

SOIL ACIDITY, ALKALINITY, AND SALINITY

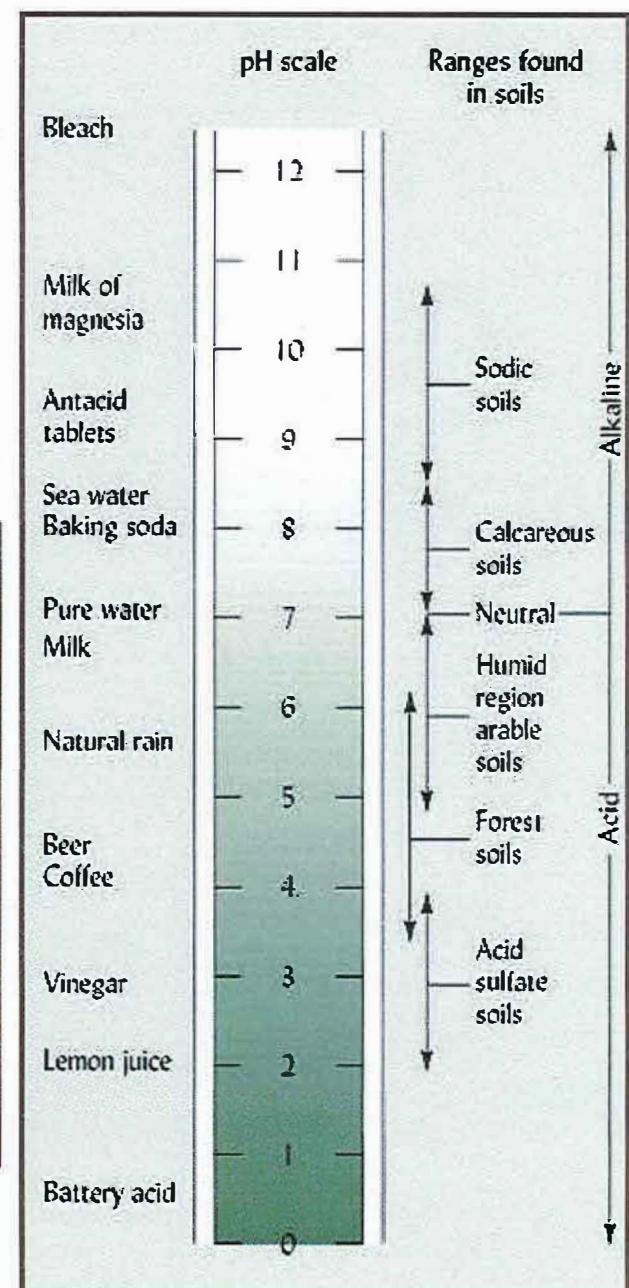
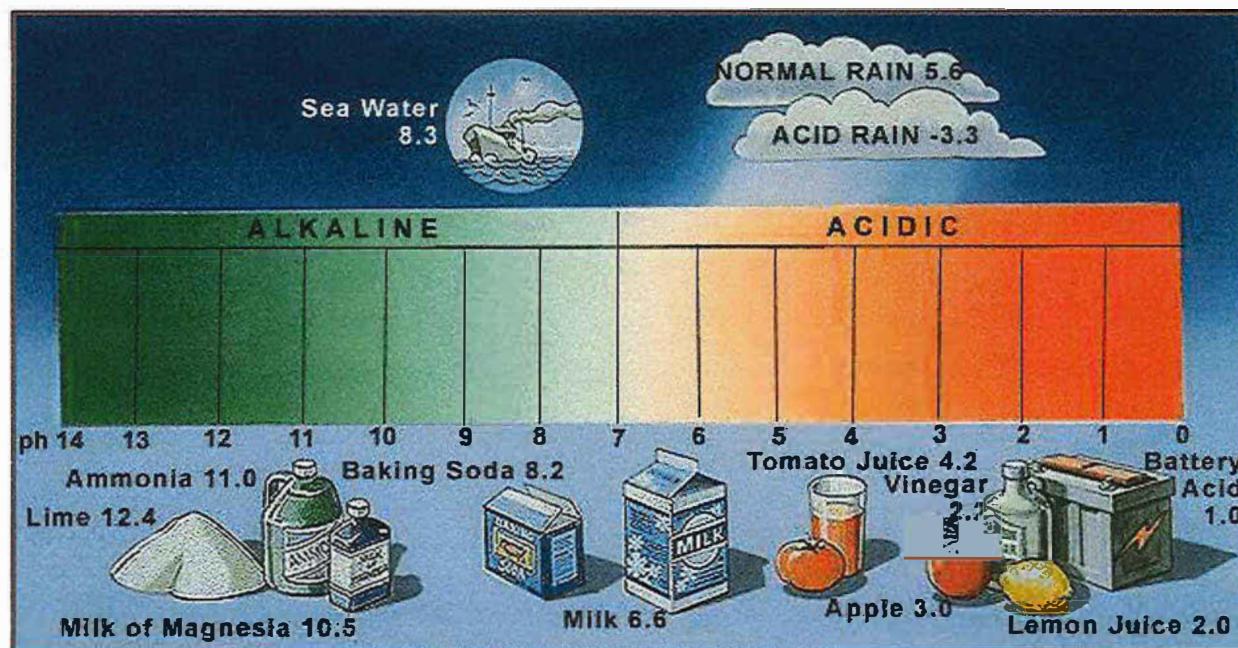
Introduction: Soil pH

- Degree of soil acidity or alkalinity in soil
 - Expressed as pH
- Soil pH considered a *master variable* affecting wide range of soil properties
 - Chemical
 - Biological
 - Physical

Introduction: Soil pH

- Plant species in natural landscape reflect pH
- Soil pH affects mobility of pollutants in soil
 - Influences rate of biochemical breakdown
 - Influences solubility
 - Influences adsorption potential to colloids
- Soil pH critical factor in predicting likelihood of pollutants to contaminant groundwater, surface water, etc

pH values for familiar substances compared to ranges of pH typical for various types of soils



Introduction: Soil pH

- 2 most important factors influencing soil pH
 - Balance between acid and nonacid cations on colloid surfaces
 - Balance between H^+ and OH^- ions in soil solution
- These balances are controlled by the nature of the soil colloids

Introduction: Soil pH

- Acidification is a natural process in soil formation
- Greatest expression of acidity in humid regions
 - Sufficient rainfall to thoroughly leach soil profile
- Least expression of acidity in drier regions
 - Scant rainfall means less leaching of soil profile
 - Soils retain sufficient Ca^{2+} , Mg^{2+} , K^+ , and Na^+ to prevent buildup of acid cations (Al^{3+} and H^+)

Introduction: Alkalinity, Salinity and Sodicity

- Dry regions of the earth may accumulate detrimental levels of:
 - Soluble salts (*saline soils*)
 - Exchangeable sodium ions (*sodic soils*)
- Due to insufficient leaching, dry areas of the world tend to have pH's above 7 (*alkaline soils*)
- Alkalinity, salinity, and sodicity affect physical condition and fertility of arid and semiarid area soils

Understanding pH

- Acidity and alkalinity measured with *pH scale*
 - Expresses activity or concentration of H⁺ ions in solution
- Pure water has equal concentrations of H⁺ and OH⁻ ions
 - $\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-$
- Ion product of concentrations of H⁺ and OH⁻ ions is a constant (K_w)
 - K_w = 1 × 10⁻¹⁴
 - [H⁺] × [OH⁻] = K_w = 10⁻¹⁴

Understanding pH

- Since in pure water the concentration of H⁺ [H⁺] ions must be equal to the concentration of OH⁻ [OH⁻] ions then concentration of each must be 10⁻⁷

$$10^{-7} \times 10^{-7} = 10^{-14}$$

Understanding pH

- Inverse relationship exists between concentrations of these two ions
 - As one increases the other must decrease proportionately
 - If H^+ ion concentration $[\text{H}^+]$ was increased 10 times (*from 10^{-7} to 10^{-6}*) then $[\text{OH}^-]$ would be decreased by 10 times (*from 10^{-7} to 10^{-8}*) since product must equal 10^{-14}
 - $10^{-6} \times 10^{-8} = 10^{-14}$

Understanding pH

- Can express the small concentrations of H^+ and OH^- ions by using the *negative logarithm* of the H^+ ion concentration or ... the pH
- 10^{-7} can be expressed more easily logarithmically as -7
 - $-\log (10^{-7}) = -(-7) = 7$

Understanding pH

- Increasing quantity of H^+ in solution decreases pH value
 - $[\text{OH}]$ decreases as $[\text{H}]$ increases
- Each integer change represents a 10 fold change in concentration
 - A solution at pH 5 is 10 times more acidic than one at pH 6; 100 times more acidic than one at pH 7

Sources of Hydrogen Ions

- Carbonic and other organic acids
 - Carbon dioxide gas from soil air and water form carbonic acid
 - H^+ dissociates in this reaction
 - Other organic acids formed as microbes break down organic matter
- Accumulation of organic matter
 - OM forms complexes with nonacid cations allowing them to be leached
 - OM itself a source of H^+ ions

Sources of Hydrogen Ions

- Oxidation of Nitrogen (Nitrification)

- NH_4^+ (ammonium) ions from OM or fertilizer react with oxygen
 - Oxidizes the ammonium ion and releases 2 H^+ ions

- Oxidation of Sulfur

- Decomposition of plant residues or presence of sulfur in rocks results in oxidation reactions forming sulfuric acid (H_2SO_4)
 - Dissociates to release H^+ ions

Sources of Hydrogen Ions

- Acids in precipitation

- Rain, snow, fog and dust contain various acids
 - Precipitation forms carbonic, sulfuric or nitric acids depending on what is in the air it is falling through

- Plant uptake of cations

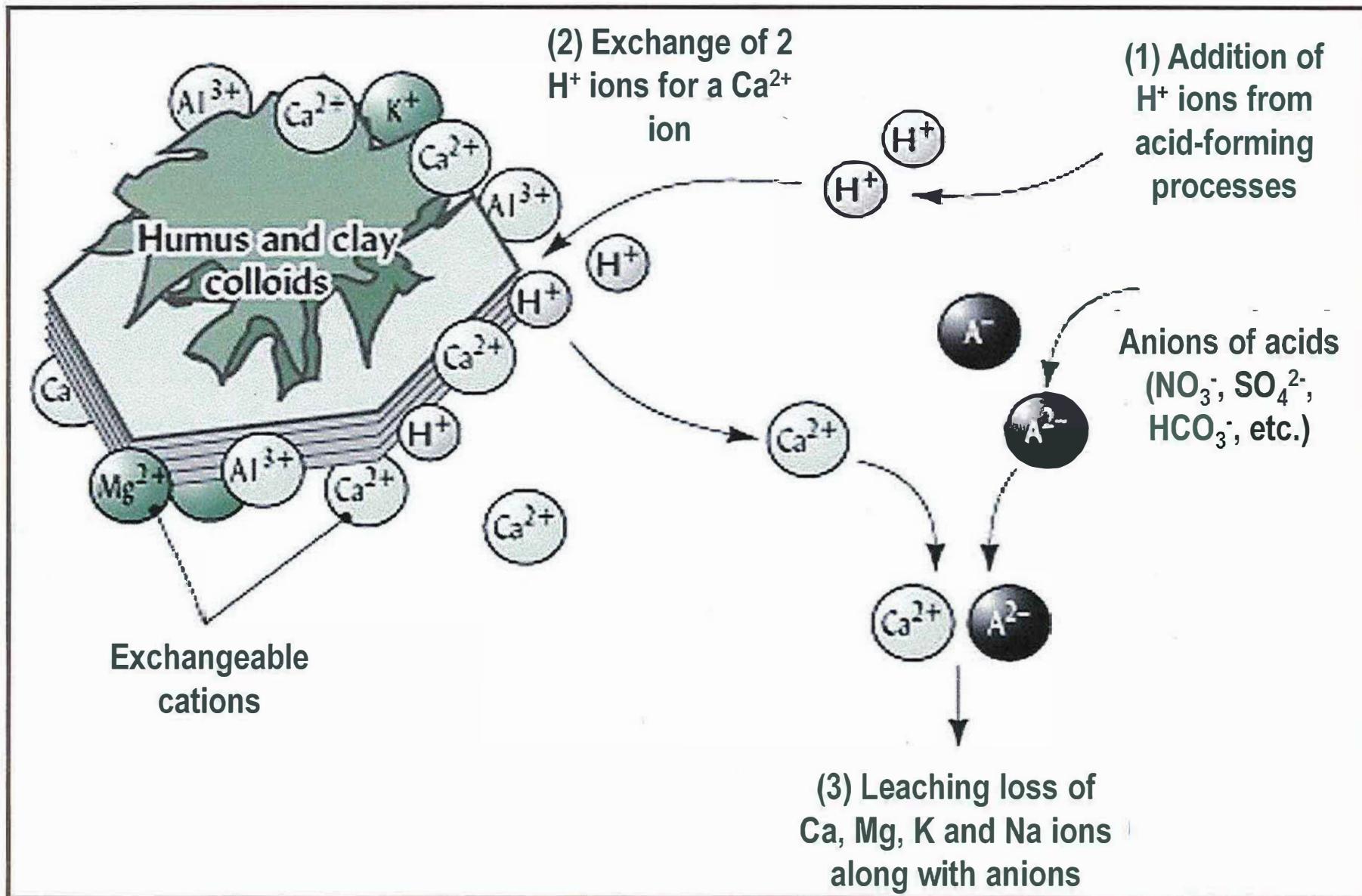
- Plants must maintain charge balance on ions they uptake
 - If they take up more cations than anions often release H⁺ back into soil solution to maintain balance

Main processes that produce or consume Hydrogen ions (H^+)

Production of H^+ ions increases soil acidity, while consumption of H^+ ions delays acidification and leads to alkalinity. The pH level of a soil reflects the long-term balance between these two types of processes.

