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Alfalfa Soil Fertility and Fertilization Requirements[1]

Professionally Reviewed

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Introduction

A productive alfalfa crop removes significant quantities of macronutrients and small amounts of micronutrients from the soil (Table 1). A complete fertilizer program is essential to ensure a highly productive, long-lived stand. Prior to establishing a field, soil testing should be used to guide fertilizer applications. Two soil sampling depths are recommended, a 0-6 inch sample for pH and lime requirement only and a 0-12 inch sample for pH and nutrients of interest, including P, K, B, and Zn. Soil testing is the best way to determine soil fertility requirements for alfalfa prior to planting (Koenig et al., 2009). Once a stand is established, a soil sample should be analyzed at least once every 3 years to ensure fertility and soil pH continues to be adequate. Test annually when fertility or pH are marginal.

Tracking or monitoring soil fertility over time in a table or spreadsheet with fertilizer additions and yields is important for making long term agronomic and economic decisions. Recognizing whether soil test or tissue results trend down, stay even, or increase gives important information to evaluate a fertilizer program and how it is performing relative to yield or quality.

As with pre-plant applications, rates of fertilizer and lime applied to established stands should be based on soil test results. Since lime and P are not readily mobile in the soil profile, broadcast applications take several years before full benefits are realized. Thus, pre-plant incorporation of lime and P is preferred to surface, broadcast applications.

The best time to perform soil tests is in the autumn, but regardless of the month of testing, samples should be taken at the same time each year so direct comparisons can be made to previous sample results.

Nutrient Recommendations for Pre-plant and Established Stands

Liming

Lime applications are required on soils having a pH below 6.5 because as pH decreases, yields decrease (Figure 1). Low pH also reduces crude protein and is associated with increases in fiber. Research at the Central Oregon Agricultural Research Center has shown that when soil pH values decreased below 6.2, nodulation was substantially reduced (James, 1989a; see also Figure 2 from Hart et al., 2013).

A soil sample taken from the surface to 6 inches using the SMP buffer test (named after Shoemaker, McLean and Pratt; Shoemaker et al., 1961) will reveal if lime is needed to increase soil pH. If needed, apply lime well in advance of planting, mixing thoroughly into the top 6 inches of soil. Fall applications are best because they provide time for soil reaction and avoid the spring rush that often delays planting. A year is needed for soil pH to fully adjust following a lime application. When a

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Table 1. Average nutrient uptake/removal [lb/ton dry matter (DM)] for Vernal and 54Q25 alfalfa cultivars over 4 years (2004-2007) with 3-cut harvest at Powell Butte (3200′ ASL) and 4-cut harvest at Madras (2440′ ASL), Oregon. Source: Mylen Bohle, unpublished data.

	P_2O_5	K_2O	Ca	Mg	S	Mn	Cu	B	Zn	Fe	Mo	Cl[1]
						lb/ton DM						
3-Cut	11.8	59.5	21.9	4.8	3.9	0.03	0.11	0.08	0.03	0.11	<0.002	0.25
4-cut	12.6	78.0	26.1	5.7	4.0	0.07	0.02	0.09	0.03	0.14	<0.002	0.25

[1] Orloff et al., 1989.

rotational crop precedes the establishment of a new alfalfa field, apply lime prior to planting the rotational crop. This will allow adequate time for the lime to react with the soil and insure the proper soil pH prior to planting alfalfa (Hart et al., 2013). If applying lime east of the Cascades use OSU Extension Service publication EM 9060 (Sullivan et al., 2013) for lime rates. If applying lime on the west side of the Cascades, utilize the EM 9057 bulletin for recommendations (Anderson et al., 2013). If lime is not applied prior to establishment and a soil test reveals a lower than desired pH, surface apply 0.5 to 2 ton/acre of 100 score lime. This may or may not solve the problem. Lime is very slow to leach into soil, and an economic decision may need to be made whether or not to keep the field in production, or start over, based on desired production, additional soil pH and SMP testing, soil texture, and precipitation. Surface applying 3-5 ton/acre over years is not the best biological or economic solution; sometimes, however, it is the most practical.

