SOIL AMENDMENTS IN ALFALFA PRODUCTION

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Soil amendments are materials added to soils for the purpose of changing (amending) the soil's chemical or physical properties. A soil amendment may change both the chemical and physical properties and may also add plant nutrients. Amendments are usually added to prevent, reduce, or correct a problem or a perceived problem.

I would like to limit our discussion to the use of soil amendments for solving soil pH, excess soil sodicity, and slow water infiltration problems related to water quality.

SOIL pH

Soil pH is a measure of hydrogen ions (H^+) in solution. A soil solution containing equal activities of hydrogen and hydroxyl ions (OH^-) yields a neutral pH of 7. As hydrogen ion concentration increases, the soil becomes more acidic. Conversely, less hydrogen coincides with less acidic or more basic soil.

Each change of one pH unit represents a ten-fold change in hydrogen ion concentrations in the soil. Therefore, soil pH of 5.0 represents soil which contains ten times the amount of H^+ ions in a soil with a pH of 6.

Acid		Neutral		Basic
5	6	7	8	9

Although soil pH generally ranges between 4.5 and 9.5, most crops perform best in a range of 6 to 8. Alfalfa is known for its ability to survive both higher and lower pH's, although crop performance can suffer through reduced nutrient availability or elemental toxicity brought on by extreme pH levels. Also, reduced activity of Rhizobium bacteria has been reported at pH values of less than 5.0.

Acidic Soils

Soils formed from granitic parent material (east side, the Sacramento-San Joaquin Valleys) tend to be neutral to acidic. Peat and muck soils of the Sacramento-San Joaquin Delta are high in organic matter and are also acidic (pH of 4.5-6). Areas of high rainfall (e.g., northern California) also experience high acidity due to the rain's excess removal of minerals and leaving behind hydrogen ions which are tightly held to the soil particles.

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Soil management can also change soil acidity. Soils can be made more acidic by the long term application of ammonium-containing fertilizers and application of high amounts of organic matter or acid-forming soil amendments.

To increase soil pH, limestone ($CaCO_3$) can be added to the soil. The limestone reacts with hydrogen ions causing the pH to rise from the resulting reduction of H^+ ions: limestone ($CaCO_3$) + H^+ ☞ Carbon dioxide (CO_2) + water (H_2O) + free calcium (Ca^+)

The amount of limestone required to increase pH varies with soil conditions. A general recommendation is given in the following table. It should be noted, however, that effectiveness of a lime application varies with material purity. All values given in Figures 1 and 2 are based on 100% purity.

Lime Required to Raise Soil pH to 6.5
(Pounds per Acre)

Initial Soil pH	Light Soil	Medium to Heavy Soil	Peat Muck
5.5	1,000 - 2,000	3,000 - 5,000	6,000
4.5	3,000 - 4,000	6,000 - 8,000	12,000
3.5	4,000 - 5,000	9,000 - 12,000	18,000

Several liming materials other than straight limestone may be used to correct soil acidity. Some of these materials are listed in the following table along with the calcium carbonate equivalent.

Liming Materials

Name	Chemical Name	Formula	$CaCO_3$ Equivalent
Limestone	Calcium Carbonate	$CaCO_3$	100%
Hydrated Lime	Calcium Hydroxide	$Ca(OH)_2$	120%
Burned Lime	Calcium Oxide	CaO	150%
Dolomite	Calcium-Magnesium Carbonate	$CaMg(CO_3)_2$	110%
Sugar Beet Lime	Calcium Carbonate + 4-10% organic matter	$CaCO_3$	80-90%

Basic Soils

Soils which are generally in the 7-10 pH range and are considered basic or alkaline. They often are calcareous and contain free carbonates. Soils of this type are those of the west side of the Sacramento-San Joaquin Valleys and southwestern desert.

Sulfur is the most common, and usually least expensive, soil amendment for correcting high pH soils. When sulfur is added to soil, it is used as an energy source for soil organisms that oxidize the sulfur, forming sulfuric acid. This process occurs more rapidly with finely ground or high surface area particles such as Popcorn Sulfur. Since the oxidation of sulfur is a biological reaction, warm moist soil encourages the speed of surface conversion. Rapid conversion also requires the sulfur to be incorporated into the soil. A typical rate of conversion for Popcorn Sulfur applied to irrigated soils during summer is approximately 90-120 days for ½ of the sulfur to be converted.

General recommendations for soil sulfur applications are shown in the following table.

