) showed Mo levels to increase as the pH of acid soil increased, with a slower rate of plant growth, and as peat decomposed. In addition, crop removal did not appreciably decrease subsequent forage levels due to increased root-soil contact as the peat subsided.

Other soil factors which may influence Mo availability to plants are hydrous oxides of iron, and interactions with other nutrient elements. Robinson and Eddington (1954) proposed that hydrous iron oxides in the soil make Mo less available and Reisenauer (1962) stated that the solubility of Mo in soil and hydrous oxide systems is determined by the percent of Mo saturation and pH of the system.

The two predominant nutrient elements affecting Mo uptake by plants are P and S. A study by Stout and Meagher (1948) using ^{93}Mo and ^{99}Mo in tomato solution cultures showed that roots accumulate Mo rapidly and while Mo is rapidly translocated to the upper parts of the plant, the amount translocated is strongly influenced by the phosphate concentration in solution. In a later article Stout et al. (1951) stated that phosphate increased Mo uptake even with constant soil Mo levels and that when applied with Mo, up to ten fold enhancement was found. In the same studies, they found that sulfate reduced Mo uptake by plants. Application of 350 pounds S/A as gypsum reduced Mo in pea plants from 12.8 ppm to 8.05 ppm and 700 pounds S/A reduced Mo from 16.0 ppm to 2.75 ppm.

Barshad (1951 II) reported that enhancement of Mo uptake by phosphate was especially noticeable in acid soils. He also found that sulfate reduced the water soluble Mo content of the soil solution, an effect of lowered pH. He suggested that the physiological effect of sulfate might be a competition in absorption between $MoO_4^=$, $CO_3^=$, OH^-, and $SO_4^=$. Reisenauer (1963) found two effects of sulfate: 1) a reduction in plant absorption of Mo probably due to a competition for primary plant absorption sites and 2) apparent inhibition of Mo utilization within the plant, particularly at low levels of Mo. Bingham and Garber (1960) found that phosphate enhanced Mo availability on acid soils but decreased its availability on an alkaline soil studied. Other results which confirm the effects of phosphate and sulfate include those of Gupta and Munro (1969) and Greenwood and Hallsworth (1960). Greenwood and Hallsworth (1960) also found that phosphate especially increased Mo uptake at high levels of N fertilization in Subterranean Clover.

In addition to increasing the Mo content of plants, P has been found to decrease Cu uptake. Bingham and Martin (1956) first reported that large quantities of superphosphate induced Cu deficiency in citrus by limiting Cu availability in the soil. Bingham, Martin and Chastain (1958) and Spencer (1960) further verified the P x Cu effect and Bingham and Garber (1960) stated that excess P caused acute Cu deficiency regardless of the source of P. The effect of P in increasing Mo and decreasing Cu levels in plants has very important implications in the Mo/Cu interaction in animal nutrition.

The antagonism of Cu by Mo in animals led to speculation that the same relationship was true in plants. Moore et al. (1957) found that the level of Cu corresponding to maximum yield was raised by Mo in solution. The Cu x Mo interaction was quite small in all systems studied but was slightly greater with nitrate rather than ammonium as N source. Mackay, Chipman and Langille (1964) reported a mutual antagonism between Cu and Mo in crops grown in peat soil. Toxicities of one were alleviated by application of the other. An interaction between Cu and Mo in plants similar to that in animals appears unlikely. However, Spencer, Reading and Thran (1958) reported that application of $CuSO_4$ to pastures in Nevada resulted in an increase of Mo in the forage. This increased Mo was of sufficient magnitude to create toxic levels in forage that had been on a borderline level. Addition of NH_4NO_3 and/or $Ca(H_2PO_4)_2$ also increased Mo levels in the forage while $(NH_4)_2SO_4$ did not.

Marston (1950) reported that uncomplicated Cu deficiency in sheep was originally found to be a problem on the southern Australian coastal fringe. The soils consist of wind deposits of marine detritus, weathered sand, and siliceous sands, all of which are Cu deficient to some extent. Cunningham (1950) reported that Cu deficiency in New Zealand was associated with coastal sands and other leached sandy soils, and in marine and some river silts as well as in peat soils. In both Australia and New Zealand, Cu deficiency is commonly concurrent with Co deficiency. Reuther (1957) identified two problem groups of soils in the United States as weathered sands and organic soils.

Lucas (1948) reported that Cu was held very tightly in organic soils and was not readily exchangeable. He also found that Cu was ionic at very low pH and precipitated, probably as a hydroxide, at a pH above 4.7. Smith, Rasmussen and Hrnciar (1962) found that the small fraction of organic material in the top soil of light sands bound Cu very tightly and that retention was less at lower pH values. They found that clay played a very minor role in Cu retention and that Cu leached from mineral soil more readily. Reuther (1957) reported the same pH relationship for Cu and clay as had been found for organic soil constituents. Blevins and Massey (1959) found that Cu uptake by plants was not correlated with soil pH but that soluble Al decreased uptake. It appears, therefore, that relationships between Cu levels in plants and other factors bear further study and that work with specific systems implicated in nutritional problems would certainly be beneficial.

While various soil factors will enhance Mo uptake by plants, toxicity of Mo to plants is apparently not of practical concern. Johnson (1966) reported Mo toxicity symptoms being shown under experimental conditions only at very high concentrations of Mo.

However, Dye and O'Hara (1959) reported 372 ppm Mo and Beath (1943) reported 333 ppm Mo in plant samples with no mention of toxicity to the plant. It appears that these levels are extremely high for natural conditions.

METHOD AND MATERIALS

The objective of this study was to survey, by chemical analysis, the Cu and Mo status of forage plants in the Burns and Klamath Falls areas. Toward this goal, plant samples were collected to represent pasture types, forage species, and management systems important in the respective geographical areas. Although the sampling programs differed between the two areas they were designed to be complimentary so results could be compared. The most extensive sampling was carried out at the grazing research areas of the two experiment stations. This will allow comparison of the plant analysis data with results of animal feeding trials being carried out. These locations also afforded better control and supervision of the sampling conditions.

Plant sampling requirements differ considerably depending upon the intended use of the results. For determining livestock nutritional value of forage the plant sample must represent as nearly as possible the intake of grazing animals. This implies sampling of the entire plant or that portion eaten by the animal. If species are sampled separately such factors as species composition of the pasture and animal preference must be taken into consideration. If the goal of plant tissue analysis is more directed toward studying plant nutrition more specificity of sampling is required. This specificity involves sampling of single species at specific stages of maturity. A specific portion of the plant anatomy is usually chosen to reproducibly represent the nutrient status of the plant. This type of sample is therefore of increased accuracy in terms of plant nutrition but may give a distorted picture of intake by livestock.

Some compromise was necessary for this study due to the nature of the objectives. Since the results of plant analyses were judged on the basis of nutrient value to livestock, whole plants were taken for samples. However, the determination of the difference between species and the effects of such factors as stage of maturity, time of growing season, soil, and management required that species by analyzed separately.

Samples from each area of study may be conveniently broken down into groups based on the type of forage they represent or the specific goal of the samples. These divisions will be used in the following discussion of the sampling program.

Burns

The Burns samples were all taken at the Section Five portion of the experiment station and fall into four categories:

1. Alfalfa maturity
2. Improved pasture

3. Native meadow

4. Species of alfalfa and grass from a forage nursery

Alfalfa Maturity

To test the effect of maturity of alfalfa on the Cu and Mo content an experiment was designed to obtain samples of alfalfa at different stages of maturity at the same point in the growing season. A uniform stand of Ladak alfalfa was divided into 24 plots, each of which was four feet square. On five dates approximately 1 week apart, four uncut plots were selected at random and clipped to simulate mowing or grazing. This gave a completely randomized design with four replications and six treatments. The treatments were: uncut mature alfalfa and alfalfa last cut on June 28, July 6, July 10, July 21, and July 27. All plots were sampled on August 15. A soil sample was taken to characterize the entire plot area.

Improved Pasture

High yielding introduced species in improved pastures are very important to increased livestock production. Because of this importance, the nutrient status of these forage plants is very critical. In order to investigate the levels of Cu and Mo in this type of pasture sampling sites were selected in two Vernal alfalfa-Fawn fescue and in two Ladino clover-Fawn fescue pastures. The sites were also located at least 75 feet from drain ditches. For comparison, a pure stand of irrigated alfalfa was also sampled. A sampling area was selected within each pasture and marked. Each area was 20 feet in diameter and selected to avoid excessively high or low spots in the field.

Separate samples were taken of grass and legume in each pasture at approximately two week intervals during the growing season. The areas were clipped three times during the growing season to simulate grazing. Clipping took place following sampling on May 30, July 6, and August 15. On August 15 and August 25 samples were taken of the previously clipped pasture and of mature (unclipped) plants for comparison.

A soil sample was taken in each pasture area on May 1, July 7, and August 15 from the 0-12" depth. A sample from the 12-24" depth was taken on May 1.

Native Meadow

Two sampling sites were selected on unimproved meadow pastures consisting of native plant species. Native meadow sites were chosen because this type of pasture is an important grazing resource as well as to compare these pastures to the improved pastures. One meadow site was in a low relief position and under wet conditions. The other site was somewhat higher and drier conditions existed. The species sampled were sedge, rush, and wildrye.

Sampling dates, clipping, and soil sampling of these areas were the same as for the improved pastures. Samples of clipped and unclipped plants were not obtained on the August dates however.

Nursery Plots

Plots had been planted with various grass species and alfalfa varieties of potential or present importance. Three alfalfa varieties and four grass species were sampled at intervals during the season to compare their relative levels of Cu and Mo. The alfalfa varieties shosen were Golden Gro, Grimm, and Ladak. Manchar, Greenar and Oahe were selected to represent the *Bromus* and *Agropyron* genera respectively. An additional legume, sainfoin, was sampled on three dates because of its possible use as an introduced species.

Four samples of each alfalfa variety and grass species were taken on 8/15/72 to obtain replicated data. This was done as an additional check for variation between species and varieties and as a check on sampling techniques.

The grass nursery and alfalfa nursery areas were physically separate. For this reason a separate soil sample was taken from each nursery area on three dates. One soil sample characterized the soil under all alfalfa varieties and the other characterized soil conditions for all grass species. The sampling dates were May 1, July 7, and August 15, 1972.

Klamath Area

The sampling program in the Klamath area fell into two categories:

1. Grass samples from a field plot experiment at the grazing plots of the Klamath Experiment Station
2. Samples from private pastures located throughout the Klamath area.

Field Plot Experiment

Quackgrass and Alta fescue are important grass species in improved pastures in the Klamath area. As part of the survey an experiment was designed to compare the content of Cu and Mo in the two grasses at various times during the growing season and at different stages of maturity. Different levels of nitrogen were included to observe a possible interaction between Mo and N, since N is known to markedly affect maturity.

The experiment was located at the grazing experiment area of the Klamath Experiment Station near Worden, Oregon. Adjacent areas of quackgrass and Alta fescue were divided into plots 7 ft. wide by 20 ft. long. Four N treatments were assigned in a randomized block design to four blocks in each species for a total of 32 plots. The N treatments were:

1. Zero N
2. 75# N/A applied May 1, 1972
3. 150# N/A applied May 1, 1972
4. 50# N/A applied May 1, 1972, June 1, 1972, and July 1, 1972 for a total of 150# N/A.

Plant samples were taken from each plot on May 18, May 31, June 19, July 6, July 31, August 17 of 1972. The plots were clipped or grazed just after sampling on May 31, July 6, and August 17. The plants therefore had about four weeks growth when the samples were taken. A soil sample was taken from the Alta fescue and quackgrass areas on May 2.

Pasture Survey

Copper deficiency in cattle has been identified and treated at several ranches in the Klamath Falls area. This situation offered an opportunity to test the feasibility of using plant sampling and analysis to identify areas with Cu and Mo nutrition problems. In conjunction with this goal the effects of species, stage of maturity, and season on Cu and Mo levels were considered.

