CHAPTER FIVE

FERTILIZATION

Roland D. Meyer, Daniel B. Marcum, and Steve B. Orloff

DAN MARCUM

Providing an adequate supply of nutrients is important for alfalfa production and is essential to maintain high and profitable yields. However, proper plant nutrition can be a complex and often difficult management process. The process includes an analysis of which nutrients are needed, selection of the proper fertilizer, application timing and placement, economics, record keeping, and environmental considerations. This chapter serves as a guide to alfalfa fertilization in the Intermountain Region and includes information on appropriate methods of sampling alfalfa and interpreting soil and tissue tests.

Before applying fertilizer to alfalfa, examine other factors affecting yield. It makes little sense to fertilize with a nutrient when another factor is more limiting to plant growth. For example, an application of sulfur, even when sulfur is deficient, may not increase yields if water is not sufficient to allow plants to grow in response to applied fertilizer.

Since historical trends help with management decisions, thorough, well-organized records of plant tissue and soil-test information are important. Records should include information about date of sampling; crop yield and fertilizer history; and, most importantly, the location of the samples.

ESSENTIAL PLANT NUTRIENTS

Seventeen elements are needed, in varying amounts, for plant growth. Carbon, hydrogen, and oxygen come from water and from carbon dioxide in the air. The other 14 elements are obtained from either the soil or fixation of atmospheric nitrogen by bacteria in root nodules. Another nutrient, cobalt, is essential to legumes, for nitrogen fixation. Growth slows or stops when a plant is unable to obtain one or more of these elements. Thus, all nutrients must be available to the plant in adequate quantities throughout the production season. The nutrients that are most commonly needed are sulfur, followed closely by phosphorus, then potassium, boron, and molybdenum (Table 5.1).

DIAGNOSIS OF NUTRIENT DEFICIENCIES

A key aspect of designing a fertilization program is evaluating the nutrition status of the alfalfa. This can be done by visual observation, soil analysis, or plant tissue testing. Using all three in combination provides the best results.

Visual Observation

Nutrient deficiencies may exhibit visual plant symptoms such as obvious plant stunting or yellowing. Table 5.2 summarizes visual symptoms of common deficiencies. (Also see color photos 5.1 through 5.7.) Unfortunately, visual symptoms are not definitive and can be easily confused or mistaken for symptoms caused by other factors—insect injury, diseases, restricted root growth. The other problem with using visual observation of plant symptoms to diagnose nutrient deficiencies is that significant yield losses may have already occurred by the time the symptoms appear. Always confirm visual diagnosis with laboratory diagnosis or test strips with selected fertilizers.

Table 5.1. Nutrition needs of alfalfa in the Intermountain Region.

ELEMENT NEEDED	SYMBOL	FERTILIZER REQUIRED[1]
Nitrogen	N	Seldom
Phosphorus	P_2O_5	Frequently
Potassium	K_2O	Less frequently
Calcium	Ca	Never
Magnesium	Mg	Never
Sulfur	S	Frequently
Iron	Fe	Seldom
Manganese	Mn	Never
Chlorine	Cl	Never
Boron	B	Less frequently
Zinc	Zn	Never
Copper	Cu	Never
Molybdenum	Mo	Less frequently
Nickel	Ni	Never
Cobalt	Co	Never[2]

1. Frequently: Over 25% of the acreage shows need for fertilization with this nutrient.
   Less frequently: Less than 25% of the acreage shows need for fertilization.
   Seldom: Less than 1% of the acreage shows need.
   Never: A deficiency has never been reported or observed.
2. Necessary for nitrogen fixation only.

Laboratory Analysis

Both soil and plant tissue test results are used to detect plant nutrient deficiencies. These two tests differ in their ability to reliably diagnose nutrition problems in alfalfa (Table 5.3). To fully understand and correct problems, test both soil and tissue.

Soil testing

Soil tests provide an estimate of nutrient availability for uptake by plants and are most useful for assessing the fertility of fields prior to planting. Soil sampling methods are critical, since soil samples must adequately reflect the nutrient status of the field. Because a representative sample of an entire field gives an average of all the variation in that field, it is not the best way to develop recommendations for parts of the field that are less productive. The best technique is to divide each field into two or three areas representing good, medium, and poor alfalfa growth. Within each area establish permanent benchmark locations approximately 50 x 50 feet in size (Figure 5.1). To ensure that

Table 5.2. Nutrient deficiency symptoms observed in alfalfa.