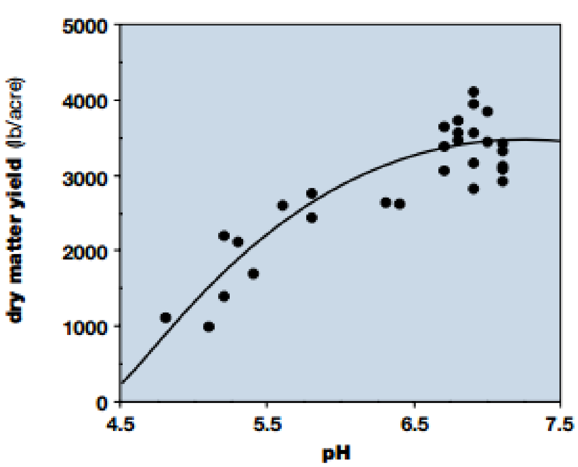

Figure 1. First-cutting alfalfa yield (lb DM/acre) relative to soil pH (Wollenhaupt and Undersander, 1991; Fig. 4 in Undersander et al., 2011).

Inoculation, Biological Nitrogen Fixation (BNF), and Nitrogen Fertilization

Alfalfa seed should be inoculated immediately prior to seeding to ensure an adequate supply of nitrogen fixing bacteria. The need to inoculate becomes more critical the longer a field is out of alfalfa and when fumigation is part of the rotation. Use a fresh, effective, live culture of the correct rhizobia strain (*Sinorhizobium meliloti*; syn. *Rhizobium meliloti*) or purchase pre-inoculated seed that has been stored properly to ensure large numbers of live bacteria. The ability to nodulate and fix N_2 decreases as pH decreases below 6.5, so maintaining an adequate soil pH is essential. A molybdenum application may help with N_2 fixation when soil pH is below 6.5.

Since legume forages are capable of fixing atmospheric nitrogen (N_2) with effective nodules, N fertilizer is not needed or recommended. Some N in the soil and applied fertilizer (up to 40 lb N/acre) may be necessary for initial alfalfa growth. However, soil nitrate will inhibit nodulation and reduce BNF. Added fertilizer N (conventional and non-composted manures, or some organic fertilizers), greater than 40 lb N/acre total, will directly reduce both the number and effectiveness of nodules (Hannaway and Shuler, 1993). When N is applied as part of other fertilizers (e.g. monoammonium phosphate, 11-52-0), total N availability should not exceed 40 lb N/acre. Applying additional N will increase weed growth and not improve alfalfa yield or quality (Eardly et al., 1985).

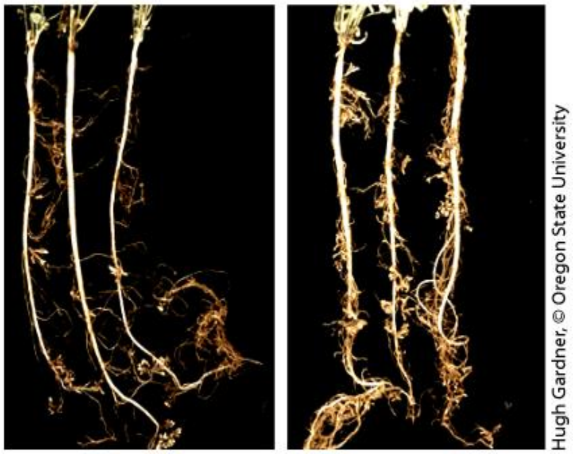

Figure 2. Roots and nodules of greenhouse grown alfalfa in a Woodburn silt loam, with soil pH 5.3 (left) and 5.8 (right) (Hart et al., 2013).