Thirteen sampling sites were selected on various pasture types throughout the Klamath area. These sites represented a variety of pasture types, soils, and management systems. Two sites were selected at locations without a history of Cu deficiency problems. They were located near Fort Klamath on the Hawkins and McAuliffe ranches. Three of the sites were on Klamath Marsh, an area of predominantly muck soils. The sites were on the wildlife refuge, Hyde Ranch and Lightner Ranch. The latter site included pasture which had been fertilized with N and unfertilized pasture. Two sites near Lorella on the Randall Ranch represented upland and bottom land positions and were clover-fescue and clover-rush pastures respectively. An additional site on the Smith Ranch near Lorella was on alfalfa-orchard grass pasture.

The Milton site near Malin was a clover-grass pasture on sandy soil. The site on the Gabriel Ranch near Olene was a meadow foxtail pasture on clay soil. An alfalfa-clover-meadow fox pasture on the Negrevski Ranch near Henley was sampled. Two sites were chosen on the Liskey Ranch on Lower Klamath Lake represented different periods of reclamation of the peat soil. The Liskey (home) site was clover-quackgrass pasture and had been drained for a longer period of time than the Liskey (Edwards) site which was a clover-Alta fescue pasture.

Each site consisted of a 4 foot by 4 foot square area protected by a wire cage. Cattle grazing in the pastures like to rub themselves on the cages and eventually trample the area immediately surrounding the cages. For this reason the cages were moved 10 to 20 feet twice during the sampling period.

A random sample of whole plants was taken from the area covered by each cage at approximately 2 week intervals. The samples were separated into species components and the legumes and grasses were placed in separate paper bags for the transport to the laboratory. On sampling dates in mid-June, mid-July, and the first of August the cages were moved to a new location as stated above. Since the pastures were grazed these dates mark the beginning of new growth. Table 1 summarizes the sampling sites, the species sampled, the dates of sampling, and the approximate stage of maturity of the sample. A soil sample was taken from each site on May 2.

Plant and Soil Analysis

Plant samples were oven dried at 75°C. and ground with a small laboratory type Wiley Mill to pass a 20 mesh screen and stored in manilla coin envelopes until analysis. Stainless steel knives and screens were used for grinding.

Analysis for Zn, Mn, K, Ca, and Mg was made on an $HClO_4$-HNO_3 digest by atomic absorption spectrophotmetry (Perkin-Elmer model 306) at standard instrument settings found in the 1971 Perkin-Elmer manual, Analytical Methods for Atomic Absorption

Table 1. Forage sample inventory. Klamath Area, Oregon, 1972.

	Growing period since last harvest (weeks)						
	2	4	6	2	4	4	6
Gabriel-Clover	5-20				7-16	7-28	
Meadow Fox	5-20		6-16	7-5	7-16	7-28	8-17
Hawkins-Clover	5-18	6-2	6-15		7-13	7-28	8-16
Grass	5-18	6-2					
Sedge					7-13	7-28	8-16
Hyde-Bluegrass		6-2	6-15		7-10	8-3	8-16
Lightner-N					7-10		8-16
P + K					7-10		8-16
Bluegrass			6-15				
Liskey(Edwards)-Fescue	5-18	6-1		7-6		8-3	8-17
Clover	5-18						
Liskey(Home)-Quack	5-18		6-19	7-6			8-17
Clover	5-18		6-19				
McAuliffe-Clover	5-18	6-2			7-13	7-28	8-16
Grass	5-18	6-2	6-15		7-13	7-28	8-16
Milton-Clover			6-16	7-5		7-28	8-17
Grass			6-16	7-5		7-28	8-17
Negrevski-Alfalfa	5-18	6-1	6-19			7-28	8-17
Clover		6-1	6-19			7-28	8-17
Meadow Fox	5-18	6-1	6-19	7-5		7-28	8-17
Randall 4A-Clover	5-18	6-1	6-16		7-11	7-28	8-17
Alta Fescue							
13 -Clover	5-18		6-16		7-11		
Sedge		6-1	6-16		7-11	7-28	8-17
Smith-Alfalfa		6-1	6-16				8-17
Orchardgrass		6-1	6-16				8-17
Wildlife Refuge-Clover		6-2	6-15				
Rush		6-2	6-15		7-10		8-16
Sedge		6-2	6-15		7-10		
Lower Klamath Station	5-18	5-31	6-19	7-6		7-31	8-17

<u>Spectrophotmetry</u>. An aliquot of this digest was used for colorimetric determination of P with ammonium vanadate-molybdate color forming reagent. Total N was determined using a modified micro-kjeldahl procedure.

For determination of Cu, Mo, and Co, a weighed quantity of plant material was ashed at 500° C. for 5 hours in silica crucibles. The cooled ash was taken up in 20 ml of 5% HCl, filtered through Watman #50 paper and the filtrate retained for analysis in 50 ml plastic vials. The dry ash procedure was used because a more concentrated solution resulted for Cu and Co and perchloric salts were found to interfere with Mo and Co analysis using flameless atomic absorption. One gram of plant material was used for samples from Burns and 2 grams for samples from the Klamath area due to the generally lower concentrations of Cu and Mo.

Copper concentration was determined by the standard flame method of atomic absorption spectrophotometry. Molybdenum concentrations were determined by atomic absorption with the P. E. model 306 in conjunction with a Perkin-Elmer HGA 70 Heated Graphite Atomizer. Instrument parameters were as follows:

Program 7 - drying 30 sec. at 100°C.
Char 35 sec. at 1100°C.
atomize 20 sec. ca. 2600"C. (V=10)

P-E 306:

Wavelength = 313 UV (3133A)

damping = 2 recorder expand = 3

Hitachi Perkin-Elmer 159 Recorder

Sample size 20 ul

Samples with a Mo concentration greater than 7 ppm were off of the recorder scale and were diluted 1:4. The resulting 1/100 final dilution was then run as above. Atomic Absorption of Co in the dry ash digest was also done using the heated graphite atomizer with the following instrument parameters:

HGA 70

Program 7 - dry 30 sec. at 100°C.

char 40 sec. at 1100°C.

atomize 10 sec. at 1c. 2400°C. (V=9)

P-E 306

Wavelength = 241 UV (2407A) slit = 4(7A)

damping = 2 recorder expand = 3

sample size = 20 ul

Soil samples were analyzed by the OSU Soil Testing Laboratory according to methods reported by Roberts et al. (1971). Determinations of pH and electrical conductivity were made for all soil samples. Selected samples were also analyzed for CEC, organic matter, P, K, Ca, Mg, Na, Zn, Mn, and Cu. Zinc, Mn, and Cu were determined from a DTPA extract of the soil by standard methods of atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

The plant samples collected for this survey were analyzed for P, K, Ca, Mg, Zn, Mn, Cu, Mo, and Co. All of the Burns samples and a portion of the Klamath samples were also analyzed for total N. The results of all analyses are listed in Appendix Table 1 by site in the order in which they are discussed below. Soil samples were taken at each site and analyzed for pH and electrical conductivity. Some soil samples were analyzed for cations, P, CEC, and organic matter. The results of soil analyses for each site are presented in Appendix Table 2 for Burns and Klamath respectively.

The concentrations of a number of elements in plant material were determined. The purpose of this survey was to determine the Cu and Mo status of the forage and discussion will be limited to these elements. Neither deficiencies nor toxicities of other elements measured were known to exist in the areas studied.

Burns

Alfalfa Maturity Study

Alfalfa ranging in age from 20 days to about 120 days was analyzed for Cu and Mo to see if levels were affected by maturity.

The results are shown in Figure 1. Both Cu and Mo levels decreased as the alfalfa became more mature. The Mo level in the youngest plants was 15 ppm and decreased to 8.8 ppm in the mature plants. The Cu level decreased from 12.3 ppm to 6.2 ppm. Completely randomized AOV with 18 degrees of freedom showed the decrease in Mo level to be significant at the 1% level of confidence and the decrease in Cu level to be significant at the 5% level.

The Cu level was high enough that it should not be considered a problem for livestock nutrition, particularly in the younger plants. However, the Mo level was higher than the Cu level at all stages of maturity resulting in a Cu/Mo ratio of less than unity. In this case it might be expected that Cu deficiency might be induced in grazing livestock.

Irrigated Improved Pasture

In this phase of study a comparison was made between alfalfa, clover, and Fawn fescue at different stages of maturity, at different times during the grazing season. The greatest difference in nutrient levels was found to be between the legumes and the grass. Alfalfa and clover were higher in both Cu and Mo than the fescue in all of the pastures sampled. The mean Cu level of all samples in the legume-grass pastures was 7.4 ppm for alfalfa and 6.5 ppm for clover compared to 2.0 ppm for the fescue. The pasture planted

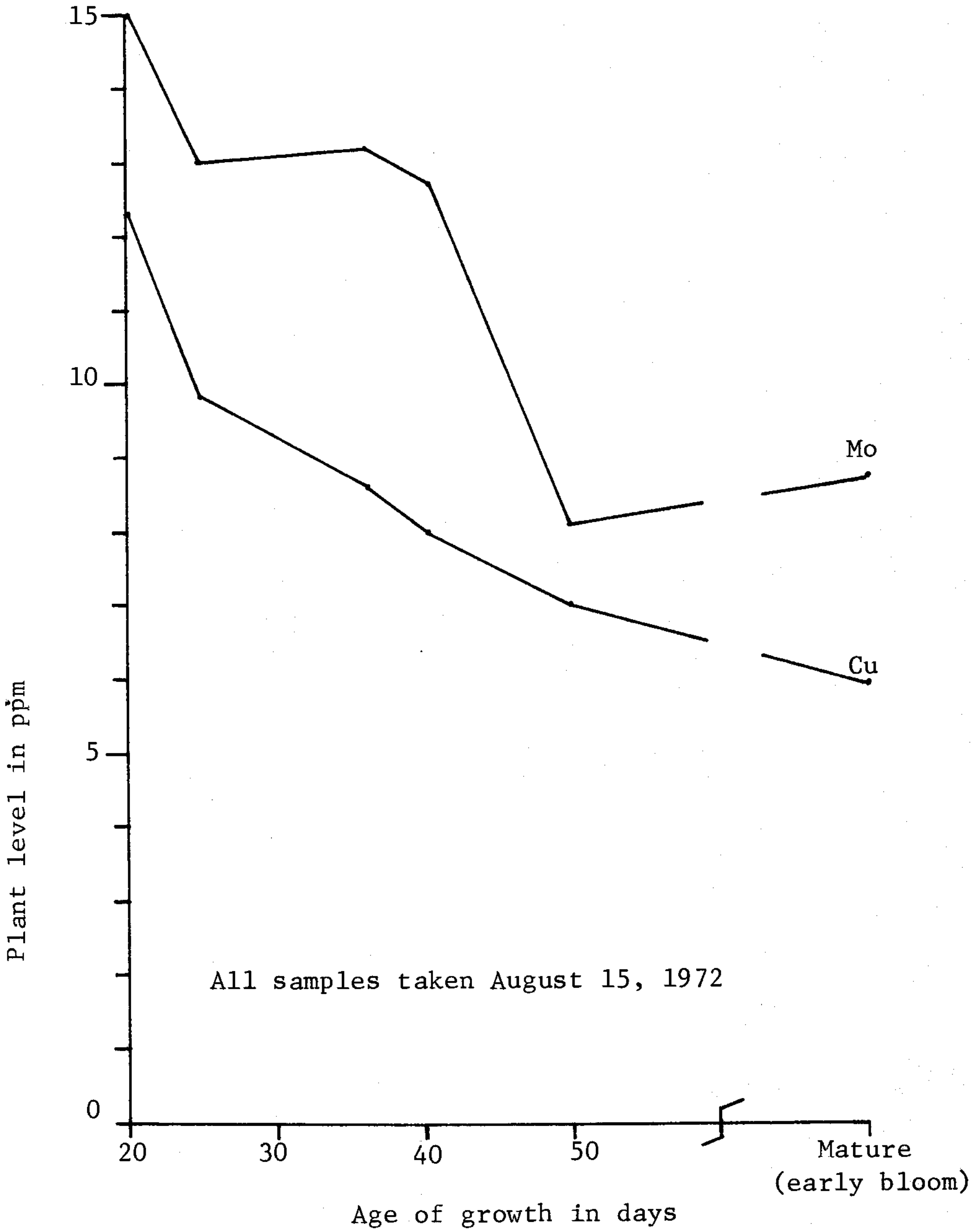

Figure 1. Cu and Mo levels in alfalfa of increasing ages of growth - Burns

only to alfalfa had a mean Cu level of 8.5 ppm. Clover had an extremely high mean Mo level at 20.7 ppm. The alfalfa samples averaged 8.6 ppm Mo and the fescue averaged 3.4 ppm Mo. The mean Mo level in the alfalfa pasture was 6.5 ppm. Although legumes had higher levels of Cu as well as Mo the Cu/Mo ratios were low. Only in a few instances did the ratio exceed 2.0 and then by very little. The fescue was also characterized by low Cu/Mo ratios. The levels of Mo in clover and alfalfa are the highest encountered in this survey. The high Mo levels and low Cu/Mo ratios indicate that livestock grazing these pastures may become Cu deficient in spite of the Cu levels present.