Sulfur Required to Lower Soil Ph to 6.5
(Pounds per Acre, Broadcast)

Initial Soil pH	Light Soil	Medium to Heavy Soil
7.5	400 - 600	800 - 1,000
8.0	1,000 - 1,500	1,500 - 2,000
8.5	1,500 - 2,000	2,000 - up
9.0	2,000 - 3,000	leach sodium out first

Other materials are available which contain sulfur, are acidic or when applied to soils, form acid. Some are listed in the following table.

Acidifying Materials

Material	% Sulfur	Pounds Required to Equal 1 lb of Sulfur
Soil Sulfur	99+	1.0
Sulfuric Acid, 98%	31	3.1
Calcium Polysulfide, Lime Sulfur	24	3.65
Ammonium Polysulfide	40 - 45	2.2 - 2.5

It is important to remember that acid is formed only when sulfur is oxidized. Elemental Sulfur can be oxidized completely to sulfate (SO_4) when no further oxidation can take place. Therefore, adding materials containing sulfate will, from the sulfate contribution, cause no change in pH. Gypsum, a neutral salt, has no influence on soil pH.

What about ammonium sulfate; doesn't it reduce soil pH? Ammonium sulfate will reduce pH by a reaction which converts ammonium to nitrate. The sulfate addition will have no effect on soil pH.

Some soils contain high free carbonate levels which make it difficult to change overall pH. For example, a soil with a carbonate content of 2% contains 80,000 pounds of carbonates per one foot depth. To neutralize this amount, nearly 25,000 pounds of sulfur would be required to neutralize the carbonates in the top foot of soil. But do not dismay, the fact that overall pH reduction is difficult does not mean that small applications of 500-1000 pounds of limestone per acre do not produce results. A decrease in pH occurs in a small zone around the sulfur particle as it is converted, and roots growing into this zone could benefit from increased solubility of phosphorous and micro-nutrients.

SALINE & SODIC SOILS

Saline (salt) and sodic (high sodium) soils occur in arid or semi-arid climates where rainfall is generally less than 10 inches per year and there is a high evaporative demand. Salts occur from the weathering of primary minerals and from the application of irrigation waters containing salts. Waters with an electrical conductivity (EC) of 1.0 dS/m contain nearly a ton of salt per acre foot of water.

Saline soils have a soluble salt content great enough to prevent or reduce crop growth. Alfalfa is not affected by salinity until salts in the root zone exceed 2.0 dS/m on a seasonal average. Figure 1 shows the response of alfalfa to increasing soil salinity. Note that no yield reduction occurs until the threshold salinity of 2.0 soil salinity is exceeded. Saline soils are those with less than 15% exchangeable sodium and do not have a pH which will significantly reduce alfalfa growth (<8.2).

Sodic or alkali soils differ distinctly from saline soils in that they contain excessive amounts of exchangeable sodium (>15%). These soils become exceedingly hard when dry and less permeable to air and water. Sodic soils gradually have pH values exceeding 8.2. Alfalfa is classified as tolerant to exchangeable sodium levels when sodium is viewed as a toxic element. It is the combined effect of high pH, which nutrient availability problems and reduced water and air infiltration are, that causes yield reductions.

Saline Soils

The excess salts associated with saline soils must be leached out of the root zone to maintain a favorable environment for alfalfa growth. If soil internal drainage permits, water in excess of crop use will move salts downward. However, the presence of a water table can complicate the drainage process.

The quantity of water required (leaching requirement, LR) to maintain a soil salinity at less than a level to reduce yield depends on:

- salinity of the applied irrigation water in dS/m (EC_w);
- average soil salinity tolerated without yield loss (EC_e)

$$LR = \frac{EC_w}{5\,(EC_e) - EC_w}$$

For example:

Irrigation water (EC_w)	=	2.0 dS/m
Soil salinity threshold (EC_e)	=	2.0 dS/m

$$LR = \frac{2}{5(2) - 2} \quad = \quad 25\%$$

The results indicate that in order to maintain salinity in the root zone at less than the threshold value, 25% of the crop water annual use must pass through the root zone. This quantity may be from applied water or by rainfall. Since alfalfa is a high water user as well as being sensitive to over-watering, applying large quantities in excess of crop use is not an easy task. Salt removal is often performed prior to planting.

Sodic Soils

To reclaim or reduce the level of sodium in soils, the sodium ions first must be exchanged (released) from the clay surface, then leached from the root zone. Calcium-containing amendments are applied to the soil for this purpose.