DEFICIENCY	SYMPTOMS
Nitrogen	Generally yellow, stunted plants
Phosphorus	Stunted plants with small leaves; sometimes leaves are dark blue-green
Potassium	Pinhead-sized yellow or white spots on margins of upper leaves; on more mature leaves, yellow turning to brown leaf tips and edges
Sulfur	Generally yellow, stunted plants
Boron	Leaves on the upper part of plant are yellow on top and reddish purple on the underside; internodes are short
Molybdenum	Generally yellow, stunted plants

Table 5.3. Relative reliability of soil and plant tissue testing for nutrient deficiency.

NUTRIENT	SOIL TESTING	TISSUE TESTING
Sulfur	Very poor	Excellent
Phosphorus	Good	Excellent
Potassium	Good	Excellent
Boron	Poor	Excellent
Molybdenum	Not recommended	Excellent

you will be able to find each benchmark area again, describe it in relation to measured distances to specific landmarks on the edge of the field. By using this method to collect soil and plant tissue samples, you will be able to compare areas of the field with different production levels, develop appropriate management responses, and track changes over the years.

The best time to sample soil is soon after an irrigation or rainfall, so the probe easily penetrates the moist soil. Before taking a soil sample, remove debris or residual plant material from the soil surface. The sample can be taken with a shovel, but an Oakfield tube or similar sampling probe is preferred. Sample the top 6 to 8 inches of soil. Take 15 to 20 cores at random from each benchmark area and mix them thoroughly in a plastic bucket to produce a single 1 pint composite sample for each benchmark area. Place each sample in a separate double-thick paper bag and dry the soil at room temperature before mailing to the laboratory. To get a complete profile of the nutrition status of an alfalfa field, perform all the soil and tissue tests cited in Table 5.4. A list of laboratories is found in University of California Special Publication 3024, *California Commercial Laboratories Providing Agricultural Testing.*

Plant tissue testing . . . by far the most precise method of determining the nutrient needs of alfalfa.

Taking soil samples every year may not be necessary once historical trends have been established. Sampling benchmark areas every time alfalfa is planted is usually sufficient to establish trends. If poor alfalfa growth is observed in other parts of the field, take samples from both good and poor growth areas so the fertility level of the two areas can be compared. Table 5.5 lists guidelines for interpreting soil tests. Values are given for deficient, marginal, adequate, and high levels. An economic yield response to fertilizer application is very likely for values below the deficient level, somewhat likely for values in the marginal level, and unlikely for values over the adequate level.

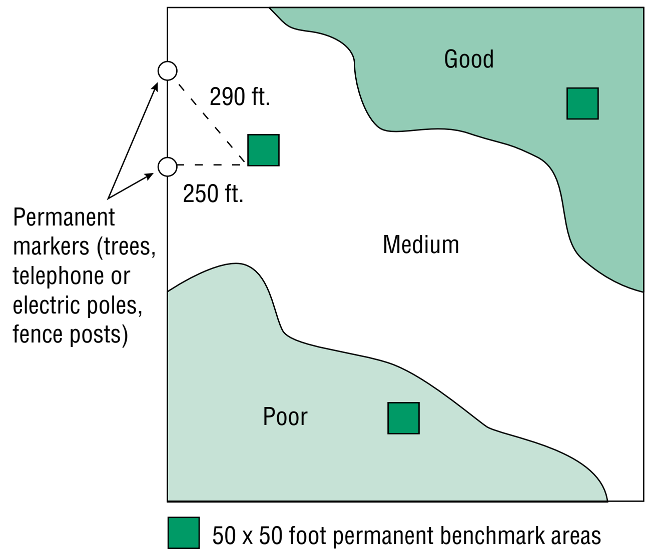

Figure 5.1. Sound soil and plant tissue-testing procedure involves establishing permanent benchmark sampling locations (50 x 50 feet in size) within areas of the field that support good, medium, and poor alfalfa growth. Define these benchmark areas in relation to measured distances to specific landmarks on the edge of the field.

Table 5.4. Suggested tests for a complete examination of soil and alfalfa tissue.