Acidifying (H^+ ion-producing) processes	Alkalinizing (H^+ ion-consuming) processes
Formation of carbonic acid from CO_2	Input of bicarbonates or carbonates
Acid dissociation such as: $RCOOH \rightarrow RCOO^- + H^+$	Anion protonation such as: $RCOO^- + H^+ \rightarrow RCOOH$
Oxidation of N, S, and Fe compounds	Reduction of N, S, and Fe compounds
Atmospheric H_2SO_4 and HNO_3 deposition	Atmospheric Ca, Mg deposition
Cation uptake by plants	Anion uptake by plants
Accumulation of acidic organic matter (e.g. fulvic acids)	Specific (inner sphere) adsorption of anions (especially SO_4^{2-})
Cation precipitation such as: $Al^{3+} + 3H_2O \rightarrow 3H^+ + Al(OH)_3^0$ $SiO_2 + 2Al(OH)_3 + Ca^{2+} \rightarrow CaAl_2SiO_6 + 2H_2O + 2H^+$	Cation weathering from minerals such as: $3H^+ + Al(OH)_3^0 \rightarrow Al^{3+} + 3H_2O$ $CaAl_2SiO_6 + 2H_2O + 2H^+ \rightarrow SiO_2 + 2Al(OH)_3 + Ca^{2+}$
Deprotonation of pH-dependent charges	Protonation of pH-dependent charges

Process by which soils may become acidic



Alkalinity, Salinity, Sodicity

- Alkaline soils are those with a pH above 7.0
- Alkalinity refers to concentration of OH^- ions generated from reaction of carbonates and water
- Alkali soil is an obsolete term for sodic or saline-sodic soils
 - Soils with high levels of exchangeable sodium

Causes of Alkalinity

- *High soil pH is the main cause of alkalinity*
 - Occurs when cations released by mineral weathering accumulate faster than they can be leached
 - Common where precipitation is less than evaporation
- Salts accumulate naturally in soils of arid/semi-arid regions due to insufficient rainfall to flush (leach) them from upper layers

Sources of Alkalinity

- Cations in soil solution and on exchange complex are mainly Ca^{2+} , Mg^{2+} , K^+ , Na^+
 - These cations do not produce H^+ (acid) when reacting with water
 - Usually don't produce OH^- ions either
 - Effect in water is neutral
 - Soils containing these cations have pH's no higher than 7 **UNLESS** certain anions present

Sources of Alkalinity

- Presence of hydroxyl generating (OH^-) anions will raise pH in soils
- Anions are carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-)
- Anions react with water and dissociate producing OH^-
- Anions form from dissolution of calcite (mineral) or carbonic acid

Influence of carbon dioxide and carbonates on pH

- Biological activity increases CO_2 in soil and limits/lowers pH
- Precipitation of CaCO_3 when soil solution is saturated with Ca^{2+} is due to the limited solubility of Ca^{2+}
 - Limits pH to 8.4
- Sodium carbonate and sodium bicarbonate much more soluble than calcium carbonate
 - Produces high concentrations of CO_3^{2-} ions
 - Allows for pH's as high as 11

Role of Aluminum in Soil Acidity

- Aluminum is a major constituent of most soil minerals
 - When H^+ ions adsorbed they will attack mineral structure releasing Al^{3+} ions from structure
 - Al^{3+} ions become adsorbed to colloid cation exchange sites while maintaining equilibrium with dissolved Al^{3+} ions in soil solution

Role of Aluminum in Soil Acidity

- The exchangeable and dissolved Al^{3+} ions are critical to soil acidity
- Aluminum is highly toxic to most organisms and plants
 - Responsible for most acidity impacts on organisms
- Al^{3+} ions have strong tendency to hydrolyze
 - That is they split water molecules into H^+ and OH^-
 - Aluminum combines with OH^- leaving H^+ free to lower pH
 - One Al^{3+} ion can release up to 3 H^+ ions
 - Al^{3+} and H^+ ions are called the acid cations

Role of Aluminum in Soil Acidity

- Hydroxy aluminum ions formed earlier are strongly adsorbed to clay surfaces or complexed with OM thus masking much of the colloids CEC potential
- As pH is raised these ions precipitate into solution as uncharged ions opening up negative exchange sites on colloid for cation exchange

Buffering of pH in Soils

- Buffering: The tendency of soils resist change in pH of the soil solution
 - Soils are most highly buffered when aluminum compounds (low pH) and carbonates (high pH) are controlling the buffer reactions
 - Soils are least well buffered at mid pH levels when H⁺ ion dissociation and cation exchange are primary buffer mechanisms

Buffering of soils against changes in pH

Low pH:

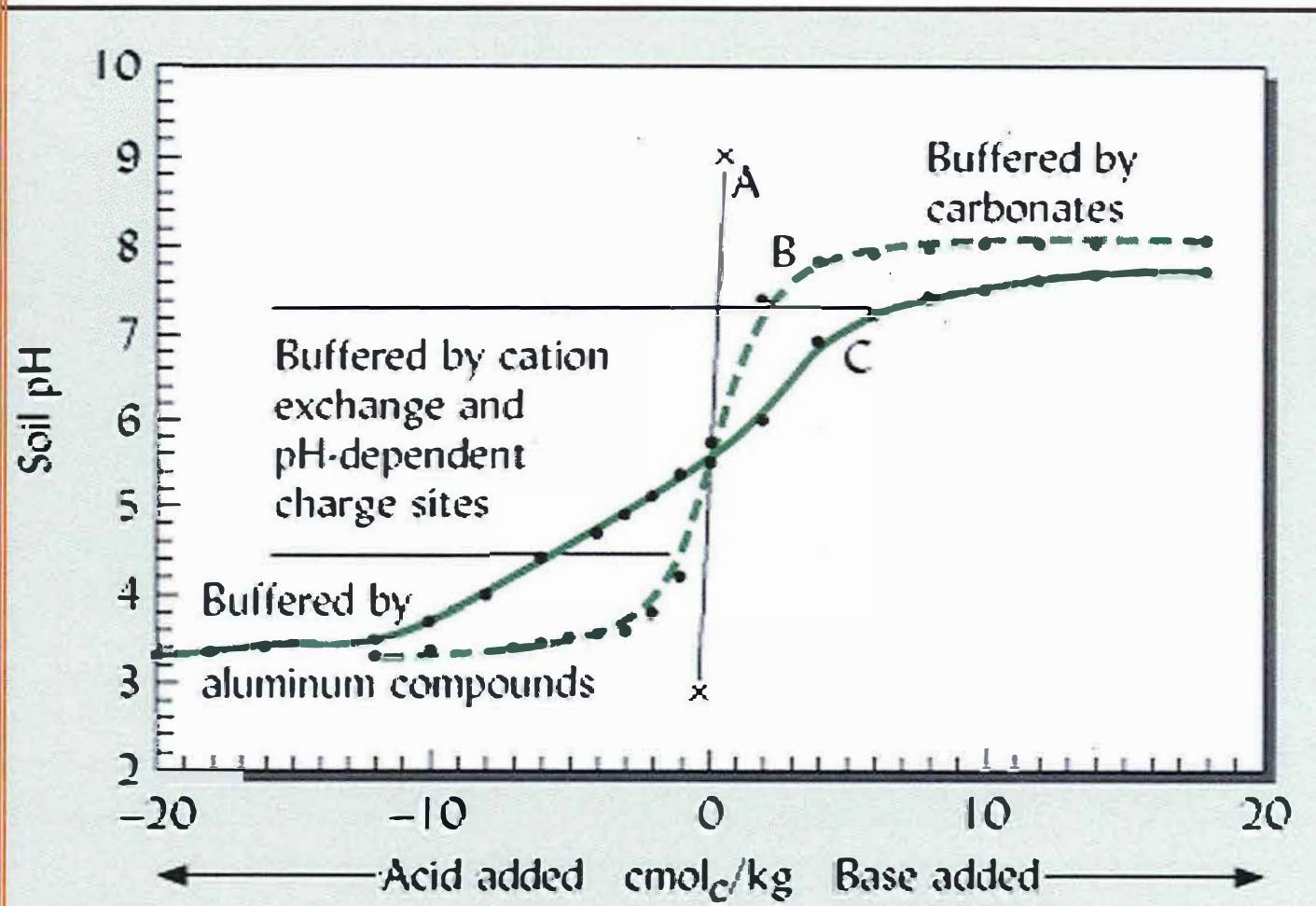
buffering by hydrolysis and precipitation of aluminum compounds.

High pH:

buffering by precipitation and dissolution of calcium carbonate.

Mid pH:

buffering by cation exchange and gain or loss of H^+ ions



Buffering of pH in Soils

- Applying a base (lime/ground limestone) increases pH by neutralizing H⁺ ions (active acidity)
- Neutralized H⁺ ions are replaced by ions from residual and exchangeable acidity reservoirs
 - Hard to change pH because these reservoirs are so large

Buffering of pH in Soils

- The higher the cation exchange capacity of a soil, the greater its buffering capacity
- The higher the clay and organic matter contents the more lime is needed to raise pH
- Soil buffering is important because it prevents fluctuations in pH that could harm plants and microorganisms

Human-Influenced Soil Acidification

- Human activities can accelerate natural processes of soil acidification
- Three major types of human-influenced soil acidification
 - 1) *Nitrogen fertilization*
 - 2) *Acid deposition from the atmosphere*
 - 3) *Exposure of acid sulfate materials*

Nitrogen Fertilization

- *Excessive use of ammonium-based fertilizers*
 - Microbes oxidize to acids, plants uptake what they need, remainder available to increase acidity
- *Application of acid forming organic material*
 - Mainly sewage sludges and animal manures
 - Oxidation of nitrogen or formation of acids during their decomposition can decrease pH

Acid Deposition from Atmosphere

- Industrial activity emits Nitrogen and Sulfur containing gases into atmosphere
- Reaction with water etc., produces sulfuric and nitric acid
 - Returned to earth as acid rain (snow, fog dust)
 - Major effects on fish and forests
 - Effect is a result of interaction between acid rain and soils in the affected watersheds