The Mo levels in the fescue tended to increase as the season progressed as shown in Figure 2. This increase is especially noticeable in the August samples which approached 10 ppm Mo. Also shown in Figure 2 are the Cu levels for the fescue which do not show a pattern of increase or decrease.

Native Meadows

Three species of native meadow grasses were sampled throughout the season for comparison of Cu and Mo levels. The genera were *Carex* (sedge), *Juncus* (rush), and *Elymus triticoides* (wildrye). One site (meadow 1) was better drained than the other (meadow 2) and therefore had drier soil conditions.

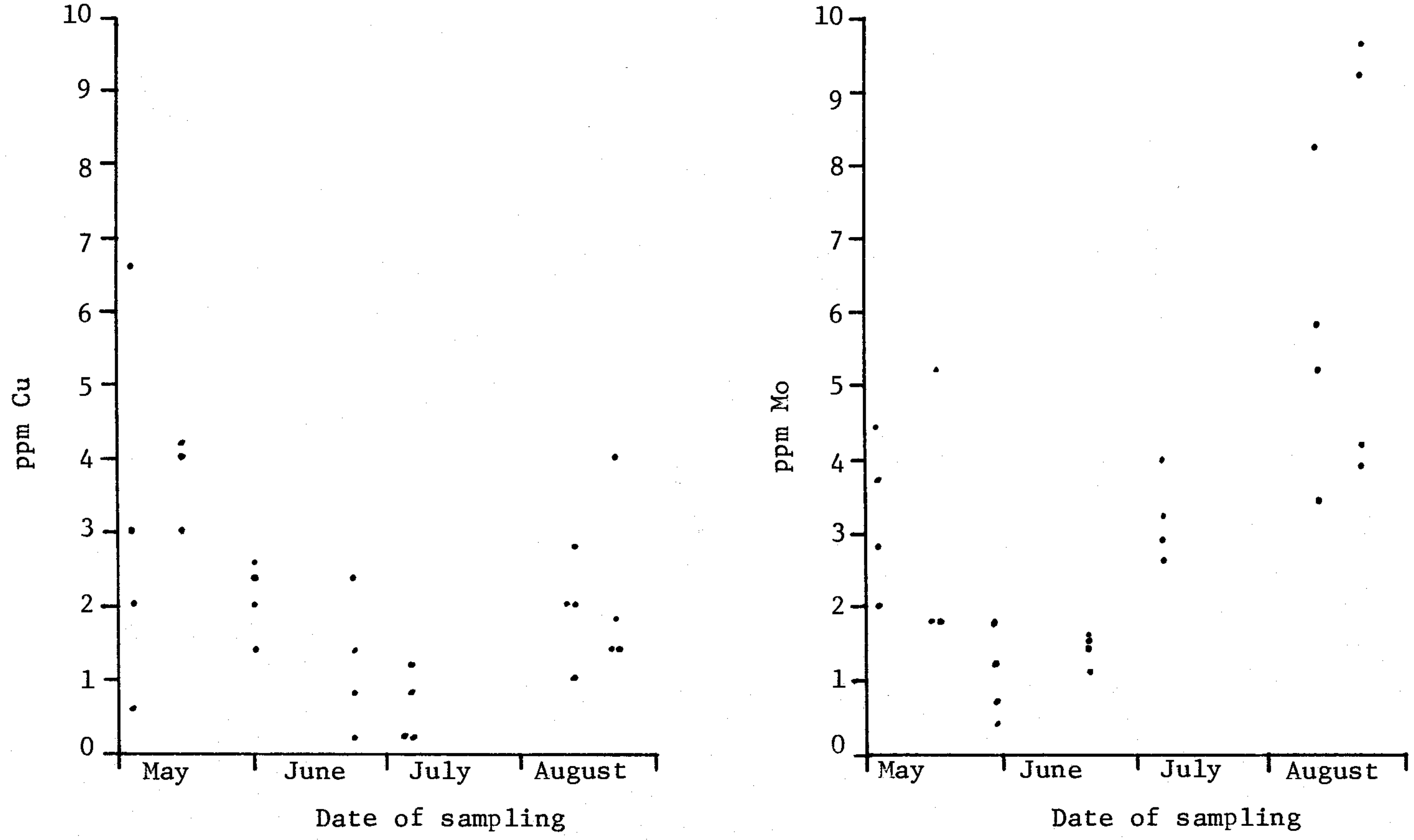

Figure 2. Seasonal variation of Cu and Mo levels in Fawn Fescue at Burns

The mean Cu and Mo levels for the three grasses and two sites are shown in Table 2. There was no appreciable difference in Mo levels between species and sites. The Mo levels averaged less than 3 ppm and would not be expected to induce Cu deficiency in livestock. These levels are also lower than the mean level of 3.5 ppm Mo for Fawn fescue. All mean Cu levels were similar, averaging between 5 and 6 ppm, with the exception of the wildrye on the dry site which was somewhat lower. Of greatest importance is the fact that Cu levels are seen to decrease with time, often to quite low levels, and the mean value is not adequate to characterize the Cu status. This decrease in Cu levels is most pronounced in Carex and Juncus and is shown in Figure 3. The decrease in Cu levels lowered the Cu/Mo ratios from favorable values to values lower than 2.0 toward the end of the grazing season. Deficiency of Cu is a distinct possibility for livestock grazing the native meadows in August or later even though it may not be induced by Mo toxicity. This data also shows the hazard of using samples from a particular stage of maturity or mean values to assess the nutrient status.

Forage Nurseries

The data from analysis of these forage samples tends to summarize the trend of the Burns data. Mean Cu and Mo levels were greater for alfalfa than for the grass species. The alfalfa samples

Table 2. Mean Cu and Mo levels for Native Meadow.

Genus	Meadow	Cu(ppm)	Mo(ppm)	Cu/Mo
Carex	1	4.9	2.1	2.3
	2	5.6	2.1	2.7
Juncus	1	5.8	1.3	4.5
	2	5.3	1.4	3.8
Elymus	1	3.7	2.9	1.3
	2	5.1	1.5	3.4

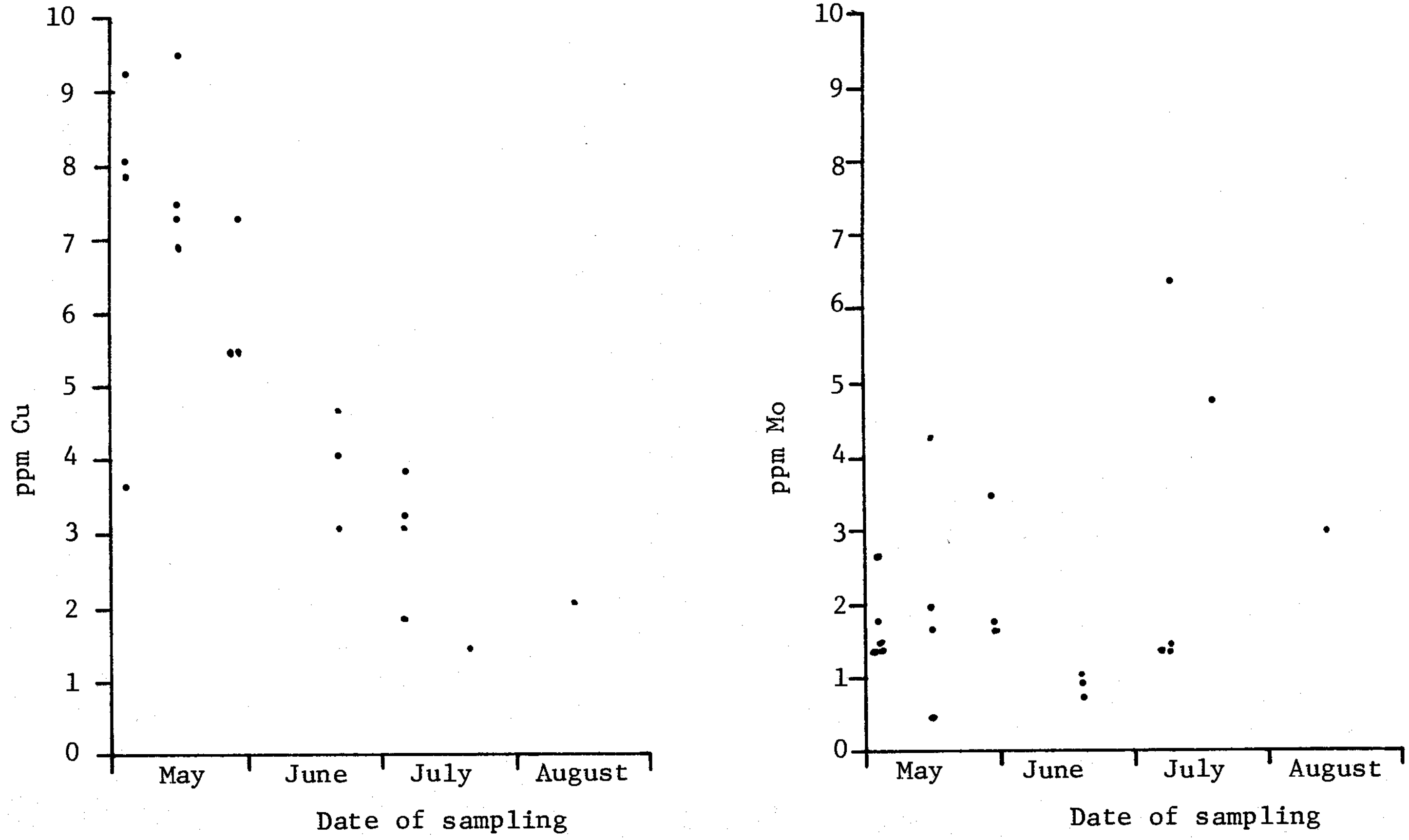

Figure 3. Seasonal levels of Cu and Mo in native meadow species (<u>Carex</u> and <u>Juncus</u>) at Burns

averaged 10.1 ppm Cu and 11.9 ppm Mo. Most Cu/Mo ratios were less than 1.0 with only one value in excess of 2.0. The mean Cu level for the grass species was 4.0 ppm and the mean Mo level was 2.4 ppm, less than half of the mean values for alfalfa. However, the most significant relationship for grass samples was the difference between the May and August samples. The level of Cu was decreased by at least half in the August samples and the Mo level was at least doubled in the later samples. This relationship is also reflected in the Cu/Mo ratio which decreased from 3.0 or much greater in May to less than 1.0 in August. The pattern of decreased Cu and increased Mo later in the grazing season is consistent with patterns found in the Fawn fescue and native meadow grasses.