SOIL	PLANT TISSUE
pH[1]	Sulfur (SO_4–S)
Phosphorus	Phosphorus (PO_4–P)
Potassium	Potassium
EC_e[1]	Boron
Calcium, magnesium, sodium[1]	Molybdenum
SAR[1]	Copper

1. These tests evaluate factors that affect the availability of nutrients and the presence of undesirable salt levels. ECe (electrical conductivity of saturation extract (mmho/cm). SAR (Sodium absorption ratio)

Plant tissue testing

By far the most precise method of determining the nutrient needs of alfalfa is plant tissue testing. Such tests are the best reflection of what the plant has taken up and are far more accurate than soil tests, particularly for sulfur, boron, and molybdenum. Plant tissue tests are useful in monitoring the nutrition status and evaluating the effectiveness of current fertilization practices.

The best time to take a tissue sample is when the crop is in the 1⁄10 bloom growth stage or when regrowth measures 1⁄4 to 1⁄2 inch in length. (Alfalfa is often cut prior to 1⁄10 bloom to attain high-quality forage.)

When alfalfa is cut prior to 1⁄10 bloom (for example, bud stage) nutrient concentrations should be approximately 10 percent higher than when sampled at 1⁄10 bloom. Samples can be collected at any cutting, but collection at first cutting is preferred because it is the best time to detect a sulfur deficiency. Collect 40 to 60 stems from at least 30 plants in each of the benchmark areas.

Different plant parts are analyzed for different nutrients (Figure 5.2). Cut each sample into three sections of equal length. Discard the bottom third; place the top one third in one paper bag and the middle one third in another. Dry the samples in a warm room or oven. After drying, separate leaves from stems in middle one third sample by rubbing the sample between your hands. Put leaves and stems into separate bags. Figure 5.2 and Table 5.4 list the analyses that should be performed on the samples. Table 5.6 lists guidelines for interpreting plant tissue-test results. Entire plant samples or baled hay samples are not recommended because they can only detect extreme nutrient deficiencies.

Tissue tests can determine only the single most limiting nutrient affecting plant growth—the concentration of other nutrients may actually increase due to reduced growth. Therefore, correct the most severe deficiency first. After it is corrected, take new plant tissue samples to determine if other nutrients are deficient. Also, low concentrations of a nutrient in plant tissue may not always indicate a deficiency in the soil. Remember that plant analysis reflects nutrient uptake by the plant; a problem affecting roots, such as nematodes, can affect nutrient uptake as well.

CORRECTION OF NUTRIENT DEFICIENCIES

Apply fertilizer to correct nutrient deficiencies after careful consideration of the amount of nutrients removed by alfalfa, the yield potential of the field, current soil-test levels, and historical responses to fertilization. Table 5.7 indicates the amount of nutrients removed by 4-, 6- and 8-ton alfalfa crops.

Nitrogen

Applying nitrogen fertilizer to alfalfa is seldom beneficial or profitable. Adequate nitrogen is provided by the symbiotic nitrogen-fixing bacteria (*Rhizobia*) that live in nodules on alfalfa roots. *Symbiotic* means that both the plant and bacteria benefit; the alfalfa benefits from the nitrogen provided by *Rhizobia* bacteria and the bacteria benefit from the food source (carbohydrates) provided by alfalfa. Because of this relationship, applying nitrogen to alfalfa seldom results in an economic yield response. In those rare cases where nitrogen fertilizer does result in a yield increase, the problem is probably ineffective inoculation or conditions that inhibit or retard the development of the *Rhizobia* bacteria (that is, low soil pH, waterlogged soils, cold conditions, compacted soil, or extremely shallow root zone). Molybdenum and cobalt deficiencies are other possibilities.

Plant tissue tests can only determine the most limiting nutrient for plant growth.

Symptoms of nitrogen deficiency include stunted growth and a light green or yellow color. A nitrogen deficiency is suspected when the field contains stunted or small yellow plants with scattered tall dark green inoculated plants (color photos 5.2 and 5.3). Examination of roots usually shows no nodules on the stunted yellow plants and several nodules on the green healthy plants. Poor nodulation is often associated with fields having no history of alfalfa production; use of outdated inoculant; or hot, dry seedbed conditions.