Phosphorus (P) Fertilization

The soil test level for P should be maintained above 20 ppm as measured by the Olsen soil test (Koenig et al., 2009). Fertilizer P is most effectively applied at planting in a band ½ to 1 inch to the side or below the seed. When broadcasting, increase the P rate and work P into the top 6 inches of soil during seedbed preparation. Providing necessary P is an important management step during establishment. Applying P post-establishment as a top-dress broadcast application has been shown to increase alfalfa yields in northern California and minimize P fixation in calcareous soils (Marcum et al., 2007, and Orloff et al., 2008). Thus, rather than applying multiple year needs of P fertilizer at establishment, topdressing P in subsequent production years can be an effective option to decrease the establishment year fertilizer expense.

Availability of soil P is affected by temperature; it is less available during cool springs than in summer. Apply P fertilizer in the late summer or early autumn according to soil test results. One ton (2,000 lb) of alfalfa dry matter contains about 12 lb of P_2O_5 (Table 1). Thus, replacement-only applications for a 4-6-ton/acre yield would require 48-72 lb/acre of P_2O_5. Typical annual applications rates are 60-100 lb/acre of P_20_5, but all applications should be made based on soil test results and/or tissue analysis or hay nutrient tests, and yield targets.

Potassium (K) Fertilization

Potassium-supplying fertilizers should be worked into the seedbed prior to planting and should not be banded near the seed due to the potential for injury of emerging roots from K salts. Potassium is more mobile than P, so topdressing after establishment is an effective way to supply the annual K requirement to an established stand. The minimum K concentration needed for optimal growth is approximately 2% K in the plant or 40 lb K or 48 lb K_2O per ton of dry matter (Koenig and Barnhill, 2006). Nutrient analysis based on plant or hay sampling can aid in monitoring K sufficiency. Specific K fertilizer recommendations based upon soil test data are provided in Pacific Northwest Extension Service publication PNW 0611 (Koenig et al., 2009). Minimum annual fertilizer “replacement” needed for K_2O can be determined by multiplying dry matter (DM) yield (ton/acre) by 40 lb/ton K or 48 lb/ton K_2O. (Example: 5 ton/acre DM yield * 40 lb K or 48 lb K_2O /ton DM = 200 lb/acre K or 240 lb/acre K_2O removed.)

When plant tissue visual symptoms or hay tests reveal there is a deficiency, 48 lb K_2O per ton of yield is the minimum amount that would need to be replaced. Yield potential, soil texture, soil depth and a current soil test and tissue analysis are required to best determine fertilizer K needs. For most locations in the PNW, 90% of maximum yield is achieved when soil test K is 150 ppm; however, alfalfa response to K is less well understood than P response (Koenig et al., 2009). Monitor soil test K values annually if they are below 150 ppm. Hay or tissue tests values below 2% K are likely to indicate the need for fertilizer K additions, based on research in Oregon (Gardner et al., 1983; James, 1989), Utah (Koenig and Barnhill, 2006), and northern California (Marcum et al., 2007). Yield loss would be expected when plant K concentrations drop below 1.7 % K (Sheard, 1987).

If the soil contains high amounts of K, alfalfa will continue to absorb this nutrient in excess of its needs. This is sometimes referred to as “luxury consumption.” Note, the average K_2O content of a ton of DM hay in Table 1 is higher than needed to produce hay. Many times, alfalfa will have K concentrations above 3%, significantly exceeding the 2% minimum. Thus, soil K can decline rapidly under established stands because of higher than expected removal rates. A K deficiency is indicated by light-colored spots around leaflet margins (Figure 3).

Since early spring K application may result in an imbalance of cations (K, Mg, and Ca) affecting both plant and animal health (Hannaway, Leggett, and Bush, 1980), fertilizer K should be applied following the first spring or early summer harvest or in autumn. A single K application is more effective than split applications, but if the amount of K needed is greater than 400 lb/acre, a split application is advised (Koenig and Barnhill, 2006; James, 1989).

Figure 3. K deficiency symptoms on alfalfa leaves. (Ludwick, 2012).