In non-calcareous soils, gypsum ($CaSO_4$) is the material of choice. In calcareous soils or those containing free carbonates ($CaCO_3$), gypsum may not be needed to be applied since calcium can be made available by applying an acid or acid-forming amendment such as sulfuric acid, sulfur or lime-sulfur. The choice of amendment depends on the presence of lime in the soil, the time of year it is applied, the cost of amendment, and the speed of reclamation desired. Sulfuric acid is very fast in reclamation in contrast to sulfur which is dependent on proper incorporation into the soil as well as temperature and moisture conditions.

Gypsum is most commonly applied in granular form, broadcast at rates from 2-10 tons/acre and is worked into the soil. Given adequate drainage potential, water is then required to leach sodium salts from the root zone.

WATER INFILTRATION

A water infiltration problem occurs if irrigation water does not enter the soil rapidly enough during a normal irrigation cycle. If this occurs, the soil will not be replenished with the water needed by the crop before the next irrigation.

While soil texture, type of clay minerals and chemical characteristics, including exchangeable cations can affect water infiltration, other factors may be important also. Since most problems result from entry of water at the surface of the soil, the irrigation water quality is most often a cause which can be remedied. Water quality problems directly relate to unfavorable changes in soil chemistry. Infiltration rate generally increases with increasing salinity and decreases with decreasing salinity or increasing sodium content relative to calcium and magnesium. Figure 2 graphically presents guidelines for the existence of water infiltration problems based on measurement of water salinity and SAR (sodium absorption ratio).

Low Salinity Water

Less than 0.5 dS/m and especially below 0.2 dS/m waters tend to leach the soil surface of soluble minerals. Over time as calcium is removed, the soil at the surface disperses, reducing the infiltration rate. Application of materials which increase the water salinity such as fertilizers or acid, will increase infiltration rates. Calcium containing amendments are preferred since they replace calcium which has been removed from the soil surface.

Gypsum added to the water would be preferred, although its low solubility in water is not easy to overcome. A process using a gypsum mixing and injection apparatus (Domtar) is effective although expensive (≅ $100/ton gypsum). Unincorporated broadcast applications of gypsum to the surface for subsequent treatment of irrigation water before it enters the soil have met with moderate success.

Excessive sodium in irrigation water also promotes soil dispersion and structural breakdown but only if sodium exceeds calcium by >3:1 ratio. At this point, presence of sodium causes the sealing of the surface much the way as does low salt water. Remedies include the application of calcium containing materials, usually gypsum, to soil or irrigation water in order to improve the calcium:sodium ratio.

Reference

Ayers, R.S. and D.W. Westcot, Water Quality for Agriculture, FAO 29, 1985

Figure 1

Effect of soil Salinity on relative yield

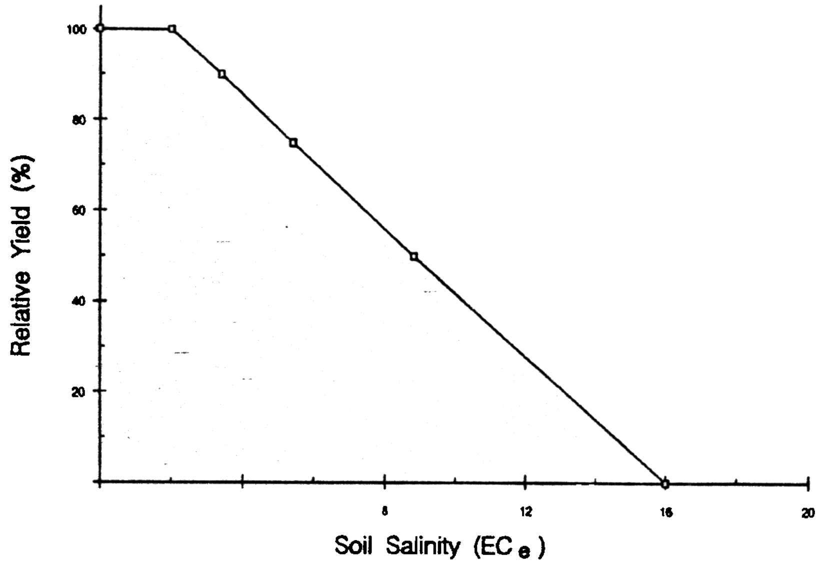

Figure 2

Relative rate of water infiltration as affected by salinity and sodium adsorption ratio (from Ayers and Westcot, 1985)