The most common cause of nitrogen deficiency is poor inoculation and nodule formation after planting. Proper inoculation is necessary to ensure that alfalfa has an adequate supply of nitrogen. For effective

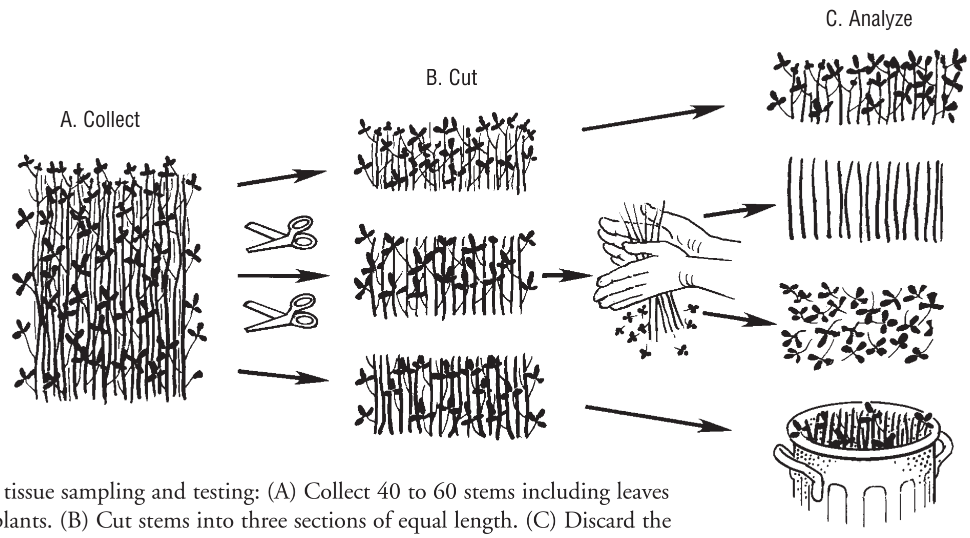

Figure 5.2. Plant tissue sampling and testing: (A) Collect 40 to 60 stems including leaves from at least 30 plants. (B) Cut stems into three sections of equal length. (C) Discard the bottom third. Place the top third in one paper bag and the middle third in another. Dry the samples. Separate leaves from stems in middle third by rubbing between hands. Put leaves in one bag and stems in another bag. Analyze top-third sample for boron, molybdenum, and copper. Analyze leaves from the middle third for sulfur (SO_4–S) and the stems from middle third for phosphorus (PO_4–P) and potassium.

Table 5.5. Interpretation of soil test results for alfalfa production.

NUTRIENT	EXTRACT[2]	SOIL VALUE (PPM)[1]			
		DEFICIENT	MARGINAL	ADEQUATE	HIGH
Phosphorus	Bicarbonate	< 5	5–10	10–20	>20
Potassium	Ammonium acetate	< 40	40–80	80–125[3]	>125
	Sulfuric acid	< 300	300–500	500–800	> 800
Boron	Saturated paste	< 0.1[4]	0.1–0 .2	0.2–0 .4	>0.4[5]

1. An economic yield response to fertilizer applications is very likely for values below the deficient level, somewhat likely for values in the marginal level, and unlikely for values over the adequate level.
2. Soil test values are based on use of the cited extract; values for other extracts are different.
3. If ammonium acetate levels are <100 ppm, it is advisable to request sulfuric acid extractable K.
4. Soil testing is not a suitable method to diagnose a deficiency. Use a plant tissue test.
5. Possible toxicity to sensitive crops such as cereals.

Table 5.6. Interpretation of test results for alfalfa plant tissue samples taken at 1⁄10 bloom.[1]

NUTRIENT	PLANT PART	UNIT	PLANT TISSUE VALUE[2]			
			DEFICIENT	MARGINAL	ADEQUATE	HIGH
Sulfur (SO_4–S)	Middle third, leaves	ppm	0–400	400–800	800–1000	Over 1000
Phosphorus (PO_4–P)	Middle third, stems	ppm	300–500	500–800	800–1500	Over 1500
Potassium	Middle third, stems	%	0.40–0.65	0.65–0.80	0.80–1.5	Over 1.5
Boron	Top third	ppm	Under 15	15–20	20–40	Over 200 [3]
Molybdenum	Top third	ppm	Under 0.3	0.3–1.0	1–5	5–10 [4]

1. Concentrations should be higher if alfalfa is cut at bud stage (multiply tabular values by 1.10).
2. An economic yield response to fertilizer applications is very likely for values below the deficient level, somewhat likely for values in the marginal level, and unlikely for values over the adequate level.
3. A concentration over 200 may cause reduced growth and vigor.
4. A concentration over 10 may cause molybdenosis in ruminants.