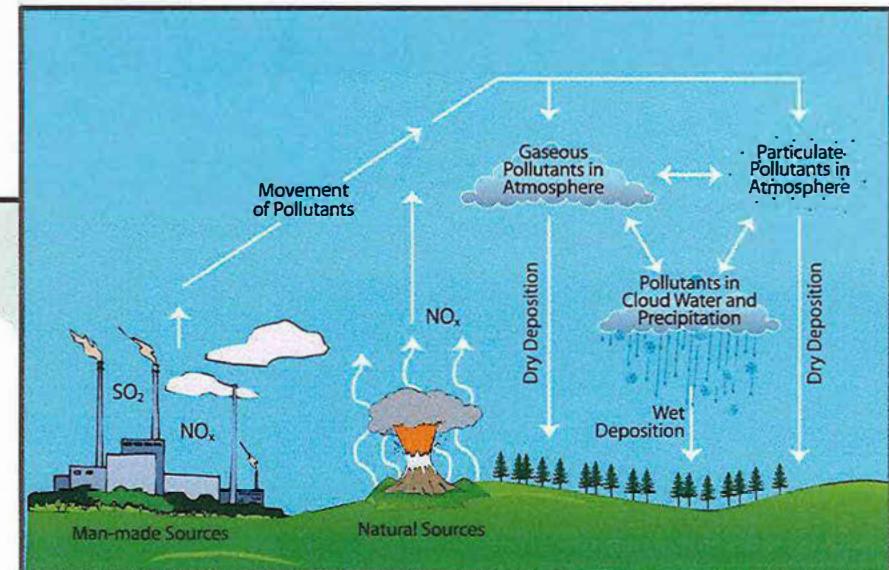
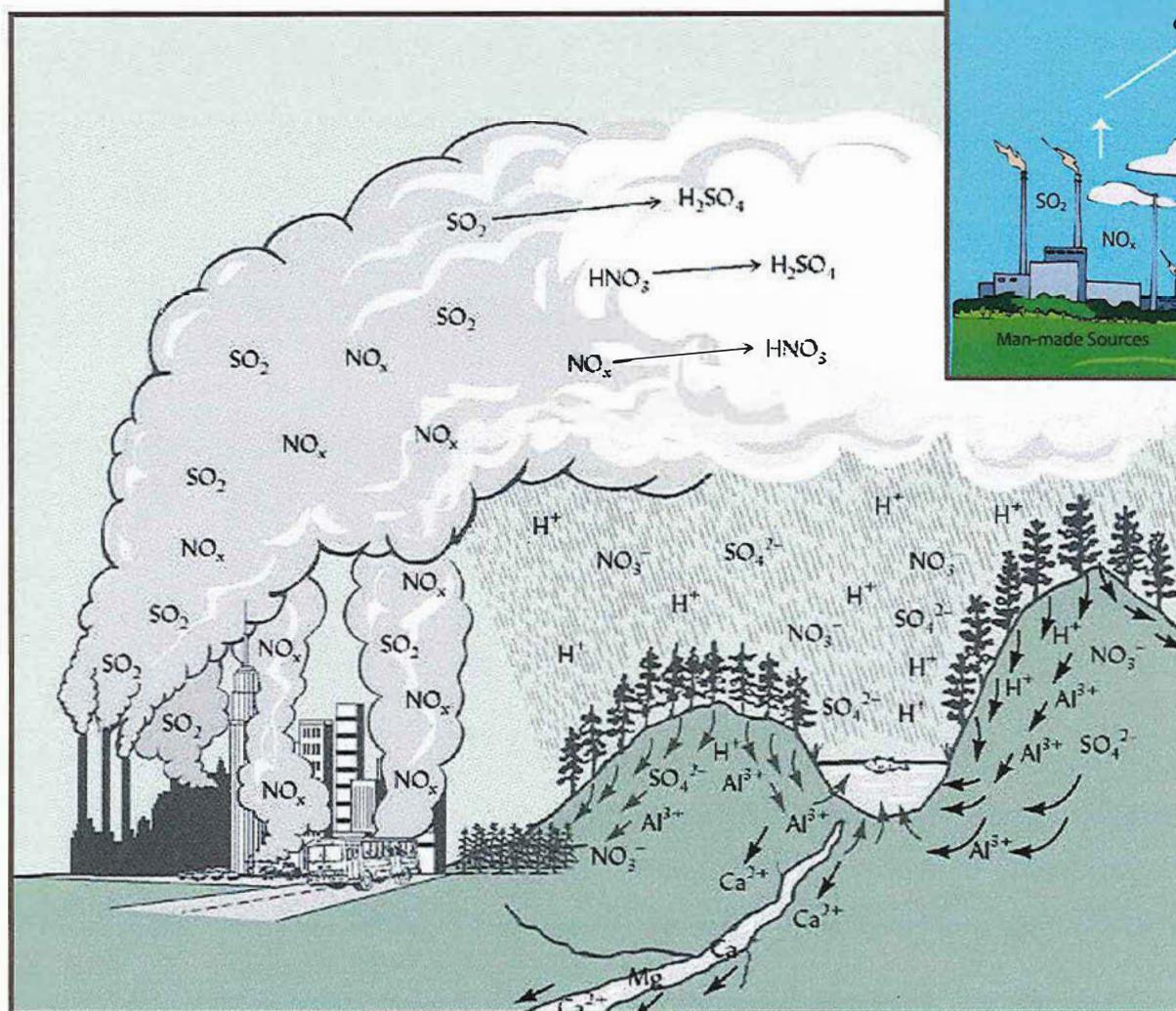
Acid Deposition from Atmosphere

- Incoming acids mobilize aluminum in the soil minerals
- Aluminum displaces Ca^{2+} and other nonacid cations from exchange complex
 - Ca^{2+} and other ions easily leached
 - Al^{3+} and H^+ become dominant on exchange complex, in soil solution, and in drainage waters

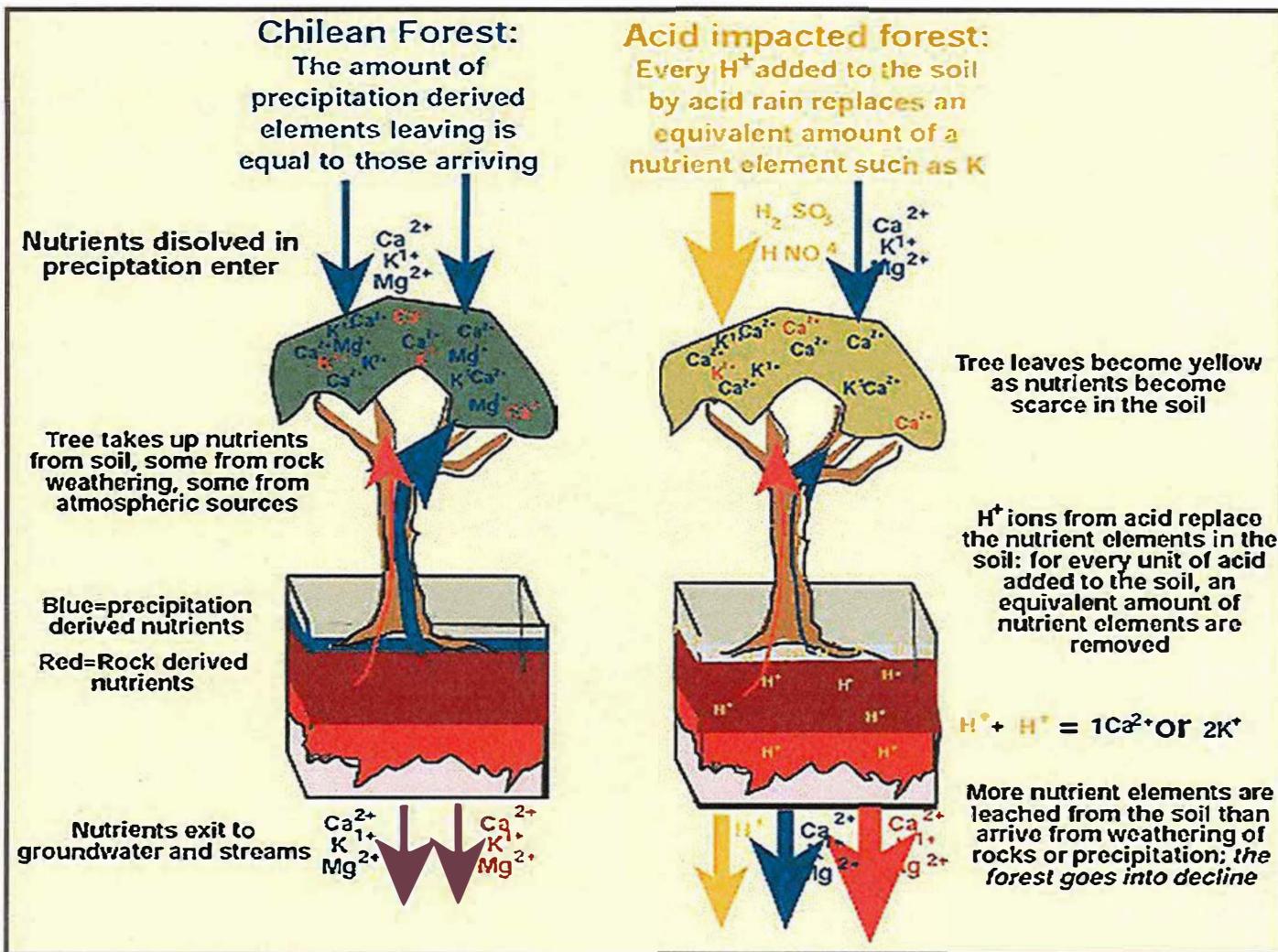
Acid Deposition from Atmosphere

- Main effects of acidification on forest and fish are a result of aluminum toxicity
- A pH drop to 6.0 damages reproductive systems of fish, a pH drop to 5.0 will kill fish
- Areas with much acid rain, soils with low CEC, and low reserves of weatherable minerals (to re-supply the leached out calcium) are most susceptible

Effects of Acid Rain on Watersheds



Effects of Acid Rain on Forests



Exposure of Acid Sulfate Materials

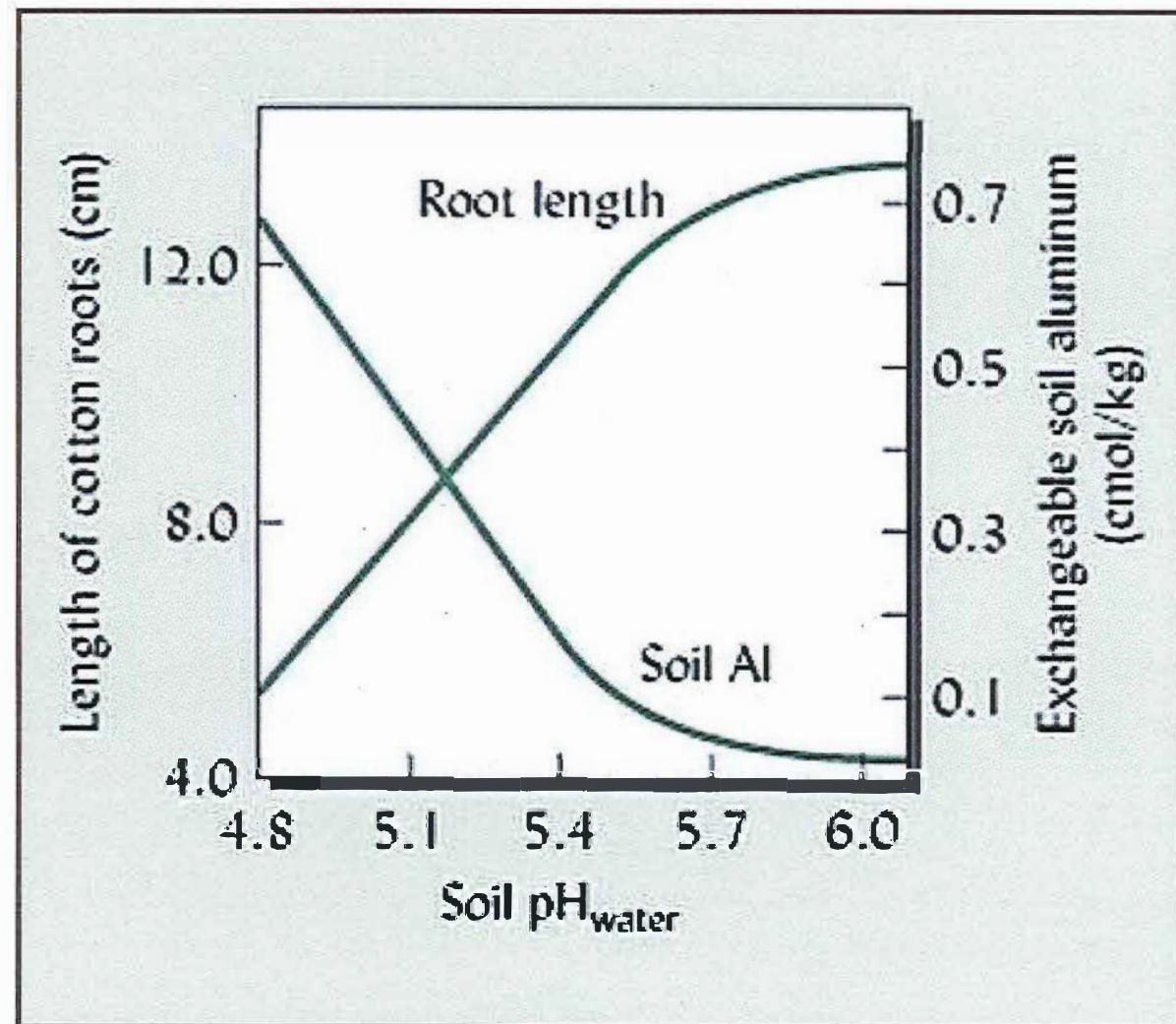
- Coastal wetlands, marshes, or sediments from the ocean are potential acid sulfate forming materials
- Sulfur and iron remain in reduced form as long as sediments remain waterlogged
 - Exposure to oxygen by drainage or dredging changes oxygen and sulfur to oxidized forms
 - Soils can now produce sulfuric acid when water is added

Biological Effects of Soil pH

- Aluminum toxicity
 - Becomes a problem when pH reaches 5.2 and below
 - Affects plants and bacteria
 - Blocks sites of calcium uptake
 - Interferes with phosphorous metabolism
 - Stunts root systems
 - Plants become easily drought stressed

Plant Response to Aluminum Toxicity

As pH drops below 5.2 exchangeable Al amount increases and root length is severely restricted