Replicated samples of alfalfa and grasses were taken on August 15 to find if there might be differences between the alfalfa varieties or grass species and to check the sampling process. For these samples, no significant differences in Cu and Mo levels were found for the grasses. Promor and Ladak alfalfa were slightly higher in Cu levels than Grimm and Golden Gro (significant at .05 level, 12 d.f. for error). The alfalfa varieties did not differ significantly in Mo content. Again, alfalfa had higher levels of both Cu and Mo than did the four grasses. The mean Cu level for grasses was 2.3 ppm and for alfalfa was 11.1 ppm. The mean Mo level for grasses was 3.5 ppm and for alfalfa was 12.1 ppm. The

Cu/Mo ratio was less than 2.0 for all samples and generally less than unity.

Klamath Area

Field Plot Experiment

Quackgrass and Alta fescue plots were treated with different N levels. Plant samples were taken and analyzed for Cu and Mo to compare levels in the two grasses and to check for an interaction with N fertilization rate. The plots were clipped at intervals to simulate grazing practices.

Plant analysis showed that there was not an interaction between the level of N applied and the Cu and Mo levels found. Therefore, the mean of the check and 150 pount N treatments was taken for further comparisons. These means of two treatments with four replications each are shown in Table 3. Some of the samples for three of the dates became contaminated with Cu and the means for these dates are deleted. However, the values of uncontaminated samples are given at the bottom of the above table. In spite of these deletions, the data conform to the seasonal trend seen in the grasses sampled at Burns. Levels of Cu decreased from over 7.0 ppm in May to less than 0.5 ppm in mid-August. The Mo levels show a definite increase over the same time period. It is important to note that the Mo levels for the Alta fescue are 1.5 to 2 times higher than those for quackgrass on corresponding dates. The increase of Mo levels into a range of possible incipient toxicity coupled with the sharp decrease in Cu levels demonstrates that the molybdenosis problem at this locality is confirmed by plant analysis.

Table 3. Mean Cu and Mo levels in Alta Fescue and Quackgrass from the Klamath field plot experiment.

	Alta Fescue		Quackgrass	
Date	Cu(ppm)	Mo(ppm)	Cu(ppm)	Mo(ppm)
5-18	1.8	4.7	*	1.7
5-31	*	2.9	*	1.9
6-19	*	5.4	1.6	2.4
7-6	1.8	4.6	*	2.2
7-31	<0.5	5.6	1.3	3.8
8-17	<0.5	8.9	<0.5	4.6

* Samples contaminated with Cu. Values of uncontaminated samples were:

Fescue 6-19 0 to possibly 6 ppm

Quackgrass 5-18 2.0 to 5.4, $\bar{x}$ = 3.4 ppm

7-6 all samples contaminated

It should be noted that the Mo levels in the fescue plots decreased between May 18 and May 31, and again between June 19 and July 6. However the Mo level in the regrowth after clipping on May 31 and July 6 shows an increase. The general trend, as stated above, is for Mo to increase but it may be that the young regrowth contains a higher concentration of Mo.

These plots were on a soil consisting of partially decomposed peat and diatomaceous material from recent lakebed material. The organic matter content is approximately 55%. The soil is poorly drained and wetness is a primary problem. Soil analysis showed the pH to be 8.1 to 8.2, approximately 80 meq/100g of Ca, and total salts resulting in EC values of 4.0 mmhos/cm for the quackgrass plots and 6.3 mmhos/cm under the Alta Fescue plots. The association of high Mo levels with wetness, salts, high pH, and muck soils and of low Cu levels with high organic matter content is borne out by these field plot data.

Pasture Survey

A survey of Cu and Mo levels in the Klamath Area was conducted by selecting thirteen sites on various ranches as described under "Methods and Materials". Each site was sampled at approximately two week intervals and the cages used were moved periodically to supply a variable based on stage of maturity. Table 1 in Methods and Materials" summarizes the sampling program. The results of plant analysis are listed in Appendix Table 1 and the results of soil analysis are given in Appendix Table 2.

Symptoms of Cu deficiency had been reported in cattle grazing all but two of the sampling sites. These two sites, Hawkins and McAuliffe, were selected to help establish a base level for Cu and Mo where livestock nutrition would not be a problem. Plant samples from the two sites did contain the highest overall levels of Cu. McAuliffe clover samples had a mean level of 9.3 ppm Cu and grass had a mean level of 4.8 ppm Cu. Hawkins clover averaged 7.1 ppm Cu, grass averaged 5.0 ppm Cu, and sedge averaged 4.1 ppm Cu. The Mo levels at both sites were low with a mean of 0.9 ppm and a range of 0.3 to 2.1 ppm Mo. The Cu/Mo ratio was greater than 2.0 for all samples. The Cu levels represent a maximum for the survey and the Mo levels are similar to those found on most sites. The Negrevski site also had relatively high Cu levels with means of 8.3 ppm Cu in Clover, 7.0 ppm Cu in Alfalfa, and 3.9 ppm Cu in meadow foxtail.

With the exception of the Lightner and Refuge sites on Klamath Marsh, the samples had a mean level of 1.2 ppm Mo and very few samples exceeded 2.0 ppm Mo. In those cases where a comparison is possible between legumes and grasses the legume samples are slightly higher in Mo content. However, at the low levels of Mo encountered this and other variations may be considered insignificant, particularly with respect to livestock nutrition. With the possible exception of the Hawkins, McAuliffe, and Negrevski sites, Cu levels were generally less than optimum and often were quite low. The mean value for each species at each site shows that Cu levels for legumes ranged from 3.7 ppm to 10.3 ppm and for grasses ranged from 1.8 ppm to 5.0 ppm. In spite of relatively low Cu levels the Cu/Mo ratio was greater than 2.0 for 74% of all samples, due primarily to the low Mo levels. The Cu/Mo ratio is of little value in cases where it would not identify uncomplicated Cu deficiency.

The lowest mean Cu levels were found at the Randall 13 site with 3.7 ppm Cu in clover and 2.8 ppm Cu in grass and the Lightner and Liskey grass samples with means of 1.8 ppm Cu and 2.1 ppm Cu respectively. Other sites not discussed above were consistent with the mean level for all samples which was 6.9 ppm Cu in legumes and 3.3 ppm Cu in grasses.

High levels of Mo were found on the Wildlife Refuge at Klamath Marsh which indicate potential Mo toxicity. The mean level in clover was 11.5 ppm Mo and for the native meadow 6.7 ppm Mo. The soil is poorly drained and formed in muck and peat containing diatomaceous sediments. Some distinguishing soil characteristics are 37% organic matter, 19 meq./100 g Ca, and a pH of 5.4. The Hyde site at Klamath Marsh did not give high Mo levels. The site is on a mineral soil with better drainage. The Cu level was below optimum and lower than on the Refuge Site. The Lightner Site at Klamath Marsh was bluegrass on mineral soil, part of which had received N fertilizer and part of which had been fertilized with P and K. Levels of Cu were quite low for these samples with a maximum of 2.2 ppm Cu. Levels of Mo were low for the N fertilized portion at 1.0 to 1.0 ppm Mo. However, the P and K fertilized grass gave levels of 4.5 and 7.6 ppm Mo which are relatively high. All of the Lightner samples had a Cu/Mo ratio of 2.0 or less.

The Liskey-Home and Liskey-Edwards sites on Lower Klamath Lake are on a muck soil with approximately 18% organic matter. The Liskey-Home site has been drained for a longer period of time and has therefore been in pasture longer. The plant analysis data for Cu and Mo are incomplete and a comparison of the two sites is not possible. The levels of Mo are well below any critical level for livestock. The Cu levels are less than 3 ppm Cu indicating that both sites may cause uncomplicated Cu deficiency in livestock.

Because there is much variation in Cu levels at each site it is not possible to isolate a consistent pattern based on the stage of maturity. However, in many cases a general decrease in Cu levels is seen over the grazing season. Examples of this decrease are the Gabriel site clover, Hyde site bluegrass, Negrevski site meadow foxtail, and the Refuge site native meadow grasses. In other cases such as at the McAuliffe and Hawkins sites the Cu levels remain relatively constant. Some sites yielded such low Cu levels that variations are not detectable. Examples of this would be the Lightner and Liskey sites.

SUMMARY

Copper deficiency and molybdenosis have been found to be nutritional disorders of ruminant livestock in the Burns and Klamath Falls areas of Oregon. Chemical analysis of plant and soil samples was utilized to survey Cu and Mo levels in forage in these areas and to study the relationship between forage levels and plant species, stage of plant maturity, time of growing season, management and soils. This information was used in an effort to identify potential Cu-Mo animal nutrition problems.

A total of approximately 400 plant samples were collected at the various sites throughout the 1972 grazing season. The samples from Burns were taken from an experiment with alfalfa at different stages of maturity, irrigated legume - grass pastures, irrigated native meadows, and from a nursery of alfalfa varieties and grass species. The Klamath samples represented two distinct phases of study. One group of samples was from an experiment comparing Alta fescue and quackgrass at varying rates of N fertilization on an alkaline peat soil. The other group of samples was taken from 13 sites selected on ranches throughout southern and central Klamath County.

The plant analysis survey was shown to be a useful tool for identifying the forage levels of Cu and Mo in the areas studied. The

samples from Burns, particularly the legumes, had high levels of Mo and moderate to low levels of Cu. With the exception of some meadow species the Cu/Mo ratios were quite low. The predominant problem is therefore probably one of Mo-induced Cu deficiency. A summary of the Cu and Mo levels in the Burns forage is shown in Table 4 below. In the Klamath area, Mo levels were generally well below those where toxicity might be expected. However, Cu levels were also low where Cu supplementation of livestock has been necessary. This leads to the conclusion that the problem for most areas is uncomplicated Cu deficiency. Two sites on muck soils had plants with levels of Mo in a range of possible toxicity to livestock. The Klamath Area survey was particularly important in demonstrating the range of values that may be encountered.

Table 4. Comparison of Cu and Mo levels in Burns forage species.

	ppm Cu		ppm Mo	
Pasture Type	Mean	Range	Mean	Range
legume-grass				
clover	6.5	5.0-10.4	20.7	13.0-37.5
alfalfa	7.4	3.0-11.0	8.6	4.7-16.7
fescue	2.0	0.2-6.6	3.4	3.7-11.0
alfalfa field	8.5	5.0-11.4	6.5	3.7-11.0
nursery				
alfalfa	10.1	6.8-12.4	11.8	8.2-22.8
grass	4.0	0.9-8.0	2.4	0.5-7.9
native meadow	5.0	* -9.4	2.4	0.4-13.0

* Not detectable.

The most striking results of this survey were the great differences between types of plants in the levels of Cu and Mo they contained. These differences are shown, or suggested, in at least three ways: 1) the difference in levels between legumes and grasses; 2) the differences in levels between varieties and species of legumes and grasses; and 3) evidence that legume and grass levels of Cu and Mo change differently with progression of the grazing season and with different stages of maturity. Legumes often had levels of both Cu and Mo two to five times higher than grasses from the same site. This is most obvious at Burns for both Cu and Mo. In the Klamath area the legumes were higher in Cu than grasses and Mo levels were usually low for all plants. Normally adequate Cu levels in legumes at Burns were accompanied by such high levels of Mo that the Cu/Mo ratio becomes an important consideration. At Burns, as shown in Table 4, the mean level of Mo for clover was significantly higher than that for alfalfa without a similar increase in Cu level. Alfalfa in the pastures averaged 8.6 ppm Mo as opposed to 20.7 ppm Mo for clover while alfalfa had 7.4 ppm Cu as opposed to 6.5 ppm Cu for clover. Thus, alfalfa appears to have an advantage over clover in this respect. The samples from the nursery at Burns provide evidence that differences exist between varieties of alfalfa. Replicated samples showed two of the varieties to be significantly higher in Cu than the other two. Some grasses were found to differ in Mo levels in the field plot experiment at Klamath. The comparison of Alta fescue and quackgrass showed that fescue with a mean of 5.4 ppm Mo had a higher level than did quackgrass with a mean of 2.8 ppm Mo.