Table 5.7. Nutrients contained in 4, 6, and 8 tons of alfalfa hay.[1]

NUTRIENT	SYMBOL	NUTRIENT YIELD (LB/A) 4-TON CROP	6-TON CROP	8-TON CROP
Nitrogen	N	200.0	300.0	400.0
Phosphorus	P_2O_5	48.0	71.0	95.0
Potassium	K_2O	173.0	260.0	346.0
Calcium	Ca	128.0	192.0	256.0
Magnesium	Mg	27.0	40.0	53.0
Sulfur	S	16.0	24.0	32.0
Iron	Fe	1.5	2.3	3.0
Manganese	Mn	1.0	1.5	2.0
Chlorine	Cl	1.0	1.5	2.0
Boron	B	0.2	0.4	0.5
Zinc	Zn	0.2	0.3	0.4
Copper	Cu	0.06	0.1	0.13
Molybdenum	Mo	0.008	0.012	0.016

1. 100% dry matter

nodulation, inoculate seed with fresh inoculant and do not expose it to hot, dry conditions prior to germination. This is particularly critical in fields planted to a first crop of alfalfa. Fields with a history of alfalfa plantings seldom have inoculation problems, because of high residual *Rhizobia* populations from previous crops. If poor nodulation occurs in a young stand of alfalfa, inoculate seed at 2 to 5 times the normal rate and drill it into the stand at 3 to 5 pounds seed per acre. Follow with a light irrigation. Usually, after a growing season, all plants in the field will be inoculated.

Light green or yellow plants may also indicate a sulfur or molybdenum deficiency. Use a plant tissue test to identify the specific deficiency. Nitrogen deficiency may also result from a molybdenum deficiency, since molybdenum has a role in nitrogen fixation. Sulfur and molybdenum deficiencies will be discussed later in this chapter.

Phosphorus

Currently, phosphorus may be the most commonly deficient nutrient in alfalfa in the Intermountain Region. Prior to planting, use a soil test to assess the phosphorus status of the soil. As indicated in Table 5.5, soil with a phosphorus level less than 5 parts per million (ppm) is considered deficient, soil with 5 to 10 ppm phosphorus is marginal, and that with 10 ppm or greater phosphorus is adequate. A tissue test for phosphorus is preferred after alfalfa is established. Phosphorus deficiency is very difficult to identify visually (color photo 5.1).

To correct a phosphorus deficiency, a high-analysis phosphorus fertilizer such as 0–45–0 or 11–52–0 is usually the most economical. In alfalfa these two common phosphorus sources result in the same yield response. Liquid or granular phosphorus fertilizers with water solubility values greater than 55 percent are nearly equal in terms of plant availability. Rock phosphate, however, is not recommended because of low phosphate availability, particularly when applied to anything other than very acidic soils (those with a pH less than 5.5). If before planting you use a nitrogen-phosphorus fertilizer such as 16–20–0 to stimulate young seedlings, take care to control weeds; the supplemental nitrogen will stimulate their growth.

Currently, phosphorus may be the most commonly deficient nutrient in alfalfa in the Intermountain Region.

Before planting, use soil tests to determine the amount of phosphorus needed (Table 5.8). Recent

Table 5.8. Recommended phosphorus and potassium application rates based on results of soil or plant tissue tests.