Sulfur (S) Fertilization

Low soil S levels (0-10 ppm) warrant S fertilization, while high S levels (> 15 ppm) indicate no need for additional S. Moderate soil test levels of S (6-14 ppm) may or may not respond to S fertilization (Koenig et al., 2009). However, soil testing for S is not as reliable as for other nutrients because it is easily transformed by soil microbes and is always in flux. This causes available S levels to change throughout the year (Castellano and Dick, 1990). Sulfur is also leachable; over-irrigation, especially with flood-irrigation, could move S out of the root zone. In addition, many irrigation waters contain S and can provide at least part of alfalfa's S need. Thus, testing your irrigation water for S content will help assess S need.

Sulfur applications should be worked into the seedbed just prior to planting. Fertilizer S materials may be in the form of sulfate or elemental S. Elemental S must be converted to sulfate prior to becoming plant available. Conversion from elemental S to sulfate occurs more rapidly for finely ground materials (less than 40-mesh) and when soil conditions are warm and moist (Marcum et al., 2007). Large granules ("popcorn S") may take several years to be completely converted to sulfate S. Sulfate is fairly mobile in the soil, since it is an anion and repelled by the clay particle's negative charge. Gypsum (calcium sulfate) is another excellent S source and does not change soil pH.

Once established, alfalfa's annual requirement for S can be met by providing 20-40 lb S/acre in the form of sulfate (gypsum is calcium sulfate, $CaSO_4$) or finely ground elemental S. This requirement is estimated using S removed by alfalfa and an efficiency factor. Alfalfa hay typically removes about 4 lb of S per ton of DM (Table 1). Thus, multiply tons per acre DM yield by 4 lb/ton S and increase this amount by 30% to estimate a reasonable S application rate (personal communication, John Hart, OSU Emeritus Extension Soil Fertility Specialist).

Adding Sulfur (S) to Saline and Alkali Soils

Adequate precipitation or irrigation is needed to move sodium (Na) and other soluble salts through a well-drained soil. If drainage is poor, adding S will decrease pH and change the form of Na, but the reaction will increase soluble salts. The economic benefit of adding S or lime should be considered based on input cost vs. potential increased yield (Horneck et al., 2007). Some alfalfa cultivars offer increased pH and salt tolerance, but typically no yield loss is experienced when soil salinity values (EC_e) are below 2.0 dS/m (Figure 4; Sanden et al., 2004; Sanden and Sheesly, 2007). High pH and Na situations can be difficult to manage. A single application of any remedial compound rarely will make significant changes.

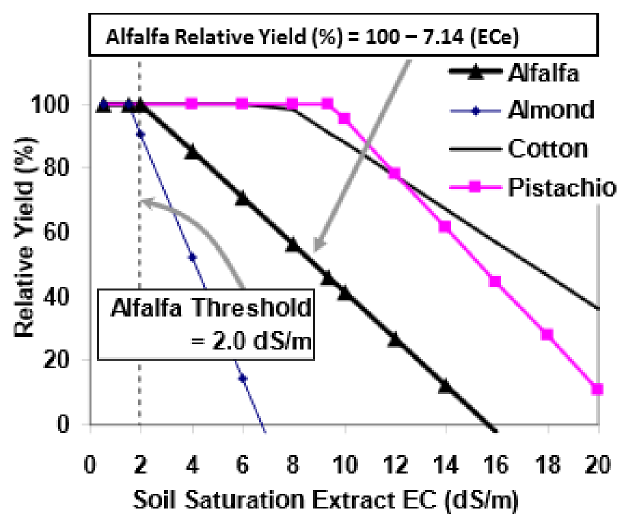

Figure 4. Salinity tolerance curves for alfalfa, almond, cotton, and pistachio. (Ayers and Westcott, 1985; Sanden et al., 2004).

Boron (B) Fertilization

When a soil test reveals that B levels are "low", B additions should be broadcast and incorporated in the top 6 inches prior to planting or be surface-applied for established stands. Boron should not be banded because high concentrations of B will damage emerging seedlings. Boron is leachable under irrigated (especially flood-irrigated) or high rainfall conditions.

Boron is a micronutrient and alfalfa hay content is typically 0.08-0.09 lb/ton DM (Table 1). On established stands, apply 2-4 lb B/acre if the soil test value is less than 0.4 ppm on fine textured soils or less than 0.3 ppm for coarse textured soils (Koenig et al., 2009). This amount should meet alfalfa's needs for several years, but monitor with soil and plant analysis testing.