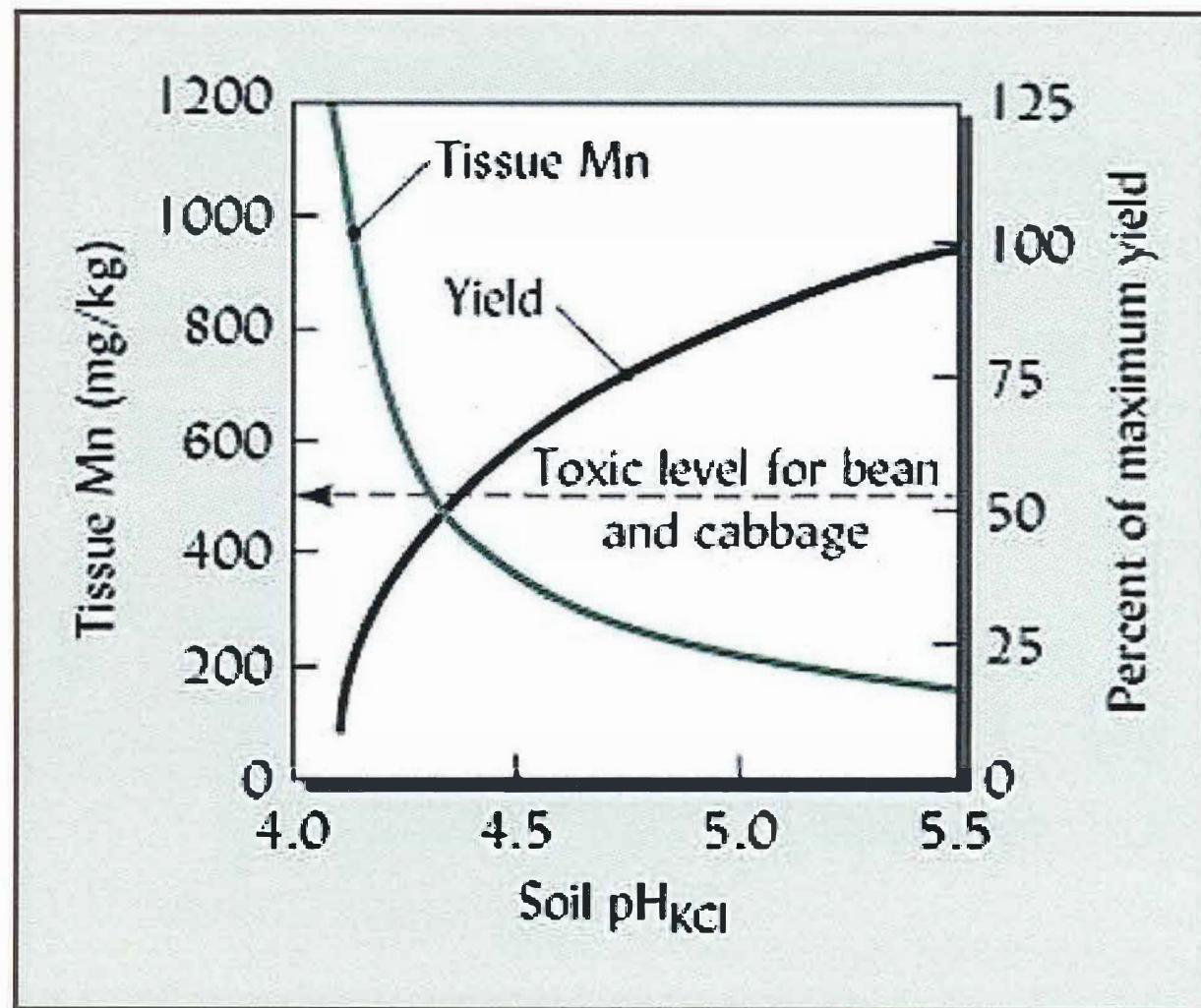


Biological Effects of Soil pH

- Manganese toxicity
 - Manganese is an essential plant nutrient but is toxic in excessive quantities
 - Some soils contain high content of manganese containing minerals
 - Toxicity common when pH reaches 5.6
 - Toxicity increased when manganese is in reduced form
 - Common in flooded, waterlogged conditions

Plant Response to Manganese Toxicity

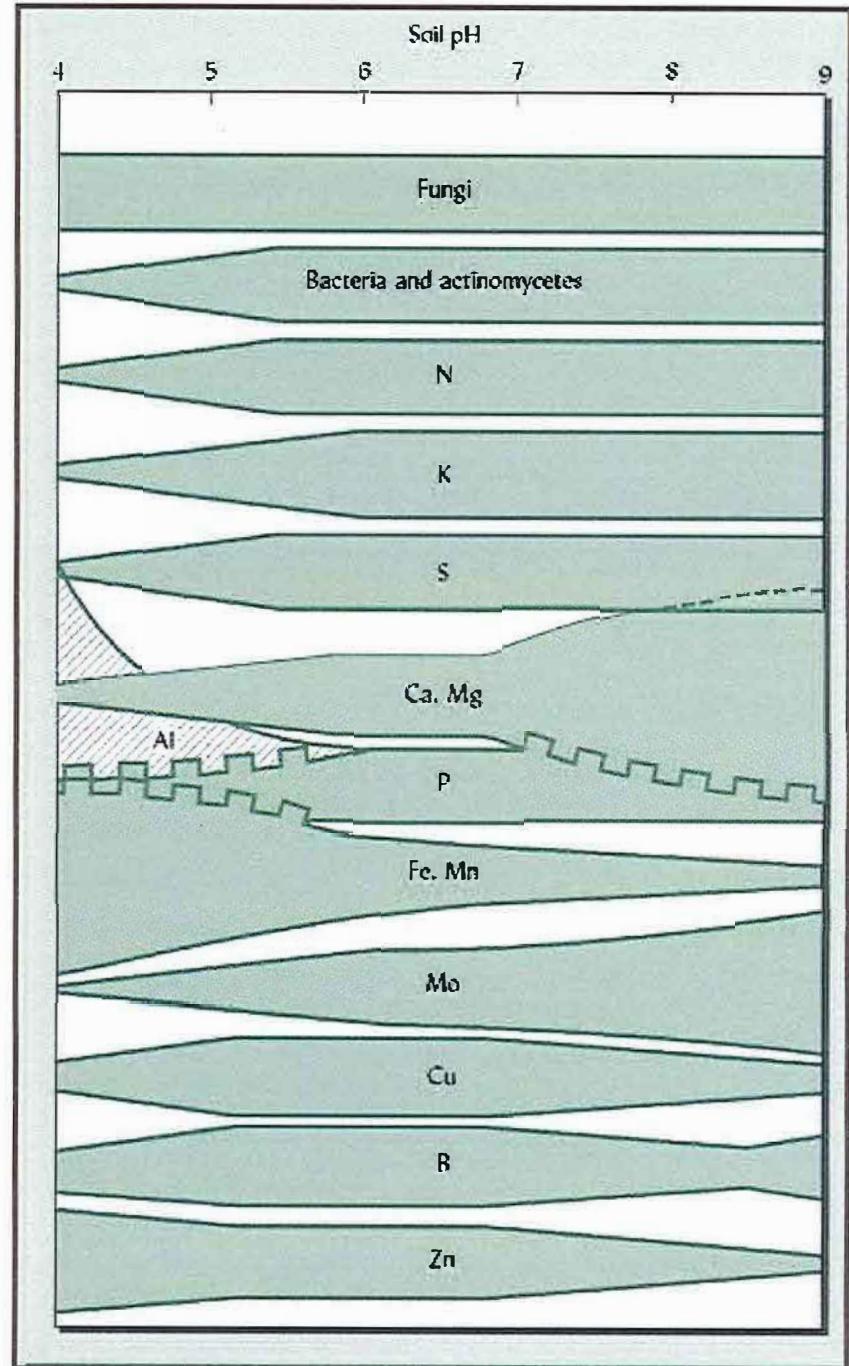
Average plant shoot growth declines and manganese content of foliage increases at low pH levels. (Soils are naturally high in manganese)



Biological Effects of Soil pH

- Nutrient availability to plants
 - In strongly acid soils Ca, Mg, K, P, N, S (macronutrients); Molybdenum and Boron (micronutrients) are curtailed
 - Phosphorous (P) and Boron (B) constrained in alkaline soils
 - P reacts with free Ca (insoluble compounds) and B strongly adsorbed to colloids
 - Most other micronutrients availability, (Fe, Mn, Zn, Cu, Co), are increased by decreasing pH
 - Plant growth may be constrained in slight to moderately alkaline soils due to micronutrient unavailability

Relationships between pH and Availability of Plant Nutrients



Acidity and Plant Growth

- Optimum pH for plant growth depends on individual species
 - pH must be at least 5.5 to neutralize Al in soil
 - Al precipitates out of solution at pH 5.5
- Generally a pH >6 (most plants) provides:
 - Optimum nutrient availability
 - Optimum herbicide action

Raising Soil pH

- Soil acidity is decreased (and pH increased) by adding alkaline materials
- Alkaline materials include carbonate (CO_3^{2-}), hydroxide (OH^-), and silicate (SiO_3^{2-})
 - Called “conjugate bases”, anions which are capable of consuming (or reacting with) H^+ to form weak acids (water is an example)
- These bases commonly called “*agricultural limes*”

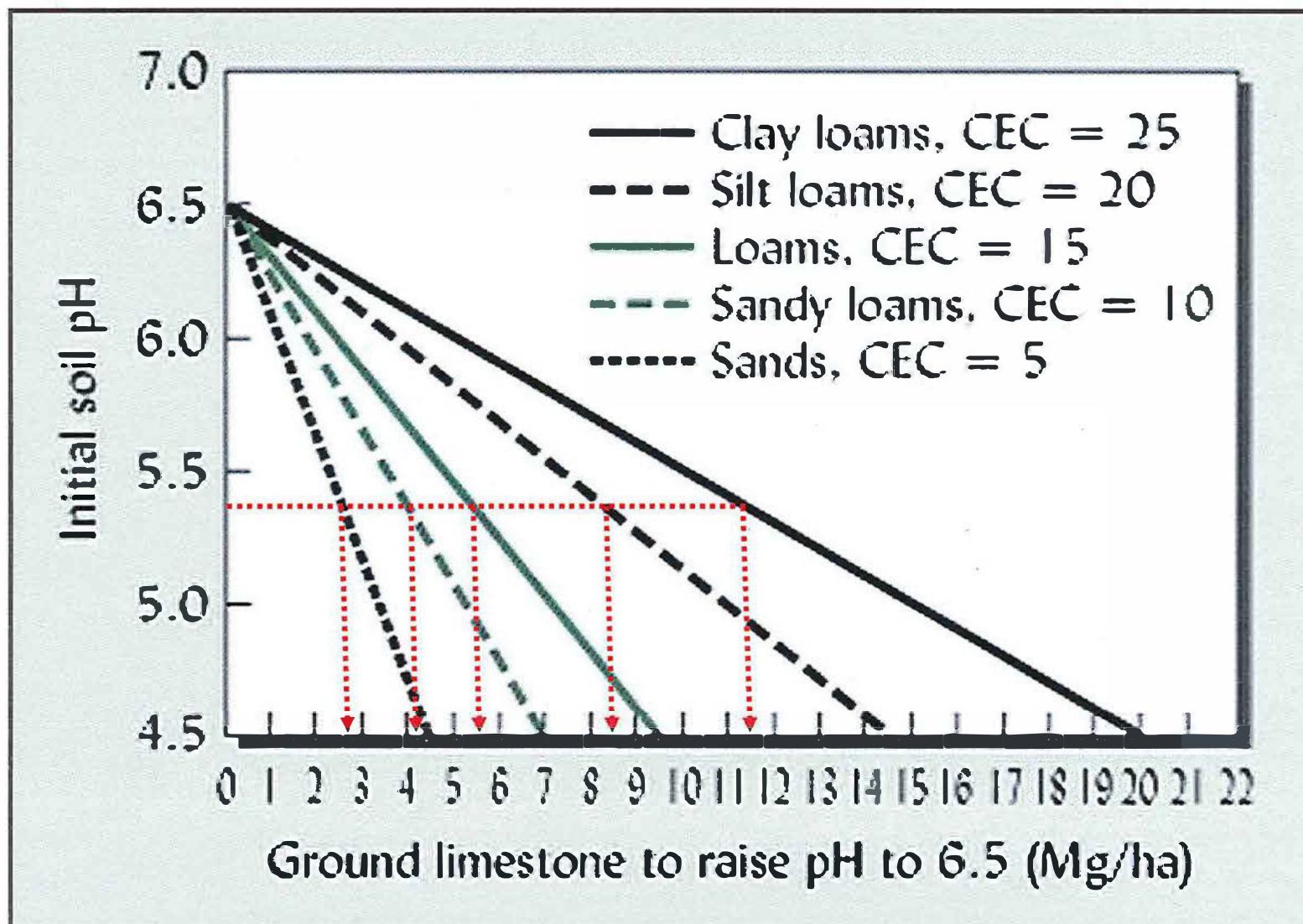
Raising Soil pH

- Adding agricultural lime to a soil is called “liming”
- Purpose of liming is to change the chemical makeup of a substantial part of the root zone
- Liming material must be added in large quantities
- Liming material must be relatively inexpensive
- Most common liming materials are derived from limestone

Raising Soil pH

- Liming materials raise pH by reacting with carbon dioxide and water to yield bicarbonates
 - Bicarbonates are more soluble than carbonates,
 - Can react with exchangeable and residual acidity pools
- Ca^{2+} and Mg^{2+} replace H^+ and Al^{3+} on the colloidal complex, increasing pH of soil solution
- Soil texture and corresponding buffering capacity important in determining amount of lime needed to change pH