NUTRIENT	YIELD LEVEL (TONS/A)	SOIL OR PLANT TISSUE TEST RESULT DEFICIENT[1] (LB/A)	MARGINAL (LB/A)	ADEQUATE (LB/A)
Phosphorus (P_2O_5)	4	60–90	30–45	0–20
	8	120–180	60–90	0–45
Potassium (K_2O)	4	100–200	50–100	0–50
	8	300–400	150–200	0–100

1. An economic yield response to fertilizer applications is very likely for values below the deficient level, somewhat likely for values in the marginal level, and unlikely for values over the adequate level.

research indicates that even if high rates of phosphorus are applied, it may be economical to reapply after 2 years. Incorporate no more than a 2-year supply of fertilizer into the top 2 to 4 inches of soil. Use tissue analysis to determine the need for phosphorus after the seedling year. Applying phosphorus fertilizers on the soil surface in an established stand has been very effective. Apply fertilizer any time, but applications made from October through February are preferred because alfalfa responses to phosphorus fertilizer are not usually observed until 60 to 90 days after application.

Table 5.8 gives a range of application rates because some soils and growing conditions require larger amounts to meet nutrition requirements and maintain high alfalfa yields. Various combinations of phosphorus amounts and application timing can be used to achieve the rates recommended. Recent research has indicated that fewer applications (at least every 2 years) of higher rates can be applied more economically than lower rates (less than 50 pounds P_2O_5 per acre) applied each year. Take plant tissue samples 60 to 90 days after a fertilizer application to re-evaluate fertility status.

Potassium

Potassium deficiency is found less frequently in the Intermountain Region of northern California. Like a lack of phosphorus, a potassium deficiency can be diagnosed by either a soil or a plant tissue test. The visual symptoms of potassium deficiency are pinhead-sized white or yellow spots on new leaves (see color photo 5.6). Unlike the symptoms of other nutrient shortages, those of potassium deficiency are distinctive and fairly reliable. Note, however, that genetic differences between alfalfa plants affect symptom development; not all potassium-deficient plants show deficiency symptoms. Also, some insects and diseases cause symptoms similar to those of potassium deficiency.

The most economical fertilizer for correcting this deficiency is muriate of potash (0–0–60). Sometimes potassium sulfate (0–0–52, 18% sulfur) is used when sulfur is also deficient. However, compared to muriate of potash, potassium sulfate and other mixed fertilizers are usually more expensive per pound of potassium. Table 5.8 lists recommended potassium rates for both preplanting and surface applications. Applications on the soil surface are very effective and can be made anytime. Like the response to phosphorus, the growth response to applied potassium may not be observed until 60 to 90 days after fertilizer application.

Sulfur

Historically, sulfur has been the most commonly deficient nutrient in alfalfa in the Intermountain Region. Visual deficiency symptoms include stunting and a light green or yellow color—symptoms that may also indicate nitrogen or molybdenum deficiency (see color photos 5.2 and 5.4). Only tissue testing can confirm a sulfur deficiency; soil tests do not provide reliable results. It is important to have an adequate level of available sulfate sulfur in the soil at the time of planting. Two principal sources of sulfur exist: (1) long-term slowly available elemental sulfur and (2) short-term rapidly available sulfate. The most economical practice is to apply and incorporate before planting 200 to 300 pounds elemental sulfur per acre. Elemental sulfur is gradually converted to the sulfate form and should last 4 to 7 years. It may be necessary to repeat the application once in the life of a 6- to 10-year stand.

To ensure a multiple-year supply of available sulfur, the particle size of elemental sulfur must range from large to small. Small particles are rapidly converted to the sulfate form; the large particles will continue to release sulfate over several years. Ideally, 10 percent of elemental sulfur should pass through a 100-mesh screen; 30 percent, through a 50-mesh screen; and the remaining 60 percent, through a 6-mesh screen. Very fine grades of sulfur are readily available but do not persist long enough to provide a multiple-year supply.

Fertilizers used to supply the sulfate form of sulfur include gypsum (15 to 17% sulfur), 16–20–0 (14 to 15% sulfur), and ammonium sulfate 21–0–0 (24% sulfur). Some growers apply 300 to 500 pounds gypsum per acre every other year rather than using elemental sulfur. The advantage to this practice is a quick response (about 2 weeks). The disadvantages are the higher cost per pound of sulfur and the fact that more sulfur is applied than is necessary. Perhaps the most important reason to avoid overfertilization with sulfur is that it can decrease the selenium concentration in the alfalfa hay. Livestock producers throughout the Intermountain Region want forage that is as high in selenium as possible because their animals often suffer from selenium deficiency.