It is difficult to compare Cu and Mo levels with the stage of maturity of the plant and with a particular point in the growing season. This survey does show that such relationships may exist and that they are different for legumes and grasses. The alfalfa maturity study at Burns showed that mature alfalfa contained half the Cu concentration found in the youngest regrowth. The Mo level decreased also, but not to as great an extent as Cu. Examination of the data for all legumes shows that some variation may be attributable to maturity of the plant but that in general the levels of Cu and Mo tend to remain relatively constant throughout the grazing season. This is in contrast with the grasses studied where the predominant pattern is the level throughout the grazing season. Although regrowth of a pasture may cause some slight increase in Cu levels, the general trend is for Cu levels to decrease drastically toward the end of the grazing season. This decrease was often to levels barely detectable by analytic techniques. At the same time it was found that some of the grasses studied showed an increase in Mo levels as the season progressed, often into ranges of possible toxicity. The net result of these seasonal trends is a marked reduction in the Cu/Mo ratio with increased possibility of Cu deficiency in livestock.

The primary goal of this study was to identify potential problems with Cu and Mo nutritional value of forages to livestock. The survey showed that toxic levels of Mo were present in forage at Burns. For much of the Klamath area it was found that Cu levels were low enough to cause Cu deficiency in ruminants and that high Mo levels could be a problem on some soils. Forage analysis for Cu and Mo would definitely be advantageous for identifying Cu and Mo problems on a localized basis in view of the wide range of values encountered. This study also showed that plant families, genera, species and varieties may differ greatly in the amount of Cu and Mo they contain on the same site. These differences exist not only in absolute quantity of Cu and Mo but in the seasonal and maturity patterns of content. The plant analysis survey was a valuable technique for identifying Cu and Mo nutrition problems and for identifying plant and environmental factors regulating forage levels.

BIBLIOGRAPHY

Allcroft, R., and G. Lewis. 1957. Copper nutrition in ruminants. Disorders associated with copper - molybdenum - sulphate content of feeding stuffs. J. Sci. Food Agr. 8:S96-S104.

Barshad, I. 1951. Factors affecting the molybdenum content of pasture plants: I. nature of soil molybdenum, growth of plants, and soil pH. Soil Sci. 71:297-313.

Barshad, I. 1951. Factors affecting the molybdenum content of pasture plants: II. effects of soluble phosphates, available nitrogen, and soluble sulfates. Soil Sci. 71:387-398.

Beath, O. A. 1943. Toxic vegetation growing on the salt wash sandstone member of the morrison formation. Amer. J. Bot. 30:698-701.

Bingham, F. T., and M. J. Garber. 1960. Solubility and availability of micronutrients in relation to phosphorous fertilization. Soil Sci. Soc. Amer. Proc. 24:209-213.

Bingham, F. T., and J. P. Martin. 1956. Effects of soil phosphorous on growth and minor element nutrition of citrus. Soil Sci. Soc. Amer. Proc. 20:282-285.

Bingham, F. T., J. P. Martin, and J. A. Chastain. 1958. Effects of phosphorous fertilization of California soils on minor element nutrition of citrus. Soil Sci. 86:24-31.

Blevins, R. L., and H. F. Massey. 1959. Evaluation of two methods of measuring available soil copper on the effects of soil pH and extractable aluminum on copper uptake by plants. Soil Sci. Soc. Amer. Proc. 23:296-298.

Brannion, H. D. 1960. Conditioned copper deficiency in cattle. Int. Grassland Congr., Proc. 8th (Reading, England) p. 564-569.

Britton, J. W. and H. Goss. 1946. Chronic molybdenum poisoning in cattle. J. Amer. Vet. Med. Assoc. 108:176-178.

Comar, C. L., L. Singer and G. K. Davis. 1949. Molybdenum metabolisms and interrelationships with copper and phosphorous. J. Biol. Chem. 180:913-922.

Cunningham, I. J. 1950. Copper and molybdenum in relation to diseases of cattle and sheep in New Zealand. p. 246-273. In W. D. McElroy and B. Glass (Ed.) A symposium on copper metabolism. Johns Hopkins Press, Baltimore.

Cunningham, H. M., J. M. Brown, and A. E. Edie. 1953. Molybdenum poisoning of cattle in the Swan River Valley of Manitoba. Can. J. Agr. Sci. 33:254-260.

Davis, G. K. 1950. The influence of copper on the metabolism of phosphorous and molybdenum. p. 216-229. In W. D. McElroy and B. Glass (Ed.) A symposium on copper metabolism. Johns Hopkins Press, Baltimore.

Dick, A. T. 1952. The effect of diet and of molybdenum on copper metabolism in sheep. Australian Vet. J. 28:20-33.

Dick, A. T. 1953. The control of copper storage in the liver of sheep by inorganic sulphate and molybdenum. Australian Vet. J. 29:233-239.

Dick, A. T. 1954. Preliminary observations on the effect of high intakes of molybdenum and inorganic sulphate on blood copper and on fleece character in crossbred sheep. Australian Vet. J. 30:196-202.

Dick, A. T. 1956a. The effects of inorganic sulfate on molybdenum and copper metabolism in sheep. Int. Grassland Congr., Proc. 7th (Palmerston, New Zeal.) p. 368-376.

Dick, A. T. 1956b. Molybdenum in animal nutrition. Soil Sci. 81:229-236.

Dick, A. T., and L. B. Bull. 1945. Some preliminary observations on the effect of molybdenum on copper metabolism in herbivorous animals. Australian Vet. J. 21:70-72.

Dye, W. B., and J. L. O'Harra. 1959. Molybdenosis. Nevada Agricultural Experiment Station Bulletin 208. 32 p.

Ferguson, W. S., A. H. Lewis, and S. J. Watson. 1938. Action of molybdenum in nutrition of milking cattle. Nature. 141:553.

Ferguson, W. S., A. H. Lewis, and S. J. Watson. 1943. The teart pastures of Somerset. I. The cause and cure of teartness. J. Agr. Sci. 33:44-51.

Greenwood, E. A. N., and E. G. Hallsworth. 1960. Studies on the nutrition of forage legumes. II. Some interactions of calcium, phosphorous, copper and molybdenum on the growth and chemical composition of Trifolium subterraneum L. Plant and Soil. 12:97-127.

Gupta, U. C., and D. C. Munro. 1969. Influence of sulphur, molybdenum, and phosphorous on chemical composition and yields of brussels sprouts and of molybdenum on sulphur contents of several plant species grown in the greenhouse. Soil Sci. 107:114-118.

Halverson, A. W., J. H. Phifer, and K. J. Monty. 1960. A mechanism for the copper-molybdenum interrelationship. J. Nutrition. 71:95-100.

Hart, E. B., H. Steenbock, J. Waddell, and C. A. Elvehjem. 1928. Iron in nutrition. J. Biol. Chem. 77:797-812.

Hideroglou, M., K. J. Jenkins, J. R. Lessard, and R. B. Carson. 1970. Copper and molybdenum status of growing beef cattle in a selenium deficient area of northern Ontario. Can. J. Animal Sci. 50:279-284.

Johnson, C. M. 1966. Molybdenum. p. 286-201. In H. D. Chapman (Ed.) Diagnostic criterea for plants and soils. University of California, Riverside.

Kretchmer, Jr., A. E., and R. J. Allen, Jr. 1956. Molybdenum in Everglades soils and plants. Soil Sci. Soc. Amer. Proc. 20:253-257.

Kubota, J., E. R. Lemon, and W. H. Allaway. 1963. The effect of soil moisture content upon the uptake of molybdenum, copper and cobalt by alsike clover. Soil Sci. Soc. Amer. Proc. 27:679-683.

Kubota, J., V. A. Lazar, L. N. Langan, and K. C. Beeson. 1961. The relationship of soils to molybdenum toxicity in cattle in Nevada. Soil Sci. Soc. Amer. Proc. 25:227-232.

Kubota, J., V. A. Lazar, G. H. Simonson, and W. W. Hill. 1967. The relationship of soils to molybdenum toxicity in grazing cattle in Oregon. Soil Sci. Soc. Amer. Proc. 31:667-671.

Lewis, A. H. 1943. The teart pastures of Somerset. II. relation between soil and teartness. J. Agr. Sci. 33:52-57.

Lucas, R. E. 1948. Effect of copper fertilization on carotene, ascorbic acid, protein, and copper contents of plants grown on organic soils. Soil Sci. 65:461-469.

MacKay, D. C., E. W. Chipman, and W. M. Langille. 1964. Crop responses to some micronutrients and sodium on sphagnum peat soil. Soil Sci. Soc. Amer. Proc. 28:101-104.

Marston, H. R. 1950. Problems associated with copper deficiency in ruminants. p. 230-245. In W. D. McElroy and B. Glass (Ed.) A symposium on copper metabolism. The Johns Hopkins Press, Baltimore.

Miltimore, J. E., and J. L. Mason. 1971. Copper to molybdenum ratio and molybdenum and copper concentrations in ruminant feeds. Can. J. Anim. Sci. 51:193-200.

Miltimore, J. E., J. L. Mason, J. M. McArthur, and R. B. Carson. 1964. Ruminant mineral nutrition. The effect of copper injections on weight gains and haemoglobin levels of cattle pastured on ground-water soils in the British Columbia interior. Can. J. Comp. Med. and Vet. Sci. 28:108-112.

Moore, D. P., M. E. Harward, D. D. Mason, R. J. Hader, W. L. Lott, and W. A. Jackson. 1957. An investigation of some of the relationships between copper, iron, and molybdenum in the growth and nutrition of lettuce: II. response surfaces of growth and accumulation of copper and iron. Soil Sci. Soc. Amer. Proc. 21:65-74.

Mylrea, P. J. 1958. Copper-molybdenum-sulfate-manganese interaction and the copper status of cattle. Australian J. Agr. Res. 9:373-384.

Reisenauer, H. M. 1963. The effect of sulphur on the absorption and utilization of molybdenum by peas. Soil Sci. Soc. Amer. Proc. 27:553-555.

Reisenauer, H. M., A. A. Tabikh, and P. R. Stout. 1962. Molybdenum reactions with soils and the hydrous oxides of iron, aluminum, and titanium. Soil Sci. Soc. Amer. Proc. 26:23-27.

Reuther, W. 1957. Copper and soil fertility. In Soil. Yearbook Agr., U.S. Dep. Agr. U.S. Government Printing Office, Washington. p. 128-135.

Richert, D. A., and W. W. Westerfield. 1953. Isolation and identification of the xanthine oxidase factor as molybdenum. J. Biol. Chem. 203:915-923.

Roberts, S., R. V. Vodraska, M. D. Kauffman, and E. H. Gardner. 1971. Methods of soil analysis used in the Soil Testing Laboratory at Oregon State University. Special Report 321, Agricultural Experiment Station. Oregon State University, Corvallis, Oregon.

Robinson, W. O., and G. Eddington. 1954. Availability of soil molybdenum as shown by the molybdenum content of many different plants. Soil Sci. 77:237-251.

Scott, M. L. 1972. Trace elements in animal nutrition. p. 555-591. In J. J. Mortvedt (Ed.) Micronutrients in agriculture. Soil Science Society of America, Madison, Wisconsin.

Smith, P. F., G. K. Rasmussen, and G. Hrnciar. 1962. Leaching studies with metal sulfates in light sandy citrus soil in Florida. Soil Sci. 94:235-238.

Spencer, W. F. 1960. Effects of heavy applications of phosphate and lime on nutrient uptake, growth, freeze injury, and root distribution of grapefruit trees. Soil Sci. 89:311-318.

Spencer, V. E., R. E. Reading, and L. W. Thran. 1958. Too much molybdenum? then use care in soil treatment. Nevada Agricultural Experiment Station Bulletin 202. 12 p.

Stout, P. R., and W. R. Meagher. 1948. Studies of the molybdenum nutrition of plants with radioactive molybdenum. Science. 108:471-473.