Effect of Soil Textural Class on Limestone Required to Raise Soil pH

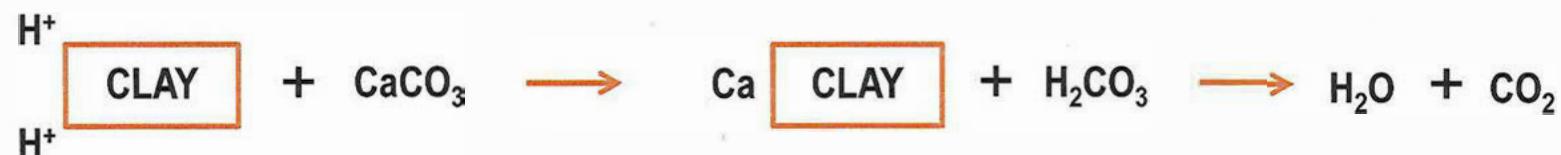


Raising Soil pH vs. Neutralizing Acidity

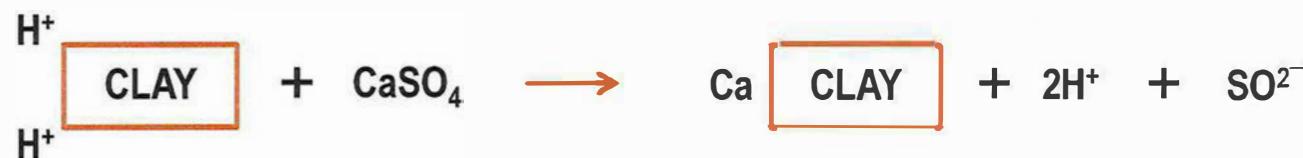
- Liming (with CaCO_3 or MgCO_3) works well for surface soil acidity
 - Neutralizes acidity directly
- For subsoils with high clay **AND** high acidity gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is effective
 - Main problem is excessive Al causing high acidity
 - Ca^{2+} replaces exchangeable Al^{3+} on the exchange site (leaching) lowering acidity
 - Does not raise or lower soil pH significantly
 - SO_4^{2-} anion available to accompany Ca^{2+} in leaching of Al^{3+}

Soil Reactions for CaCO_3 and Gypsum

LIMING REACTION (with CaCO_3)



GYPSUM REACTION



Lowering soil pH

- Sometimes need to lower pH of alkaline (or even acid) soil
 - Usually to promote growth of certain plant species
 - Lower pH by adding acid-forming organic and inorganic materials
 - Acid organic matter
 - Inorganic chemicals

Lowering soil pH

- Acid organic matter

- Material should be low in calcium
 - Pine needles/sawdust, acid peat moss, leaf mold

- Inorganic chemicals

- Ferrous sulfate
 - Provides available iron to plants and lowers pH
 - Aluminum sulfate (alum)
 - Elemental sulfur

Changing pH in Soil

Soil pH directly affects the life and growth of plants because it affects the availability of *all* plant nutrients. Between pH 6.0 and 6.5, most plant nutrients are in their most available state. A nutrient must be soluble and remain soluble long enough to successfully travel through the soil solution into the roots. Nitrogen, for example, has its greatest solubility between soil pH 4 and soil pH 8. Above or below that range, its solubility is seriously restricted.

Soil acidity or alkalinity (pH) is extremely important because it has an effect on the decomposition of mineral rock into essential elements that plants can use. It also changes fertilizers from their form in the bag to a form that plants can easily uptake. Soil microorganisms that change organic nitrogen (amino acids) to the ammonium form of nitrogen to the nitrate form that plant can use also depends on the soil pH. Soil pH should be checked periodically and consistent testing will indicate whether your pH-control program is working.

Raising pH

The ideal pH range for soil is from 6.0 to 6.5 because *most* plant nutrients are in their most available state. If a soil test indicates a pH below 6.5, the usual recommendation is for the application of ground limestone. In addition to having the ability to raise pH, limestone contains calcium. Some prefer dolomitic limestone because it contains both calcium and magnesium, however soils high in magnesium (serpentine) do not need more magnesium. Table 1 indicates the number of tons per acre of ground limestone required to raise the pH of a given soil to based on the original pH, desired pH, and soil type.

In order to select the correct application rate use a soil test to determine both the soil texture group and the current pH. As the percentage of clay in a soil increases, it requires proportionately more limestone to raise the pH. This means it is much harder to change the pH of clay soil than sandy soil. Consider that limestone moves *very slowly*, taking years to move down a few inches in the soil. This is why it is so important to test soil early in the planning process. Limestone should be tilled into the soil root zone (top 7 inches).

Table 1. Approximate Amount of Finely Ground Limestone Needed to Raise the pH of a 7-inch Layer of Soil

Lime Requirements (Tons per Acre)		
Soil Texture	From pH 4.5 to 5.5	From pH 5.5 to 6.5
Sand and loamy sand	0.5	0.6
Sandy loam	0.8	1.3
Loam	1.2	1.7
Silt loam	1.5	2.0
Clay loam	1.9	2.3
Muck	3.8	4.3

Table 2. Common Liming Materials

Name	Chemical Formula	Equivalent % CaCO ₃	Source
Shell meal	CaCO ₃	95	Natural shell deposits
Limestone	CaCO ₃	100	Pure form, finely ground
Hydrated lime	Ca(OH) ₂	120-135	Steam burned
Burned lime	CaO	150-175	Kiln burned
Dolomite	CaCO ₃ – MgCO ₃	110	Natural deposit
Sugar beet lime	CaCO ₃	80-90	Sugar beet by-product lime
Calcium silicate	CaSiO ₃	60-80	Slag

Lowering pH

Some soils are alkaline and have a pH above 6.5. Some fertilizers (ammonium sulfate, urea, and ammonium nitrate) create an acid reaction in the soil, so they aid in lowering or maintaining a specific pH. Certain acidifying organic materials such as pine needles or peat moss can lower soil pH gradually over many years. In nature this takes thousands of years. For more rapid results in lowering pH, sulfur is used. Sulfuric acid forms when sulfur is added to the soil, the smaller the particles of sulfur, the faster the reaction. Lowering the pH is a *slow* process and will take 1-2 years to see a reaction.

Table 3. Tons of sulfur needed per acre to lower pH to 6.5

Original pH	Sandy Soil	Clay Soil
8.5	0.7 - 1.0	1.0 - 1.3
8.0	0.5 - 0.7	0.7 - 1.1
7.5	0.2 - 0.3	0.4 - 0.5

Table 4. Commonly Used Materials and Their Equivalent Amendment Values

Material (100% Basis)*	Chemical Formula	Tons of Amendment Equivalent to	
		1 Ton of Pure Gypsum	1 Ton of Soil Sulfur
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	1.00	5.38
Soil sulfur	S	0.19	1.00
Sulfuric acid (conc.)	H_2SO_4	0.61	3.20
Ferric sulfate	$\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$	1.09	5.85
Lime sulfur (22% S)	CaS	0.68	3.65
Calcium chloride	$\text{CaCl}_2 \cdot \text{H}_2\text{O}$	0.86	--
Aluminum sulfate	$\text{Al}_2(\text{SO}_4)_3$	--	6.34

* The percent purity is given on the bag or identification tag

Common Amendment Reactions in Soil

- Gypsum (calcium sulfate) + sodic soil → calcium soil + sodium sulfate (leachable with water)
Sodium sulfate is then leached out of the soil by rainfall or heavy irrigations. The removal of sodium lowers the sodium permeability hazard allowing for soil aggregation and improved drainage.
Gypsum does not change pH nor improve drainage in non-sodic situations. Gypsum is used to add calcium to soils such as serpentine with very high or toxic Mg levels.
- Sulfur (elemental) + oxygen + water → sulfuric acid + soil calcium → gypsum
Gypsum then acts as above. Sulfur and sulfuric acid also lower pH
- Lime (calcium or magnesium carbonate) + water → calcium soil + OH
Lime neutralizes the (acidity) - H⁺ ion concentration and adds calcium to soil

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Soil pH is a measure of soil acidity or alkalinity. It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability, and soil micro-organism activity, influencing key soil processes. Soil pH can be managed by practices such as applying the proper amount of nitrogen fertilizer, liming, and using cropping systems that increase soil organic matter content and improve overall soil health.

Inherent Factors Affecting Soil pH

Inherent factors that affect soil pH include climate, mineral content, and soil texture.

Natural soil pH reflects the combined effects of the soil-forming factors (parent material, time, relief or topography, climate, and organisms). The pH of newly formed soils is determined by the minerals in the parent material.

Temperature and rainfall affect the intensity of leaching and the weathering of soil minerals. In warm, humid environments, soil pH decreases over time through acidification due to leaching from high amounts of rainfall. In dry environments where weathering and leaching

are less intense, soil pH may be neutral or alkaline.

Soils that have a high content of clay and organic matter are more resistant to changes in pH (higher buffering capacity) than are sandy soils. Although clay content cannot be altered, organic matter content can be altered by management practices. Sandy soils commonly have a low content of organic matter, resulting in a low buffering capacity and a high rate of water percolation and infiltration. Thus, they are susceptible to acidification.

Soil pH Management

Soil pH is affected by land use and management. The type of vegetation on a soil impacts pH levels. For example, areas of forestland tend to be more acidic than areas of grassland. Conversion of land from forestland or grassland to cropland can result in drastic changes in pH over time. These changes are a result of loss of organic matter, removal of soil minerals when crops are harvested, and erosion of the surface layer. Also, application of nitrogen and sulfur fertilizers can lower soil pH over time.

Measures that minimize or reduce acidification:

- Liming to raise the pH of an acid soil.
- Applying nitrogen and sulfur according to the needs of the crop grown.

- Applying nitrogen fertilizer in appropriate amounts and in a timely manner (relative to crop uptake) and using proper irrigation management to minimize leaching of nitrate nitrogen.
- Diversifying crop rotations to minimize acidifying effects of applied nitrogen fertilizer.
- Applying irrigation water and manure and other organic material that have a high content of calcium or magnesium bicarbonates.
- Using continuous no-till cropping systems, using cover crops, applying solid manure, and using diverse rotations that include high-residue crops, which increase organic matter content and improve soil buffering capacity, minimizing changes in pH.

Table 1.—Crop Yields Relative to pH.

Crop	Soil pH				
	4.7	5	5.7	6.8	7.5
	Relative yield (100 is best; 0 is worst)				
Corn	34	73	83	100	85
Wheat	68	78	89	100	99
Soybeans	65	79	80	100	93
Oats	77	93	99	98	100
Barley	0	23	80	95	100
Alfalfa	2	9	42	100	100
Timothy (grass)	31	47	66	100	95

Methods for Assessing Soil Quality, page 173 (SSSA, 1996).

Problems Related to pH and Relationship of pH to Soil Function

Soil pH is an excellent indicator of the suitability of a soil for plant growth. For most crops, pH of 6 to 7.5 is optimal (table 1).

Soil pH levels that are too high or too low (fig. 1) lead to a deficiency of many nutrients, decline in microbial activity, decrease in crop yields, and deterioration of soil health. For example, soil pH values below 5.5 and between 7.5 and 8.5 limit the availability of phosphate for plants (figures 2 and 3).

Four major management practices that increase the availability of phosphate for plants are:

1. Liming acid soils to increase pH to between 6.5 and 7.0.
2. Applying small amounts of phosphorus fertilizer frequently rather than a large amount at one time.

3. Banding or injecting the source of the phosphorus (manure and/or fertilizer) into the soil to reduce the contact between the soil and the phosphorus.
4. Applying phosphorus fertilizer near crop rows, where roots are most active.

Nitrogen cycling is inhibited by low pH. The effectiveness and degradation of herbicides and insecticides and the solubility of heavy metals are dependent on the soil pH. Some diseases thrive in alkaline or acidic soils. The effectiveness and potential carryover of certain herbicides is also impacted by soil pH.

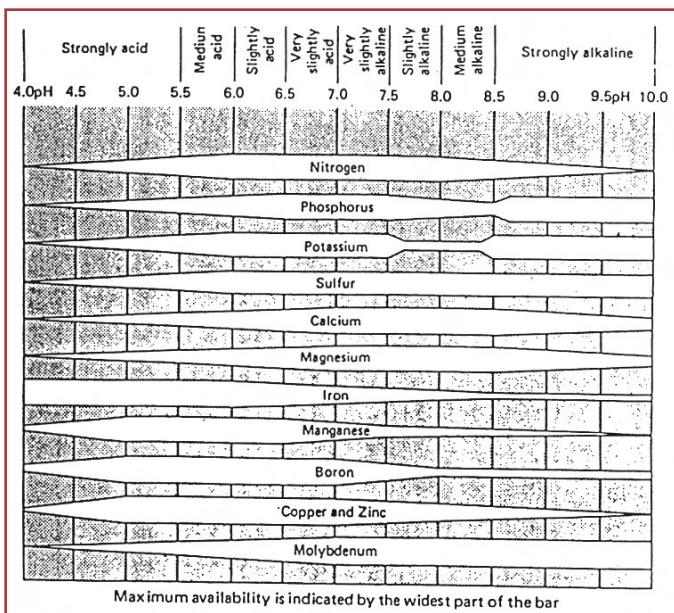


Figure 1.—Relationship between the availability of plant nutrients and soil pH (National Soil Survey Manual, USDA, NRCS).