Iron

On rare occasion, growers have observed symptoms of iron deficiency in alfalfa, but only tissue tests have been effective in confirming the problem. The deficiency usually produces nearly white or canary yellow plants in areas where drainage is poor. Iron deficiency in alfalfa is characteristically associated with high pH or poorly drained soils high in lime. If the soil pH is greater than 8.0 and free lime is present, begin to correct the iron deficiency by applying high rates of elemental sulfur (at least 1,000 pounds per acre); this will lower the soil pH. Also, improve drainage in low areas of the field.

Boron

Although deficiency symptoms are easily identified, boron deficiency is more effectively confirmed with a plant tissue test (color photo 5.7). Adequate supplies of boron are more important for production of alfalfa seed than hay. 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. The most common boron fertilizers are 45 to 48 percent borate (14.3 to 14.9% boron) and 65 to 68 percent borate (20.4 to 21.1% boron). Boron is usually applied as a granular product, either by air or through the small seed box in a grain drill. Some forms can be applied as a liquid along with herbicide applications; make sure the boron and herbicide are compatible before mixing them.

Molybdenum

Molybdenum deficiency is infrequent in the Intermountain Region, but it has occurred in several areas. Symptoms of molybdenum deficiency are like those of nitrogen and sulfur deficiency: light green or yellow stunted plants (color photo 5.5). A positive response to ammonium sulfate fertilizer could mean a nitrogen, sulfur, or molybdenum deficiency. A positive response to urea rules out a sulfur deficiency but could indicate a shortage of nitrogen or molybdenum. Plant tissue testing or applying sulfur and molybdenum fertilizers to separate trial strips are the only means of confirming a molybdenum deficiency.

The most common molybdenum fertilizer is sodium molybdate (40% molybdenum), but ammonium molybdate can be used as well. Apply 0.4 pound molybdenum per acre during the winter or before regrowth has occurred after cutting. A single application of molybdenum should last from 5 to 15 years. Thorough records of molybdenum application times and amounts along with repeated tissue testing are essential to determine when to apply or reapply the nutrient.

Do not apply excessive molybdenum (that is, double or triple coverage)—the concentration of the element in alfalfa may become so high that the forage becomes toxic to livestock. For the same reason, do not apply molybdenum to foliage. Analyzing the top third of the plant for both copper and molybdenum can detect deficiencies and suboptimum ratios of these elements. Consult a nutrition specialist if you suspect molybdenum problems.

RECORD KEEPING

Clear and complete records are essential to a successful alfalfa fertility program. Keep a record for each field and include the location of permanent benchmark areas, dates of sampling, soil and plant tissue test results, fertilizer application dates, fertilizers applied and the rate of application, and crop yields. This information can help you evaluate both the need for and the response to applied fertilizer and allow you to develop an economical, long-term fertilization program.

ADDITIONAL READING

DANR Analytical Lab. 1991. *California commercial laboratories providing agricultural testing*. Oakland: University of California Division of Agriculture and Natural Resources, Special Publication 3024.

Kelling, K. A., and J. E. Matocha. 1990. Plant analysis as an aid in fertilizing forage crops. In R. L. Westerman, (ed.), *Soil testing and plant analysis,* third edition, 603–43. Madison, WI: Soil Science Society of America.

Martin, W. E., and J. E. Matocha. 1973. Plant analysis as an aid in the fertilization of forage crops. In L. M Walsh,. and J. D. Beaton (eds.), *Soil testing and plant analysis,* revised edition, 393–426. Madison, WI: Soil Science Society of America.

Meyer, R. D., and W. E. Martin. 1983. Plant analysis as a guide for fertilization of alfalfa. In H. M. Reisenauer, (ed.), *Soil and plant tissue testing in California,* 32-33. Oakland: University of California Division of Agriculture and Natural Resources, Bulletin 1879.

Reisenauer, H. M., J. Quick, R. E. Voss, and A. L. Brown. 1983. Chemical soil tests for soil fertility evaluation. In H. M. Reisenauer, (ed.), *Soil and plant tissue testing in California,* 39–41. Oakland: University of California Division of Agriculture and Natural Resources, Bulletin 1879.

Soil Improvement Committee, California Fertilizer Association. 1985. *Western fertilizer handbook,* 7th edition. Danville, IL: The Interstate Printers and Publishers.