Stout, P. R., W. R. Meagher, G. A. Pearson, and C. M. Johnson. 1951. Molybdenum nutrition of crop plants: I. the influence of phosphate and sulfate on the absorption of molybdenum from soils and solution cultures. Plant and Soil. 3:51-87.

Vanderveen, J. E., and H. A. Keener. 1964. Effects of molybdenum and sulfate sulphur on metabolism of copper in dairy cattle. J. Dairy Sci. 47:1224-1230.

Wynne, K. N., and G. L. McClymont. 1955. Copper-molybdenum, sulphate interaction in induction of hypocuprosis. Nature. 175:471-472.

APPENDIX

Appendix Table 1. Nutrient analysis of forage samples.

SECTION 5, SQUAW BUTTE EXPERIMENT STATION-BURNS, OREGON. 1972

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm Mn	Zn	Co	Cu	Mo	Cu/ Mo
Improved Pasture: Clover-Grass												
Field 11W - Fawn Fescue												
5-1		2.85	0.14	2.13	0.36	0.15	34	29	0.1	03.0	02.8	1.07
5-16		2.50	0.18	2.20	0.27	0.16	23	23	0.2	04.0	01.8	2.22
5-30		1.36	0.28	1.85	0.21	0.13	13	21	0.2	02.4	01.8	1.33
6-20		0.90	0.18	1.68	0.21	0.14	21	22	0.1	00.8	01.5	0.53
7-6		1.30	0.20	1.75	0.38	0.20	37	12	0.2	00.2	03.2	0.06
8-15		1.41	0.21	1.73	0.70	0.28	40	14	0.3	02.8	08.2	0.34
8-25		1.39	0.21	1.68	0.60	0.29	38	12	0.0	04.0	09.6	0.42
Field 11W - Clover												
5-30		3.30	0.24	2.58	1.69	0.37	21	23	0.5	05.2	22.1	0.24
8-15		2.54	0.22	2.13	1.96	0.46	46	20	1.1	06.2	21.4	0.29
8-15		2.70	0.21	2.00	1.44	0.41	43	20	0.4	06.2	13.0	0.48
8-25		2.77	0.20	2.33	1.70	0.38	45	18	0.8	05.0	15.8	0.32
Field 14W - Fawn Fescue												
5-1		2.69	0.18	1.60	0.40	0.17	36	22	0.1	00.6	03.7	0.16
5-16		2.65	0.20	2.05	0.25	0.14	18	22	0.1	03.0	05.2	0.58
5-30		1.78	0.24	1.95	0.22	0.15	12	21	0.3	02.0	01.2	1.67
6-20		1.78	0.23	2.38	0.28	0.21	28	18	0.2	01.4	01.4	1.00
7-6		1.57	0.20	2.20	0.37	0.25	25	16	0.1	00.8	02.9	0.28
8-15		2.03	0.23	2.33	0.47	0.27	34	17	0.7	02.0	03.4	0.59
8-25		1.90	0.23	2.00	0.45	0.24	47	17	0.5	01.4	03.9	0.36
Field 14W - Clover												
5-30		3.84	0.28	2.30	1.31	0.37	29	20	0.4	06.2	37.5	0.17
8-15		3.36	0.24	2.08	1.43	0.42	39	35	0.8	10.4	14.4	0.72
Improved Pasture: Alfalfa												
5-1		4.66	0.25	2.45	1.79	0.29	19	35	0.5	11.4	08.0	1.42
5-16		3.50	0.24	3.53	1.42	0.30	19	38	0.1	06.2	11.0	0.56
5-30		3.31	0.39	3.50	1.72	0.26	22	30	0.6	10.6	05.6	1.89
6-20		2.27	0.20	2.20	1.33	0.24	08	13	0.4	07.2	03.7	1.95
7-6		2.66	0.23	1.78	2.34	.25	13	21	1.6	05.0	07.2	0.69
7-21		1.95	0.16	1.73	2.12	0.22	11	17	0.4	05.6	06.0	0.93
8-15		1.95	0.15	1.53	1.75	0.27	10	17	1.2	08.8	03.9	2.26
8-15		3.09	0.23	3.13	2.09	0.28	23	25	0.8	10.2	05.1	2.00
8-15		3.34	0.25	3.60	2.04	0.33	24	30	1.2	11.4	09.2	1.24
8-25		1.90	0.14	1.18	1.98	0.27	09	19	1.6	08.6	05.3	1.62

Appendix Table 1. Continued

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm Mn	Zn	Co	Cu	Mo	Cu/ Mo
					Improved Pasture: Alfalfa-Grass							
Field 12E - Fawn Fescue												
5-1			0.21	2.08	0.29	0.17	34	28	0.1	02.0	02.0	1.00
5-16		2.95	0.17	2.33	0.30	0.20	24	27	0.2	04.2	01.8	2.33
5-30		1.41	0.22	2.03	0.12	0.14	15	20	0.2	02.6	00.4	6.50
6-20		1.14	0.16	1.98	0.20	0.17	22	19	0.2	02.4	01.6	1.50
7-6		0.46	0.09	1.60	0.07	0.09	10	12	0.1	00.2	01.1	0.18
7-21		0.82	0.11	1.83	0.32	0.16	31	19	0.2	00.0	04.0	0.00
8-15		2.42	0.30	2.50	0.44	0.33	41	35	0.5	02.0	05.8	0.34
8-25		2.14	0.29	2.85	0.39	0.31	38	27	0.4	01.4	09.2	0.15
Field 12E - Alfalfa												
5-1		4.56	0.17	2.03	2.30	0.35	38	31	1.2	11.0	09.0	1.22
5-16		4.78	0.23	2.65	2.07	0.32	22	28	0.8	09.0	08.0	1.12
5-30		3.34	0.36	2.93	2.32	0.41	16	25	0.7	06.8	06.5	1.05
6-20		2.22	0.20	2.05	2.22	0.38	21	22	1.0	05.6	05.7	0.98
7-6		1.97	0.14	1.28	2.23	0.29	30	15	0.7	05.2	04.7	1.11
7-21		1.82	0.14	1.18	2.79	0.38	26	17	0.9	03.0	04.8	0.62
8-15		2.30	0.17	1.50	2.21	0.34	24	14	3.1	06.4	08.4	0.76
8-15		3.36	0.31	3.13	2.13	0.35	34	23	0.7	09.0	11.6	0.78
8-25		2.91	0.23	2.48	2.09	0.31	26	16	1.1	07.2	05.8	1.24
8-25		2.46	0.20	1.48	2.47	0.32	31	16	2.2	08.4	06.6	1.27
Field 13E - Fawn Fescue												
5-1		3.60	0.17	2.43	0.33	0.19	35	29	0.3	06.6	04.4	1.50
5-30		1.30	0.24	2.03	0.23	0.16	14	19	0.2	01.4	00.7	2.00
6-20		0.94	0.18	1.68	0.10	0.16	11	17	0.1	00.2	01.1	0.18
7-6		1.01	0.15	1.83	0.24	0.18	10	14	0.2	01.2	02.6	0.46
8-15		2.06	0.24	2.33	0.47	0.33	37	27	0.6	01.0	05.2	0.19
8-25		1.79	0.22	2.25	0.46	0.26	44	21	0.3	01.8	04.2	0.43
Field 13E - Alfalfa												
5-1		4.21	0.25	2.33	2.01	0.29	28	25	0.5	08.6	08.0	1.08
5-16		4.42	0.24	3.58	1.73	0.35	20	21	0.4	09.6	05.2	1.85
5-30		3.22	0.26	2.85	1.94	0.32	18	20	0.5	05.6	13.4	0.42
6-20		2.21	0.22	2.95	1.62	0.33	12	19	0.4	07.0	08.2	0.85
7-6			0.16	2.73	1.76	0.29	13	13	0.5	07.0	10.0	0.70
8-15		3.42	0.26	2.98	1.95	0.32	22	25	0.7	08.0	16.7	0.48
8-25		3.22	0.21	2.60	2.17	0.28	40	18	1.2	08.0	14.4	0.56

Appendix Table 1. Continued

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm Mn	Zn	Co	Cu	Mo	Cu/ Mo
					Native Meadow							
Meadow 1 - Carex												
5-1		2.37	0.14	2.08	0.42	0.13	53	25	0.1	03.6	02.6	1.38
5-16		3.21	0.19	2.40	0.31	0.11	25	21	0.1	07.2	04.2	1.71
5-30		2.38	0.22	2.13	0.28	0.13	30	19	0.2	05.4	01.7	3.18
6-20		1.63	0.24	2.75	0.16	0.13	50	16	0.3	04.6	00.7	6.57
7-6		1.42	.23	2.70	0.30	0.12	39	13	0.2	03.8	01.3	2.92
Meadow 2 - Carex												
5-1		4.17	0.18	2.00	0.31	0.15	86	32	0.2	09.2	01.4	6.57
5-16 (1)		2.70	0.12	2.08	0.21	0.14	63	31	0.1	06.8	01.9	3.58
5-16 (2)		3.08	0.11	2.18	0.34	0.13	66	31	0.1	09.4	00.4	23.50
5-30		1.89	0.19	2.10	0.30	0.12	25	25		07.2	03.4	2.12
6-20		1.46	0.16	2.08	0.32	0.11	78	23	0.1	04.0	01.0	4.00
7-6		1.28	0.14	2.15	0.34	0.11	85	17	0.2	03.0	01.4	2.14
7-21		1.09	0.11	1.55	0.67	0.14	106	15	0.2	01.4	04.7	0.30
8-15		1.98	0.11	1.55	0.49	0.13	35	22	0.1	02.0	02.9	0.69
Meadow 1 - Juncus												
5-1 (1)		3.34	0.17	1.78	0.37	0.13	73	29	0.1	07.8	01.3	6.00
5-1 (2)		3.43	0.17	1.78	0.42	0.15	70	33	0.2	08.0	01.3	6.15
7-6		1.86	0.25	2.90	0.70	0.17	83	25	0.4	01.8	06.3	0.29
5-1		3.32	0.12	1.75	0.39	0.30	80	28	0.1	07.4	01.7	4.35
5-16		2.45	0.11	1.90	0.32	0.12	90	33	0.1	07.4	01.6	4.62
5-30		1.92	0.17	1.93	0.31	0.07	89	27	0.1	05.4	01.6	3.38
6-20		1.47	0.15	1.93	0.30	0.10	82	23	0.1	03.0	00.9	3.33
7-6		1.42	0.13	1.85	0.36	0.07	71	24	0.1	03.2	01.3	2.46
Meadow 1 - Elymus												
5-1		3.44	0.14	2.00	0.40	0.11	27	29	0.1	04.6	13.0	0.35
5-16		3.26	0.10	2.33	0.28	0.09	20	23	0.1	05.8	06.0	0.97
5-30		3.18	0.34	2.48	0.19	0.08	27	27	0.5	05.0	01.5	3.33
6-20		1.71	0.23	2.88	0.16	0.10	30	21	0.1	02.6	01.3	2.00
7-6		1.46	0.18	2.70	0.28	0.05	23	22	0.2	04.6	01.3	3.54
7-21		1.06	0.15	2.25	0.35	0.09	28	19	0.1	00.6	02.3	0.26
8-15		2.43	0.20	2.25	0.48	0.11	44	23	0.4	02.2	04.4	0.50
8-15		0.98	0.11	2.08	0.34	0.10	33	11	0.0	03.6	03.6	1.00