Other Nutrients

Yield responses to other nutrients such as magnesium (Mg) and zinc (Zn) have not been demonstrated in Pacific Northwest alfalfa fields. No yield responses have been observed for any micronutrients other than B. Always test your hay or tissue sample prior to applying a micronutrient to a field. An untreated check will also help determine if a micronutrient was beneficial.

Note in Table 1, the small amounts of micronutrients removed in a ton of DM alfalfa. If you suspect a micronutrient deficiency, determine nutrient needs through plant tissue analysis. Applying a micronutrient to part of the field and comparing yield, forage quality, and tissue test values is a cost-effective approach to determine sufficiency or deficiency (Marcum et al., 2007).

Conclusion

High yielding, high quality, and long-lived stands of alfalfa require large amounts of available soil macronutrients (P, K, Mg, Ca, S). A complete fertilizer program, focused primarily on monitoring P, K, S, and B, is essential to ensure a long-lived stand. Fertilizer applications should be based on the results of a soil test and/or hay or plant tissue sample analysis. Fall is the best time to perform soil tests, but it is more important to be consistent by taking samples at the same time each year so direct year-to-year comparisons can be made.

Proper soil testing is one of the keys to correcting pH and nutrient deficiencies. A 0-6 inch soil sample for pH and a 0-12 inch sample for pH and all other nutrients should be used to determine soil fertility sufficiency or diagnose deficiencies.

Soil pH is especially important to monitor because a near-neutral value is essential for providing alfalfa's nitrogen needs through biological nitrogen fixation. As soil pH drops below 6.5, nitrogen fixation declines and yields are reduced.

Notes

- *For a more comprehensive treatment of alfalfa soil fertility east of the Cascades, see Nutrient Management Guide for "Dryland and Irrigated Alfalfa in the Inland Northwest" (PNW Bulletin 0611).* http://cru.cahe.wsu.edu/CEPublications/pnw0611/pnw0611.pdf
- *For more information regarding alfalfa soil fertility west of the cascades, see OSU Fertilizer Guide 18 – "Alfalfa: Willamette Valley and Northwest Oregon,"* http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20629/fg18-e.pdf *and OSU Fertilizer Guide 60-E "Alfalfa: Southwest Oregon (Coos, Curry, Jackson, Josephine counties)"* http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20633/fg60-e.pdf

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Additional Information Resources

OSU EC 628: "How to Take a Soil Sample ... and Why" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/18696/ec628.pdf

OSU EC 1478-E "Soil Test Interpretation Guide" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/22023/ec1478.pdf

OSU EM 8677 "A List of Analytical Laboratories Serving Oregon" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20037/em8677.pdf

OSU EM 9014-E "Evaluating Soil Nutrients and pH by Depth in Situations of Limited or No Tillage in Western Oregon" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/19024/em9014.pdf

OSU FG 18 "Alfalfa: Willamette Valley and Northwest Oregon"http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20629/fg18-e.pdf http://extension.oregonstate.edu/catalog/pdf/fg/fg60-e.pdf)

OSU FG 52-E "Fertilizer and Liming Materials Guide" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20620/fg52-e.pdf

OSU FG 60-E "Alfalfa: Southwest Oregon (Coos, Curry, Jackson, Josephine counties)" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20633/fg60-e.pdf

PNW 508-E "Fertilizing with Biosolids" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20714/pnw508-e.pdf

PNW 570-E "Monitoring Soil Nutrients Using a Management Unit Approach" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20762/pnw570-e.pdf

PNW 597-E "Irrigation Water Quality for Crop Production in the Pacific Northwest" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20786/pnw597-e.pdf

PNW 599-E "Acidifying Soil for Crop Production: Inland Pacific Northwest" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20789/pnw599-e.pdf

PNW 601-E "Managing Salt-affected Soils for Crop Production" http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20788/pnw601-e.pdf