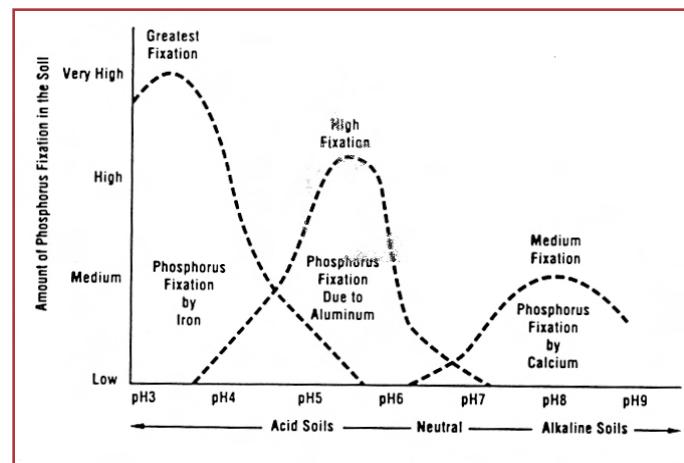


Figure 2.—Availability of phosphorus relative to pH (California Fertilizer Association, 1995).



Figure 3.—Corn that is deficient in phosphorus (R.L. Croissant, Bugwood.org).

What current practices affect soil pH?

What impact are these practices expected to have on soil pH and why?

Measuring Soil pH

Materials needed to measure pH:

- ____ Probe and plastic container for gathering and mixing soil samples
- ____ Roll of pH test strips
- ____ 1/8-cup (29.5 mL) measuring scoop
- ____ Calibrated 120-mL vial with lid for shaking
- ____ Squirt bottle
- ____ Distilled water or rainwater
- ____ Pen, field notebook, permanent marker, and resealable plastic bags

3. Place a scoop of the mixed soil in palm, and saturate with “clean” water (distilled water or rainwater).
4. Squeeze hand gently until a soil and water slurry forms.
5. Touch tip of piece of pH test strip 1 inch long to the soil and water slurry. Leave until the liquid is drawn up at least 1/4 to 1/2 inch beyond the area covered by the soil (fig. 4).
6. Compare the color approximately one-third up the strip to the color chart on the test strip dispenser (fig. 5). Record soil pH and interpretations (table 2).

Considerations:

Electrical conductivity should always be measured on a sample before measuring pH. Soil pH levels can be measured using the steps in the following paragraphs.

Quick in-field hand test:

1. Soil pH levels vary depending on the location of the field and the time of year. They are affected by the placement of fertilizer (in rows or between rows), soil texture, organic matter content, and application of manure or other fertilizer. Using a soil probe, gather at least 10 small samples to a depth of 8 inches or less randomly from an area that represents a particular soil type and management history. Place samples in the plastic container. Do not include large stones and plant residue. Repeat this step for each sampling area.
2. Neutralize hands by rubbing moist soil across palms. Discard soil.



Figure 4.—Quick hand test.

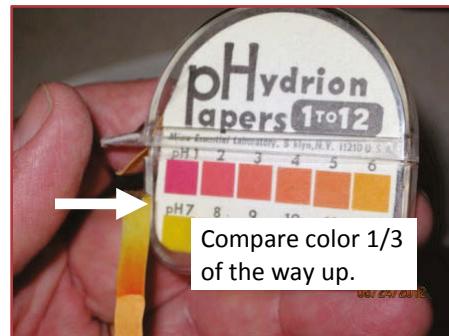


Figure 5.—Soil pH color chart.

1:1 soil to water pH test in classroom:

1. Soil sampling should be completed as instructed in step 1 under “Quick in-field hand test.”
2. Fill scoop (29.5 mL) with the mixed soil, tamping down during filling by carefully striking scoop on a hard, level surface. Place soil in vial. Add one scoopful (29.5 mL) of water to the vial, resulting in a 1:1 ratio of soil to water, on a volume basis.
3. Tightly cap the vial and shake 25 times. Let settle for 1 minute. Remove lid, and carefully decant 1/16 inch of soil and water slurry into lid. Allow to settle for 2 to 3 minutes.
4. Immerse tip of piece of pH test strip 1 inch long into soil and water slurry. Leave until

liquid is drawn up at least 1/4 to 1/2 inch beyond area covered by soil (fig. 6).

5. Compare the color approximately one-third up the strip to the color chart on the test strip dispenser (fig. 5). Record soil pH and interpretations (table 2).



Figure 6.—1:1 soil to water test.

Interpretations

Record soil pH, and complete table 2 by comparing measured soil pH to that given in figure 1, figure 2, and table 1. Answer discussion questions.

In general, pH values between 6 and 7.5 are optimum for crop and forage production and

nutrient uptake. Soil pH impacts nutrient availability and overall soil health. Soil acidification can be an indication of excessive application of nitrogen fertilizer.

Table 2.—Soil pH and Interpretations

Site	Soil pH	Soil pH category (from figure 1)	Nutrients impacted by soil pH (from figures 1 and 2)	Crops impacted by soil pH level (from table 1)	Notes
Ex. 1	5.8	Medium acid	Phosphorus, potassium, calcium, molybdenum	All but oats	Spring test on corn stubble

Compare test results recorded in table 2 to values in figure 1, figure 2, and table 1. Are soil pH levels ideal for crops or forage grown? Why or why not?

Based on results of soil pH test, is liming or other measures to adjust pH recommended? Why or why not?

Glossary

Acidity.—Soil pH lower than 7.

Alkalinity.—Soil pH higher than 7.

Anion.—Negatively charged ion.

Buffering capacity.—Ability of soils to resist changes in pH levels. Soils that have a high content of clay and organic matter have a higher buffering capacity.

Cation.—Positively charged ion.

Nitrification.—Oxidation of ammonium-nitrogen compounds in organic material or fertilizer into nitrites and nitrates by soil bacteria, making nitrogen available to plants.

Phosphorus fixation.—Tying up of phosphorus by calcium, iron, or aluminum compounds, making it unavailable for plant use. Fixation is impacted by soil pH.

Soil pH.—Measure of soil acidity or alkalinity.

Soil Quality Information Sheet

Soil Quality Indicators: pH

USDA Natural Resources Conservation Service

January 1998

What is pH?

Soil pH is a measure of the acidity or alkalinity in the soil. It is also called soil reaction.

The most common classes of soil pH are:

Extremely acid	3.5 – 4.4
Very strongly acid	4.5 – 5.0
Strongly acid	5.1 – 5.5
Moderately acid	5.6 – 6.0
Slightly acid	6.1 – 6.5
Neutral	6.6 – 7.3
Slightly alkaline	7.4 – 7.8
Moderately alkaline	7.9 – 8.4
Strongly alkaline	8.5 – 9.0



What is the significance of pH?

Availability of Nutrients

Soil pH influences the solubility of nutrients. It also affects the activity of micro-organisms responsible for breaking down organic matter and most chemical transformations in the soil. Soil pH thus affects the availability of several plant nutrients.

A pH range of 6 to 7 is generally most favorable for plant growth because most plant nutrients are readily available

in this range. However, some plants have soil pH requirements above or below this range.

Soils that have a pH below 5.5 generally have a low availability of calcium, magnesium, and phosphorus. At these low pH's, the solubility of aluminum, iron, and boron is high; and low for molybdenum.

At pH 7.8 or more, calcium and magnesium are abundant. Molybdenum is also available if it is present in the soil minerals. High pH soils may have an inadequate availability of iron, manganese, copper, zinc, and especially of phosphorus and boron.

Micro-organisms

Soil pH affects many micro-organisms. The type and population densities change with pH. A pH of 6.6 to 7.3 is favorable for microbial activities that contribute to the availability of nitrogen, sulfur, and phosphorus in soils.

Pesticide Interaction

Most pesticides are labeled for specific soil conditions. If soils have a pH outside the allowed range, the pesticides may become ineffective, changed to an undesirable form, or may not degrade as expected, which results in problems for the next crop period.

Mobility of heavy metals

Many heavy metals become more water soluble under acid conditions and can move downward with water through the soil, and in some cases move to aquifers, surface streams, or lakes.

Corrosivity

Soil pH is one of several properties used as a general indicator of soil corrosivity. Generally, soils that are either highly alkaline or highly acid are likely to be corrosive to steel. Soils that have pH of 5.5 or lower are likely to be highly corrosive to concrete.

What controls soil pH?

The acidity or alkalinity in soils have several different sources. In natural systems, the pH is affected by the mineralogy, climate, and weathering. Management of soils

often alters the natural pH because of acid-forming nitrogen fertilizers, or removal of bases (potassium, calcium, and magnesium). Soils that have sulfur-forming minerals can produce very acid soil conditions when they are exposed to air. These conditions often occur in tidal flats or near recent mining activity where the soil is drained.

The pH of a soil should always be tested before making management decisions that depend on the soil pH.

How is pH measured?

A variety of kits and devices are available to determine the pH in the field. The methods include:

- dyes
- paper strips
- glass electrodes.

Soil pH can change during the year. It depends on temperature and moisture conditions, and can vary to as much as a whole pH unit during the growing season. Since pH is a measure of the hydrogen ion activity [H⁺], many different chemical reactions can affect it. Temperature changes the chemical activity, so most measurements of pH include a temperature correction to a standard temperature of 25 degrees C (77°F). The soil pH generally is recorded as a range in values for the soil depth selected.



(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

How is soil pH modified?

A soil pH below about 5.6 is considered low for most crops. Generally, the ideal pH range is between 6.0 and 7.0. Liming is a common method to increase the pH. It involves adding finely ground limestone to the soil. The reaction rate for limestone increases when soil temperatures are warm and soil moisture is high. If the limestone is more finely ground, the reaction is faster.

The amount of limestone to apply depends on the amount of organic matter and clay as well as the pH. Fertility testing laboratories that have local experience make this determination.

A soil pH that is more than about 8.0 is considered high for most crops. Soils that have a pH in this range are often also calcareous.

Calcareous soils have a high content of calcium carbonate. The pH of these soils does not change until most of the calcium carbonate is removed. Acids that are added to the soil dissolve the carbonates and lower the soil pH. Treatments with acid generally are uneconomical for soils that have a content of calcium carbonate of more than about 5%. Because phosphorus, iron, copper, and zinc are less available to plants in calcareous soils, nutrient deficiencies are often apparent. Applications of these nutrients are commonly more efficient than trying to lower the pH.

When the soil pH is above 8.6, sodium often is present. These soils generally do not have gypsum or calcium carbonates, at least not in the affected soil horizons. Addition of gypsum followed by leaching using irrigation is a common reclamation practice. However, salts flushed into drainage water may contaminate downstream waters and soils.

The application of anhydrous ammonia as a nitrogen fertilizer contributes to lowering the soil pH. In some parts of the country, applications of ammonia lower the surface soil pH from ranges of 6.6 to 7.3 to below 5.6. This reduction can be easily overlooked in areas of no-till cropping unless the pH is measured in the upper 2 inches.

Chemical amendments that contain sulfur generally form an acid, which lowers the soil pH.

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Soil Quality Indicators

Soil pH

Soil pH generally refers to the degree of soil acidity or alkalinity. Chemically, it is defined as the \log_{10} hydrogen ions (H^+) in the soil solution. The pH scale ranges from 0 to 14; a pH of 7 is considered neutral. If pH values are greater than 7, the solution is considered basic or alkaline; if they are below 7, the solution is acidic. It is important to recognize that because the pH scale is in logarithmic units, a change of just a few pH units can induce significant changes in the chemical environment and sensitive biological processes. For example, a soil with pH 5 is 10 or 100 times more acidic than a soil with pH 6 or 7, respectively. Sources of H^+ ions in soil solution include carbonic acid produced when carbon dioxide (CO_2) from decomposing organic matter, root respiration, and the soil atmosphere is dissolved in the soil water. Other sources of H^+ ions are root release, reaction of aluminum ions (Al^{+3}) with water, nitrification of ammonium from fertilizers and organic matter mineralization, reaction of sulfur compounds, rainwater, and acid rain. Certain soils are more resistant to a drop or rise in pH (buffering capacity). Therefore, the lime requirement, which is the quantity of limestone ($CaCO_3$) required to raise the pH of an acid soil to a desired pH, must be determined specifically for each field before amending the soil.