Appendix Table 1. Continued

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm Mn	Zn	Co	Cu	Mo	Cu/ Mo
Meadow 2 - Elymus												
5-1		4.27	0.18	2.63	0.33	0.13	36	28	0.1	07.2	01.6	4.50
5-16		3.04	0.14	2.70	0.20	0.10	34	23	0.2	06.2	00.8	7.75
5-30		2.22	0.25	3.15	0.24	0.11	22	23	0.2	05.8	00.6	9.67
6-20		0.98	0.11	2.10	0.17	0.07	38	12	0.1	03.2	01.9	1.68
7-6		1.47	0.14	2.20	0.16	0.08	23	22	0.1	06.4	02.2	2.91
7-21		1.06	0.15	1.90	0.31	0.07	14	18	0.1	00.0	02.3	0.00
8-15		2.88	0.22	2.60	0.34	0.16	41	32	0.2	06.6	01.0	6.60
Forage Nurseries												
Alfalfa - Golden Gro												
5-1		5.21	0.41	2.25	2.11	0.31	42	32	0.9	11.0	22.8	0.48
5-16		4.36	0.25	2.75	1.77	0.32	18	29	0.1	11.4	18.0	0.63
5-30		3.12	0.34	3.20	2.00	0.37	24	20	0.5	06.8	08.4	0.81
8-15		2.86	0.29	3.39	2.09	0.32	22	23	1.2	10.0	12.4	0.81
Alfalfa - Grimm												
5-1		5.07	0.20	2.40	1.85	0.31	34	32	0.5	11.2	04.8	2.30
5-16		4.17	0.31	3.40	1.50	0.31	16	33	0.4	10.2	14.0	0.73
5-30		3.25	0.36	3.30	1.96	0.31	10	19	0.5	07.0	08.4	0.83
8-15		3.65	0.34	3.60	1.97	0.36	31	25	1.1	10.6	13.2	0.80
Alfalfa - Ladak												
5-16		4.85	0.42	3.25	1.78	0.32	23	36	0.5	12.4	12.4	1.00
5-30		3.42	0.34	3.18	2.27	0.36	25	18	1.0	08.4	09.2	0.91
8-15		3.41	0.36	3.68	2.00	0.37	30	27	1.1	11.8	10.4	1.13
8-25		3.98	0.35	3.35	1.93	0.37	30	19	1.5	10.8	08.2	1.32
Sainfoin												
5-16		3.53	0.27	2.58	1.15	0.30	31	37	0.3	14.4	04.4	3.27
5-30		2.32	0.29	2.23	1.12	0.36	14	23	0.2	05.8	17.2	0.34
8-15			0.24	1.68	1.22	0.26	26	14	0.3	05.4	12.0	0.45
Grass - Greenar												
5-1		3.54	0.31	2.78	0.37	0.14	46	30	0.2	06.4	01.0	6.40
5-30		2.32	0.32	2.75	0.29	0.10	20	22	0.3	04.0	01.2	3.33
8-15		2.22	0.28	2.03	0.47	0.20	49	22	0.5	02.1	02.3	0.91
8-25		2.18	0.28	2.10	0.46	0.20	41	24	0.3	01.0	03.2	0.31

Appendix Table 1. Continued

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm Mn	Zn	Co	Cu	Mo	Cu/ Mo
Grass - Manchar												
5-16		2.62	0.20	2.90	0.32	0.18	30	21	0.1	04.2	01.4	3.00
5-30		2.05	0.25	2.43	0.30	0.13	20	18	0.2	07.0	00.8	8.75
8-15		2.43	0.27	2.35	0.63	0.29	52	23	0.3	02.5	04.2	0.60
8-25		2.53	0.26	2.73	0.58	0.26	56	20	0.1	03.6	07.9	0.46
Grass - Oahe												
5-1		4.58	0.23	3.05	0.45	0.15	41	24	0.2	08.0	00.5	16.00
5-16		3.42	0.25	2.93	0.34	0.09	21	24	0.2	06.4	00.8	8.00
8-15		2.16	0.23	1.73	0.57	0.17	41	21	0.2	00.9	03.1	0.29
8-25		2.46	0.25	2.03	0.57	0.20	47	23	0.4	01.6	03.0	0.53
Alfalfa Maturity - Sampled 8-15-72 - Mean of 4 Reps												
7-27	20		0.48	3.23	1.91	0.37	35	34	1.2	12.3	15.0	0.80
7-21	26		0.36	3.42	1.80	0.38	28	29	0.9	09.8	13.0	0.70
7-10	37		0.32	3.36	1.85	0.32	26	26	0.8	08.6	13.2	0.60
7-6	41		0.28	2.86	1.81	0.30	27	19	1.0	08.0	12.7	0.60
6-28	49		0.24	2.66	1.81	0.28	24	19	1.0	07.0	08.1	0.80
Mature			0.16	1.58	1.85	0.26	25	14	1.4	06.2	08.8	0.70
Alfalfa Varieties - Sampled 8-15-72 - Mean of 4 Reps												
Variety												
Golden Gro			0.29	3.39	2.01	0.32	22	23	1.2	10.0	12.4	0.80
Grimm			0.34	3.60	1.97	0.36	31	25	1.1	10.6	13.2	0.80
Ladak			0.36	3.68	2.00	0.37	30	27	1.1	11.8	10.4	1.10
Promor			0.31	3.62	1.85	0.38	27	24	0.8	12.0	12.3	0.90
Grass Varieties - Sampled 8-15-72 - Mean of 3 Reps												
Variety												
Fescue			0.30	1.91	0.47	0.30	40	16	0.6	03.9	04.3	0.90
Greenar			0.28	2.03	0.47	0.20	49	22	0.5	02.1	02.3	0.90
Manchar			0.27	2.35	0.63	0.29	52	23	0.3	02.5	04.2	0.60
Oahe			0.23	1.73	0.57	0.17	41	21	0.2	00.9	03.1	0.20

Appendix Table 1. Continued

KLAMATH FALLS, OREGON. 1972

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm					Cu/
							Mn	Zn	Co	Cu	Mo	Mo
						Field Plot Experiment						
Alta Fescue												
5-18			0.22	2.35			46	27	0.2	01.8	04.7	0.38
5-31		2.49	0.18	1.86	0.38	0.50	54	27	0.0	07.3	02.9	2.52
6-19			0.19	1.96	0.20	0.23	86	29	0.4		05.4	
7-6			0.20	2.59			64	28	0.2	01.8	04.6	0.39
7-31			0.22	1.97	0.26	0.26	84	26	0.5	<0.5	05.6	0.04
8-17			0.18	2.01	0.28	0.26	78	26	0.6		08.9	
Quackgrass												
5-18			0.22	2.92			43	22	0.2		01.7	
5-31		2.99	0.21	2.44	0.42	0.31	48	25	0.0	07.4	01.9	3.89
6-19			0.22	2.51	0.18	0.14	50	23	0.2	01.6	02.4	0.67
7-6			0.20	2.64			42	21	0.1		02.2	
7-31			0.24	2.88	0.22	0.18	48	28	0.4	01.3	03.8	
8-17			0.19	2.49	0.25	0.18	48	22	0.2	<0.5	04.6	0.07
Gabriel - Olene: Clover												
5-20			0.44	3.33	1.29	0.27	87	31	1.2	09.1	01.3	7.00
7-16		3.45	0.44	2.98	0.61	0.28	87	38	0.6	06.0	01.4	4.29
7-28			0.36	5.50	2.02	0.70	119	25	0.4	02.2	01.2	1.83
Gabriel: Meadow Foxtail												
5-20			0.46	3.43	0.91	0.20	95	28	1.3	03.9	00.7	5.57
6-16		2.78	0.45	3.03	0.20	0.17	111	30	0.4	02.2	00.6	3.67
7-5			0.38	3.05	0.28	0.16	90	27	1.2	02.3	00.7	3.29
7-16		2.59	0.44	3.10	0.17	0.15	92	28	0.4	02.2	00.8	2.75
7-28			0.48	3.08	0.72	0.52	116	37	1.1	04.8	00.7	6.86
8-17			0.41	3.23	0.94	0.23	107	32	1.4	04.4	01.2	3.67
Hawkins - Fort Klamath: Clover												
5-18		4.48	0.56	3.70	0.95	0.34	34	59	0.3	13.0	01.0	13.00
6-2			0.45	3.03	1.15	0.27	75	62	0.9	07.0	01.2	5.83
6-15			0.35	2.40	1.20	0.24	142	39	0.8	07.1	01.4	5.07
7-13		2.61	0.30	2.50	0.36	0.19	124	37	0.4	05.2	00.7	7.43
7-28			0.30	2.20	1.01	0.23	100	48	0.5	04.3	02.1	2.05
8-16			0.30	2.70	1.03	0.25	56	36	0.5	06.2	01.6	3.88

Appendix Table 1. Continued

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm Mn	Zn	Co	Cu	Mo	Cu/ Mo
Hawkins: Grass												
5-18		2.95	0.39	2.40	0.24	0.16	84	52	0.2	04.0	00.6	6.67
6-2			0.40	2.75	1.03	0.21	70	54	1.2	06.0	00.7	8.57
Hawkins: Sedge												
7-13		2.51	0.28	2.45	0.22	0.14	140	35	0.2	04.0	00.8	5.00
7-28			0.28	1.83	0.56	0.40	115	34	0.6	03.9	01.4	2.79
8-16			0.33	2.25	0.88	0.18	89	44	0.7	04.3	01.1	3.91
Hyde - Klamath Marsh: Bluegrass												
6-2			0.36	2.68	0.94	0.20	130	31	0.8	05.7	00.9	6.33
6-15			0.35	2.63	0.56	0.41	124	47	0.8	05.2	00.5	10.40
7-10		2.18	0.24	2.18	0.32	0.18	149	38	0.2	02.8	01.0	2.80
8-3			0.30	2.38	0.99	0.20	143	33	0.4	03.4	02.7	1.26
8-16			0.23	1.95	0.95	0.17	152	40	0.5	02.3	02.4	0.96
Lightner - Lenz: N												
7-10		1.90	0.18	2.18	0.39	0.13	123	22	0.1	02.0	01.0	2.00
8-16			0.20	1.60	0.92	0.15	152	20	0.4	01.9	01.6	1.19
8-16			0.12	1.50	1.05	0.18	190	12	0.3	01.4	02.0	0.70
Lightner: P + K												
7-10		1.31	0.22	1.98	0.41	0.13	111	17	0.1	02.2	04.5	0.49
8-16			0.27	1.63	0.94	0.18	181	25	0.6	01.6	07.6	0.21
Lightner: Bluegrass												
6-15		1.80	0.24	1.93	0.30	0.13	114	23	0.2	01.4	03.8	0.37
Liskey (Edwards) - Merrill: Fescue												
5-18			0.51	2.75	0.30	0.19	42	28	0.0	00.0	03.3	
6-1			0.35	2.78	0.90	0.18	47	28	1.2	02.7	01.2	2.25
7-6		2.17	0.32	2.45	0.36	0.20	62	16	0.3	01.0	00.8	1.25
8-3			0.34	2.50	1.14	0.21	75	15	0.8	02.0	01.4	1.43
8-17			0.34	2.78	1.10	0.22	88	18	1.2	02.2	02.4	0.92
Liskey (Edwards): Clover												
5-18			0.53	2.68	0.26	0.19	81	28	0.0	00.0	01.9	