Factors Affecting

Inherent - The natural soil pH reflects the combined effects of the soil-forming factors. Weathering and associated chemical reactions release cations (Ca^{+2} , Mg^{+2} , K^{+1} , Na^{+1}) that remain freely in soil solution, form complexes with dissolved organic carbon compounds, or are adsorbed at the surface of clay minerals and humus. Over time, the leaching of free cations, basic oxides, and carbonates, as well as the removal of cations by plant uptake and harvesting, and the continuous formation of carbonic acid result in soil acidification. When cations are lost, H^+ ions replace them in the soil solution and on the surface of clay minerals and humus. In very acid soils (where pH is less than 5), aluminum becomes soluble and its ions (Al^{+3}) tend to react with water to produce H^+ ions, which further exacerbate acidification. In arid climates, soil weathering and leaching are less intense, cations accumulate, and OH^- ions offset H^+ ions. As a result, the



Phosphorus deficiency in corn. Source: R.L. Croissant, Bugwood.org

soil becomes neutral or alkaline. Soils with coarse textures may acidify easily compared to clay soils, because they have low organic matter content, a low buffering capacity, a low cation-exchange capacity (poor cation retention), and high rates of water percolation and infiltration. Clay and organic matter in mineral soils act as buffers to resist pH variations. Soil parent material influences soil properties including pH as shown by the contrasting pHs of soil formed in calcareous and granitic materials. The effect of vegetation on soil pH is due partly to the type of humus produced as certain types of humus are soil acidifying. Water erosion removes surface horizons, which can be rich in organic matter, creating a pH gradient along the slope.

Dynamic - The conversion of uncultivated land into cultivated soils can result in drastic pH changes after a few years. These changes are caused by the removal of cations by crops, the acceleration of leaching, the effect of fertilizers and amendments, and the variations in organic matter content and soil buffering capacity. Inorganic amendments (lime and gypsum) and organic amendments rich in cations increase soil pH. Ammonium from organic matter mineralization (nitrification), ammonium-based fertilizers, and sulfur compounds lower the pH. High rates of water percolation and infiltration increases leaching of cations and accelerate soil acidification.

Relationship to Soil Function

Soil pH affects the soil's physical, chemical, and biological properties and processes, as well as plant growth. The nutrition, growth, and yields of most crops decrease where pH is low and increase as pH rises to an optimum level

(see table 1). Many crops grow best if pH is close to neutral (pH 6 to 7.5) although a few crops prefer acid or alkaline soils. In acid soils, calcium and magnesium, nitrate-nitrogen, phosphorus, boron, and molybdenum are deficient, whereas aluminum and manganese are abundant, sometimes at levels toxic to some plants. Phosphorus, iron, copper, zinc, and boron are frequently deficient in very alkaline soils. Bacterial populations and activity decline at low pH levels, whereas fungi adapt to a large range of pH (acidic and alkaline). Most microorganisms have an optimum pH range for survival and function (see table 2). At very acid or alkaline pH levels, organic matter mineralization is slowed down or stopped because of poor microbial activity linked to bacteria. Nitrification and nitrogen fixation are also inhibited by low pH. The mobility and degradation of herbicides and insecticides, and the solubility of heavy metals are pH dependent. The effects of soil pH on cation availability influence aggregate stability since multivalent cations, such as calcium ions, act as bridges between organic colloids and clays. Some diseases thrive when the soil is alkaline or acidic. Take-all, which is caused by the fungus *Gaeumannomyces graminis*, is favored by alkaline pH and infects wheat, barley, rye, and several grasses.

Problems with Poor Soil pH Levels

Deficiencies of many nutrients, decline of microbial activity and crop yield, and deterioration of environmental conditions are associated with pH levels as discussed in the previous section.

Improving Soil pH

Liming, addition of organic residues rich in basic cations, and crop rotation to interrupt the acidifying effect of leguminous crops increase soil pH. Applying ammonium based fertilizers, urea, sulfur/ferrous sulfate, irrigating with acidifying fertilizers, or using acidifying residues (acid moss, pine needles, sawdust) decrease soil pH. Increasing organic matter increases buffering capacity.

Measuring Soil pH

Soil pH is measured in the field using a portable pH pocket meter as described in the Soil Quality Test Kit Guide, section I, chapter 6, page 15. See also section II, chapter 5, pages 63 to 66 for interpretation of results.

Specialized equipment, shortcuts, tips:

Always calibrate the pH meter with the appropriate buffer solution before using it and report the soil to water ratio used to take the reading. Wait 10 to 15 minutes after measuring electrical conductivity to allow soil particles to settle.

Time needed: 10 minutes

References:

Brady CN and RR Weil. 2002. The Nature and Properties of Soils, 13th Edition. Prentice-Hall.

Karlen D, Andrews S, Wienhold B, and Zobeck T. 2008. Soil quality assessment: Past, present and future. Journal of Integrated Biosciences 6(1):3-14.

Smith JL and JW Doran. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. In Methods for assessing soil quality. Soil Science Society of America Special Publication 49: 169-182.

Table 1. Relative yield of selected crops grown in a corn, small grain, legumes or timothy rotation at different pH levels.
(adapted from Smith and Doran 1996)

Crop	pH				
	4.7	5	5.7	6.8	7.5
Relative Average Yield					
Corn	34	73	83	100	85
Wheat	68	78	89	100	99
Oats	77	93	99	98	100
Barley	0	23	80	95	100
Alfalfa	2	9	42	100	100
Soybean	65	79	80	100	93
Timothy	31	47	66	100	95

Table 2: Maximum, minimum, and optimum pH values for microbial groups. (adapted from Smith and Doran 1996)

Microorganisms	Range	Optimum
Bacteria	5 - 9	7
Actinomycetes	6.5 - 9.5	8
Fungi	2 - 7	5
Blue green bacteria	6 - 9	> 7
Protozoa	5 - 8	> 7

Calcium and Magnesium

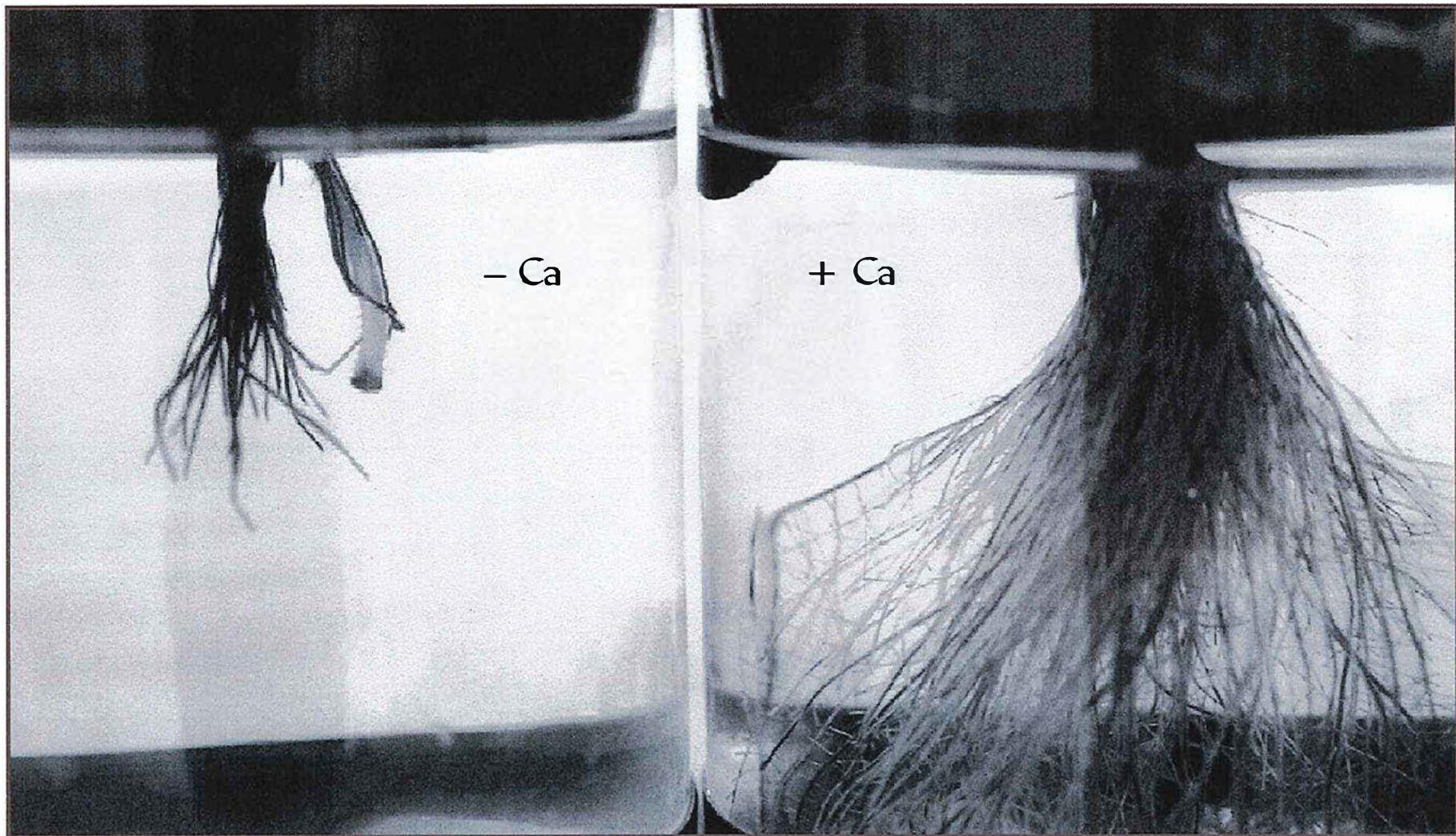
- Calcium and Magnesium are macronutrients required by all plants
- Ability of soil to supply these nutrients tied to soil alkalinity, acidity (and liming)

Calcium and Magnesium

□ Calcium

- Usually in plentiful supply except at lower pH (~5.5 and lower) when Al plentiful
 - Sources are calcium containing minerals (calcite), calcium in complex with humus, calcium on cation exchange complex
- Deficiencies are uncommon but can make Mg, Mn, and Zn toxic to plants
 - Toxicity results in stunted and gelatinous roots

Effect of Calcium Deficiency on Root Growth



Calcium and Magnesium

□ Magnesium

- Magnesium important in photosynthesis
- Magnesium deficiency more common than Calcium
 - Deficiency appears as chlorosis on leaves
- Sources of Mg include:
 - Exchangeable Mg on clay-humus complex (colloid)
 - Mg containing minerals
 - Plant residue and organic matter

Salt-Affected Soils

- Salt-affected soils found throughout world, typically in areas with little rainfall
- Soluble salts originate from weathering of minerals in rocks
 - Dissolved salts carried by water from high to lower elevations, wetter to drier zones
 - Water eventually evaporates leaving salt accumulations behind

Salt-Affected Soils

- Salt concentration in soils can be increased by human activity
 - Changing perennial vegetation for annual row crops can upset water balance
 - ▣ More water percolating through strata can pick up more salt and carry it to low lying areas
 - Irrigation water will have dissolved salts present

Classes of Salt-Affected Soils

- Saline soils
 - Electrical conductivity >4 deci-Siemens/m (dS/m)
 - pH values of 8.5 or less
 - Exchangeable sodium % 15 or less
 - Exchange complex dominated by calcium and magnesium
 - Plant growth is not limited by poor infiltration, aggregate stability, or aeration

Classes of Salt-Affected Soils

- Saline-sodic soils
 - Detrimental levels of neutral soluble salts and a high proportion of sodium ions
 - Exchangeable sodium is 15% or more
 - Electrical conductivity $>4 \text{ dS/m}$
 - Plant growth may be limited by salinity and sodium levels
 - Can become sodic if soluble salts are leached from soil

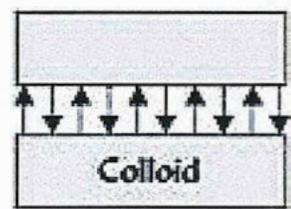
Classes of Salt-Affected Soils

- Sodic soils

- Electrical conductivity less than 4 dS/m and ESP >15%
 - pH is greater than 8.5
 - High solubility of sodium carbonate maintains high concentrations of CO_3^{2-} and HCO_3^- in soil solution
 - Soil colloids repel each other leaving a dispersed surface and poor physical condition
 - Plant growth highly limited or restricted

Effect of Ion Type on Dispersion and Flocculation

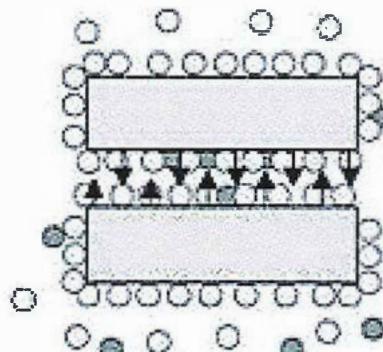
If there were no intervening hydrated ions, then short range by van der Waals forces ($\downarrow\uparrow$) would cause colloids to cohere.