Appendix Table 1. Continued

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm					Cu/
							Mn	Zn	Co	Cu	Mo	Mo
Liskey (Home): Quackgrass												
5-18			0.68	2.00	0.20	0.20	78	29	0.0		02.0	
6-19			0.40	3.25	1.12	0.23	63	36	0.0		00.0	
7-6			0.43	2.03	0.65	0.27	117	53	0.9		00.0	
8-17			0.34	3.00	0.94	0.15	72	25	0.8	02.3	01.9	1.21
Liskey (Home): Clover												
5-18			0.53	2.23	0.67	0.25	61	45	0.2	01.8	01.2	1.50
6-19			0.42	2.58	1.54	0.29	63	47	1.0	02.7	00.7	3.86
McAuliffe _Ft. Klamath: Clover												
5-18		5.09	0.45	3.58	1.24	0.34	56	54	0.3	11.0	01.3	8.46
6-2			0.47	2.45	1.21	0.44	65	40	0.9	07.2	00.3	24.00
7-13		3.00	0.26	2.15	0.89	0.30	46	28	0.2	08.4	00.7	12.00
7-28			0.38	2.30	2.17	0.71	77	37	1.1	10.1	00.6	16.83
8-16			0.31	2.03	1.61	0.37	59	50	1.3	09.6	00.9	10.67
McAuliffe: Grass												
5-18		3.84	0.63	3.05	0.24	0.15	69	47	0.5	04.0	00.4	10.00
6-2			0.48	2.85	1.04	0.19	69	33	1.2	06.9	00.5	13.80
6-15			0.32	2.75	0.93	0.16	75	36	0.8	05.5	00.4	13.75
7-13		2.57	0.24	2.50	0.38	0.16	50	23	0.1	04.4	00.5	8.80
7-28			0.33	1.75	1.23	0.29	100	32	0.7	03.5	00.7	5.00
8-16			0.36	2.15	1.17	0.24	83	43	0.8	04.4	00.5	8.80
Milton-Malin: Clover												
6-16		2.65	0.40	2.25	0.70	0.27	62	21	0.3	03.2	01.8	1.78
7-5			0.41	2.40	1.50	0.37	97	24	0.7	04.0	01.2	3.33
7-28			0.33	2.40	1.45	0.41	75	25	0.7	09.3	01.6	5.81
8-17			0.29	1.88	1.28	0.34	93	31	0.6	05.3	01.8	2.94
Milton: Grass												
6-16		1.53	0.22	1.48	0.17	0.16	65	20	0.2	00.8	00.7	1.14
7-5			0.39	2.13	1.16	0.28	82	23	1.2	02.0	00.8	2.50
7-28			0.36	1.98	1.13	0.31	80	26	0.8	03.7	01.2	3.08
8-17			0.27	1.73	0.92	0.22	95	27	0.8	01.9	01.3	1.46

Appendix Table 1. Continued

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm Mn	Zn	Co	Cu	Mo	Cu/ Mo
Negrevski - Henley: Alfalfa												
5-18		4.61	0.36	2.78	1.39	0.35	34	36	0.4	08.2	01.1	7.45
6-1			0.38	3.05	1.53	0.29	33	21	1.4	07.6	01.4	5.43
6-19			0.29	2.25	1.54	0.45	30	12	0.9	06.0	01.9	3.16
7-28			0.39	2.90	1.65	0.34	49	22	1.8	08.6	01.2	7.17
8-17			0.28	2.33	1.55	0.24	37	21	1.4	04.7	01.9	2.47
Negrevski: Clover												
6-1			0.36	2.55	1.32	0.28	89	25	1.2	09.5	01.7	5.59
6-19			0.43	2.55	1.82	0.65	94	40	0.9	09.2	00.7	13.14
7-28			0.36	2.53	1.60	0.34	100	24	1.8	07.5	00.9	8.33
8-17			0.28	2.18	1.76	0.35	74	23	1.8	07.0	01.1	6.36
Negrevski: Meadow Foxtail												
5-18		3.04	0.29	2.45	0.18	0.11	59	21	0.3	05.4	02.3	2.35
6-1			0.34	2.45	0.77	0.13	84	21	0.7	03.6	00.6	6.00
6-19			0.28	1.58	0.61	0.34	76	16	0.6	03.6	00.5	7.20
7-5			0.36	2.43	0.97	0.16	60	27	1.0	04.6	00.7	6.57
7-28			0.47	2.85	0.95	0.24	149	32	1.3	03.7	01.0	3.70
8-17			0.35	2.58	0.92	0.20	130	26	1.1	02.7	01.2	2.25
Randall-Lorella: 4A Clover												
5-18			0.50	3.68	1.17	0.39	74	37	0.4	11.0	00.8	13.75
6-1			0.48	3.50	1.51	0.37	90	32	1.0	07.1	00.8	8.88
6-16			0.50	3.13	0.79	0.37	121	36	0.5	04.4	00.9	4.89
7-11			0.34	3.05	0.35	0.27	80	21	0.5	01.8	00.4	4.50
7-28			0.36	1.90	1.50	0.69	175	24	0.4	05.1	01.2	4.25
8-17			0.36	2.68	1.63	0.43	140	30	1.3	08.9	01.9	4.68
Randall: 4A Alta Fescue												
5-18		2.63	0.50	2.73	0.16	0.24	97	32	0.4	01.2	00.4	3.00
6-1			0.46	2.90	0.97	0.27	94	30	1.0	03.0	00.6	5.00
6-16		3.06	0.48	2.78	0.29	0.28	102	28	0.4	02.2	01.2	1.83
7-11		3.18	0.34	3.30	1.00	0.39	102	26	0.6	08.0	01.1	7.27
7-28			0.39	1.90	0.99	0.65	123	23	1.2	02.6	00.6	4.33
8-17			0.44	2.95	0.94	0.30	81	31	1.4	02.4	01.1	2.18

Appendix Table 1. Continued

Date	Age (da.)	% N	% P	% K	% Ca	% Mg	ppm Mn	Zn	Co	Cu	Mo	Cu/ Mo
Randall: 13 Clover												
5-18			0.52	2.13	0.15	0.23	280	35	0.0	02.4	00.9	2.67
6-16		3.21	0.33	2.78	0.69	0.43	135	28	0.2	06.8	02.4	2.83
7-11		2.48	0.27	2.23	0.44	0.41	154	26	0.3	01.8	02.4	0.75
Randall: 13 Sedge												
6-1			0.31	1.98	0.90	0.23	332	36	0.6	03.0	00.9	3.33
6-16		2.59	0.29	2.03	0.25	0.27	176	28	0.3	03.0	01.3	2.31
7-11		2.50	0.29	1.93	0.27	0.28	130	26	0.3	02.2	02.1	1.05
7-28			0.30	2.33	0.50	0.51	184	25	0.7	03.4	01.1	3.09
8-17			0.23	1.95	0.89	0.26	190	22	0.4	02.4	01.4	1.71
Smith-Lorella: Alfalfa												
6-1			0.39	3.45	2.00	0.38	39	25	1.7	07.9	00.7	11.29
6-16		2.83	0.29	2.75	1.20	0.29	38	18	0.6	06.8	00.6	11.33
8-17			0.29	2.25	2.05	0.33	42	21	2.3	08.5	01.6	5.31
Smith: Orchardgrass												
6-1			0.38	2.83	0.52	0.35	89	17	1.3	05.1	00.4	12.75
6-16		1.54	0.30	2.78	0.21	0.15	121	50	0.4	01.8	00.4	4.50
8-17			0.51	3.13	1.03	0.31	123	25	1.5	03.9	01.0	3.90
Wildlife Refuge - Klamath Marsh: Clover												
6-2			0.25	2.33	2.14	0.66	107	42	0.8	08.5	13.5	0.63
6-15			0.16	1.73	1.04	0.26	96	34	0.2	07.0	09.5	0.74
Wildlife Refuge: Rush												
6-2			0.13	1.68	0.58	0.32	65	17	0.4	08.3	08.1	1.02
6-15		1.89	0.13	1.88	0.22	0.16	75	18	0.2	06.6	07.5	0.88
7-10		1.67	0.11	1.60	0.47	0.17	114	32	0.1	02.4	07.4	0.32
8-16			0.07	1.18	0.91	0.14	104	14	0.1	00.9	02.5	0.36
Wildlife Refuge: Sedge												
6-2			0.15	1.45	0.65	0.28	62	24	0.2	04.6	04.5	1.02
6-15		1.81	0.11	1.50	0.32	0.15	49	26	0.1	01.8	09.0	0.20
7-10		1.64	0.10	1.40	0.51	0.20	66	19	0.1	01.8	07.9	0.23

Appendix Table 2. Analysis of soil samples from forage sites.

				BURNS SITES						
			% ppm				meq/100g			
Depth	Date	pH	EC	OM	CEC	P	Ca	Mg	K	Na
Field 11W										
0-12	5-1	8.0	0.70	05.06	47.00	07	31.2	09.2		3.17
12-24	5-1	8.5	0.48							
0-12	7-7	8.3	1.29							
0-12	8-17	8.0	0.90							
Field 12E										
0-12	5-1	8.0	0.80	07.20	46.60	12	36.4	10.2		3.21
12-24	5-1	8.1	0.42							
0-12	7-7	8.0	0.87							
0-12	8-17	7.7	0.92							
Field 13E										
0-12	5-1	8.1	1.10	16.65	48.80	19	62.4	10.4		3.64
12-24	5-1	8.3	0.78							
0-12	7-7	8.5	1.13							
0-12	8-17	7.7	1.61							
Field 14W										
0-12	5-1	8.2	1.10	11.60	46.20	39	59.8	11.2		4.47
12-24	5-1	8.4	0.62							
0-12	7-7	8.4	1.02							
0-12	8-17	7.9	1.12							
Alfalfa Field										
0-12	5-1	8.5	1.20	05.61	40.70	16	36.4	10.0		6.50
12-24	5-1	8.3	1.02							
0-12	7-7	8.3	1.37							
0-12	8-17	7.9	1.30							
Meadow 1										
0-12	5-1	8.3	0.90	07.38	35.40	12	59.8	11.6		1.52
12-24	5-1	8.1	0.46							
0-12	7-7	8.1	0.85							
0-12	8-17	7.5	0.88							

Appendix Table 2. Continued

Depth	Date	pH	EC (% ppm)	OM (% ppm)	CEC (% ppm)	P (% ppm)	Ca (meq/100g)	Mg (meq/100g)	K (meq/100g)	Na (meq/100g)
Meadow 2										
0-12	5-1	8.7	1.20	07.20	40.90	09	49.4	13.3		7.02
12-24	5-1	8.7	0.70							
0-12	7-7	8.1	0.82							
0-12	8-17	7.3	0.50							
Alfalfa Nursery										
0-12	5-1	8.3	1.25	07.30	43.10	16	36.4	12.0		4.68
12-24	5-1	8.4	0.86							
0-12	7-7	8.4	1.60							
0-12	8-17	7.4	1.35							
Grass Nursery										
0-12	5-1	8.3	1.00	05.49	38.40	20	41.6	08.4		3.12
12-24	5-1	8.5	0.41							
0-12	7-7	8.2	1.08							
0-12	8-17	7.9	0.99							
Cutting Date										
0-12	8-17	7.7	1.61							

KLAMATH AREA SITES

0-12" depth sampled

	pH	EC	P	Ca	Mg	K	Na	Zn	Mn	Cu
			ppm	meq/100g				DTPA Extract ppm		
Gabriel	6.9	0.38	28	12.2	05.3	1.45	00.29	2.6	24.4	02.16
Hawkins	7.5	0.62	23	07.5	02.5	0.96	01.59	0.5	07.8	02.78
Hyde	6.7	0.22	18	07.1	02.1	1.02	00.78	1.0	06.5	01.70
Lightner	6.1	0.24	24	08.9	02.0	1.53	00.34	1.9	06.5	01.86
Liskey-Home	6.6	3.18	67	47.0	11.2	0.78	02.43	1.7	03.3	01.54
Liskey-Edwards	7.8	1.74	44	81.0	16.6	1.07	01.55	2.1	02.6	00.92
McAuliffe	6.4	0.45	13	03.6	01.1	0.32	00.32	1.4	06.7	01.06
Milton	8.3	0.93	04	09.1	05.5	1.63	02.21	0.3	01.9	01.78
Negrevski	6.5	1.49	08	07.0	03.5	0.75	00.67	0.5	21.4	28.00
Randall-4A	7.5	0.63	08	08.2	05.6	0.86	00.27	0.8	21.0	02.92
Randall-13	8.4	1.29	04	17.2	10.1	1.50	01.38	0.3	08.6	01.26
Refuge	5.4	0.32	13	18.9	06.3	0.54	00.84	1.4	00.9	01.26
KES-Quack	8.1	4.00	09	81.0	65.0	1.50	14.50	1.4	06.2	03.76
KES-Alta	8.2	6.30	12	78.0	65.0	1.61	18.90	3.0	06.2	01.60