Without
hydrated ions

(a)

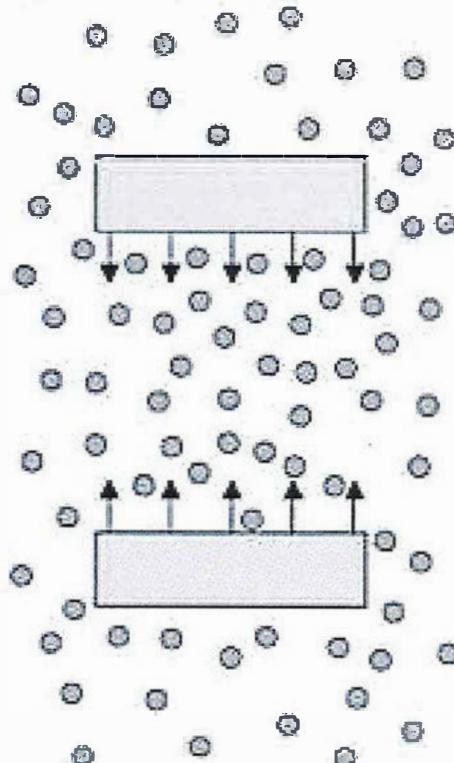
With tightly bound hydrated ions, colloids are still close enough to cohere by van der Waals forces.



Hydrated Ca
and Mg ions

(b)

With loosely bound hydrated ions, colloids are too far apart to cohere by van der Waals forces.



Hydrated
Na ions

(c)

soil Electrical Conductivity

Soil Health – Guides for Educators



Soil electrical conductivity (EC) is a measure of the amount of salts in soil (salinity of soil). It is an excellent indicator of nutrient availability and loss, soil texture, and available water capacity. It affects crop yields, the suitability of the soil for certain crops, the amount of water and nutrients available for plant use, and the activity of soil micro-organisms, which influences key soil processes such as the emission of greenhouse gases, including nitrogen oxides, methane, and carbon dioxide. Excessive salts hinder plant growth by affecting the soil and water balance. Soils containing excessive salts occur naturally in arid and semiarid climates. Salt levels can increase as a result of cropping, irrigation, and land management. Although EC does not provide a direct measurement of specific ions or salt compounds, it has been correlated to concentrations of nitrates, potassium, sodium, chloride, sulfate, and ammonia. For certain nonsaline soils, determining EC can be an easy, economical way to estimate the amount of nitrogen (N) available for plant use. Soil EC can also be an effective way to determine the texture of the surface layer because smaller clay particles conduct more electrical current than larger silt and sand particles.

Inherent Factors Affecting Soil EC

Inherent factors affecting EC include soil minerals, climate, and soil texture. Other factors include bulk density, soil structure, water potential, timing of measurement, soil aggregation, and electrolytes in soil water. Salts originate from the disintegration (weathering) of minerals and rocks. In areas that receive a high amount of rainfall, soluble salts are flushed below the root zone and eventually into deep groundwater systems or into streams that transport the salts to the ocean. Nonsaline soils that have a higher EC value have more available nutrients than those that have a lower EC value.

In arid areas, areas that receive less rainfall, and areas where saline irrigation water is applied, soluble salts are more likely to accumulate and remain near the soil surface, resulting in high EC. Salt-affected soils are mainly in the western part of the United States, in arid or semiarid areas where the annual rainfall is low.

Low areas, depressions, or other areas where water accumulates tend to have higher EC than surrounding higher lying, better drained areas. Water that infiltrates into soils can interact with the underlying bedrock and other material that weathers, releasing salts and creating saline seeps on side slopes. This occurs at the loess-till interface in areas where loess soils are underlain by glacial till.

Soils that have a higher content of smaller soil particles (higher content of clay) conduct more electrical current than do soils that have a higher content of larger silt and sand particles (lower content of clay). Soils that consist dominantly of clay minerals that have a high cation-exchange capacity (CEC), such as smectite, can have higher EC than soils that consist dominantly of clay minerals that have a low CEC, such as kaolinite. Soils that have a restrictive layer, such as a claypan, typically

have higher EC. The salts accumulate on the soil surface because the restrictive layer limits

water flow; thus, they cannot be leached from the root zone.

Salinity Management

Soil EC is affected by cropping, irrigating, land use, and application of fertilizer, manure, and compost. When managing for salinity on irrigated land, the salt content of the irrigation water must be determined. Applying irrigation water in amounts too low to leach salts or applying water that is high in content of salts results in an accumulation of salts in the root zone, increasing EC.

Existing salinity levels and the amount of salts in manure and municipal waste need to be closely monitored, especially in arid climates. Nitrogen fertilizer can also increase salinity, especially in areas where it is already a potential concern.

Management that leads to low organic matter content, poor infiltration, poor drainage, saturated soil conditions, or compaction can

increase salinity and decrease the ability of the soil to support some plants.

When irrigating, applying more water than is needed for crops can help to leach excess salts below the root zone and maintain the desired EC level for the crop grown. Care is needed when applying excess irrigation water because the soil can become waterlogged, allowing salts to accumulate. Leaving crop residue on the surface limits evaporation and helps to retain soil moisture, allowing rainfall and irrigation water to be more effective in leaching salts. In some areas, both irrigation and drainage are needed to reduce salinity. Proper soil management to maintain the organic matter content and overall soil health is needed to keep EC at the desired level.

Problems Related to EC and Relationship of EC to Soil Function

Areas of saline soils need to be managed differently than areas of nonsaline soils (e.g., different crops and irrigation practices). Soil micro-organism activity declines as EC increases above the desired level. This impacts important soil processes such as respiration, residue decomposition, nitrification, and denitrification (table 1).

A high concentration of sodium salts (sodic conditions) in soils can result in poor soil structure, poor infiltration or drainage, and toxicity for many crops. Each crop has a particular salt tolerance. Table 3 shows the percent reduction in yields based on the soil EC level.

Soils that have $EC_{1:1}$ of less than 1 deciSiemen per meter (dS/m) are

considered to be nonsaline (table 2). Salinity in these soils does not affect most crops and soil microbial processes (tables 1 and 3). Soils that have $EC_{1:1}$ of more than 1 dS/m are considered to be saline. Important microbial processes, such as nitrogen cycling, production of nitrous gases and other N oxide gases, respiration, and decomposition of organic matter are affected. Populations of parasitic nematodes and loss of nitrogen can be higher in these soils.

Even slight to moderate salinity can impede crop growth, as shown in figure 1. In nonsaline soils, EC levels can be an indirect indicator of the amount of water-soluble nutrients, such as nitrate nitrogen, available for plant use.

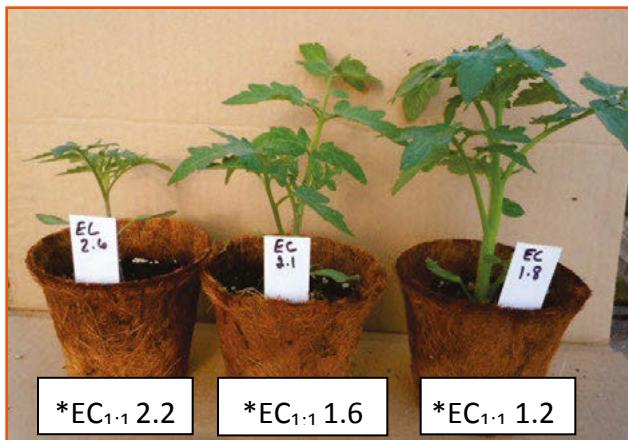


Figure 1.—EC_{1:1} values for tomatoes, using three types of compost with different EC values and tap water (Gage, 2012).

*EC_{1:1} value using compost and distilled water that has no EC value (0 dS/m). The EC_{1:1} value was adjusted using the formula: EC_{1:1} value of compost with tap water – (EC of tap water ÷ EC_{1:1} of compost with tap water). For example, the EC value of the smallest tomato plant with tap water is 2.6; therefore, $2.6 - (1 \div 2.6) = 2.6 - (0.385)$, or 2.22 dS/m with distilled water.

Table 1.—Soil EC influence on microbial processes and gaseous N production in soils amended with sodium chloride (NaCl) or nitrogen fertilizer (adapted from Smith and Doran, 1996 (tables 10-5 & 10-6) and Adviento-Borbe and others, 2006).

Process	EC _{1:1} range (dS/m)	Relative decrease/increase (percent)	EC _{1:1} threshold
Respiration	0.7 to 2.8	-17 to -47	0.7
Decomposition	0.7 to 2.9	-2 to -25	0.7
Nitrification	0.7 to 2.9	-10 to -37	0.7
Denitrification	1.0 to 1.8	+32 to +88	1.0
Anaerobic N ₂ O gas production (high nitrate)*	0.02 to 2.8	+1500 to +31,500	1.0-1.5
*Anaerobic N ₂ O gas production (low nitrate)	0.5 to 2.0	+ 200 to + 90,000	0.7-1.0

*Soils that have an EC value of more than 1 dS/m and a relatively high nitrate level will have increased production of nitrous oxide (N₂O) gas by denitrification under anaerobic conditions (90 percent or more water-filled pore space) by more than 15 to 315 times. Nitrous oxide is nearly 300 times more potent than carbon dioxide (CO₂) as a greenhouse gas that depletes ozone in the upper atmosphere.

Table 2.—Salinity classes and relationship between EC_{1:1} and EC_e values (Smith and Doran, 1996, adapted from Dahnke and Whitney, 1988).

Texture	Degree of salinity (salinity classes)					
	Nonsaline	Slightly saline	Moderately saline	Strongly saline	Very strongly saline	Ratio of EC _{1:1} to EC _e
EC _{1:1} method (dS/m)						
Coarse sand to loamy sand	0-1.1	1.2-2.4	2.5-4.4	4.5-8.9	9.0+	0.56
Loamy fine sand to loam	0-1.2	1.3-2.4	2.5-4.7	4.8-9.4	9.5+	0.59
Silt loam to clay loam	0-1.3	1.4-2.5	2.6-5.0	5.1-10.0	10.1+	0.63
Silty clay loam to clay	0-1.4	1.5-2.8	2.9-5.7	5.8-11.4	11.5+	0.71
EC _e method (dS/m)						
All textures	0-2.0	2.1-4.0	4.1-8.0	8.1-16.0	16.1+	N/A

Table 3.—Salt tolerance and decrease in yields beyond EC threshold (Smith and Doran, 1996; EC_{1:1} based on Hoffman and Maas, 1977).

Crops	EC _e threshold (dS/m)	EC _{1:1} threshold (dS/m)	Percent decrease in yields per EC _{1:1} unit (dS/m) beyond threshold
Barley	8.0	4.5 to 5.7	5.0
Cotton	7.7	4.3 to 5.5	5.2
Sugar beets	7.0	3.9 to 5.0	5.9
Wheat	6.0	3.4 to 4.3	7.1
Perennial ryegrass	5.6	3.1 to 4.0	7.6
Soybeans	5.0	2.8 to 3.6	20.0
Tall fescue	3.9	2.2 to 2.8	5.3
Crested wheatgrass	3.5	2.0 to 2.5	4.0
Peanuts	3.2	1.8 to 2.3	29.0
Rice, common vetch	3.0	1.7 to 2.1	12.0
Tomatoes	2.5	1.4 to 1.8	9.9
Alfalfa	2.0	1.1 to 1.4	7.3
Corn, potatoes	1.7	1.0 to 1.2	12.0
Berseem clover, orchardgrass, grapes, peppers	1.5	0.8 to 1.1	5.7
Lettuce, cowpeas	1.3	0.7 to 0.9	13.0
Green beans	1.0	0.6 to 0.7	19.0

What current practices affect soil EC?

What impact do these practices have on soil EC? Why?

Measuring Soil EC (EC_{1:1} Method)

Materials needed to measure soil EC:

- _____ Soil probe and plastic container for gathering and mixing soil samples
- _____ 1/8-cup (29.5-mL) measuring scoop
- _____ Squirt bottle
- _____ Distilled water or rainwater
- _____ Calibrated 120-mL vial with lid
- _____ EC probe (blue with black cap)
- _____ Probe holder with field calibration resistor (470 ohm)
- _____ 1.41-dS/m calibration solution
- _____ Pen, field notebook, permanent marker, and resealable plastic bags



Figure 2.—EC probe inserted into resistor on holster to check calibration (Doran and Kucera, 2012).

2. Using a soil probe, gather at least 10 randomly selected samples from an area that represents a particular soil type, condition, and management history. The probe should extent to a depth of 8 inches or less. Place samples in the small plastic container and mix. Do not include large stones and plant residue. Repeat step 1 for each sampling area.
3. Fill one scoop (29.5 mL) with mixed soil, tamping down during filling by carefully striking scoop on a hard, level surface. Place soil in calibrated vial. Add one scoopful (29.5 mL) of distilled water. The vial will contain a 1:1 ratio of soil to water, on a volume basis.
4. Tightly cap vial and shake 25 times.
5. Remove EC probe cap, turn probe on, and insert probe into soil and water mixture in vial, keeping the tip of the probe in the center of the suspended soil particles. Take reading while soil particles are still suspended in solution. To keep soil particles from settling, stir gently with EC probe. Do not immerse probe below maximum immersion level.
6. Reading will stabilize in about 10 seconds. Record EC_{1:1} as dS/m.

Considerations:

Because soil EC is variable, multiple samples should be taken from multiple locations. Soil EC levels vary depending on past management, field location, and time of year. Examples of variables include placement of fertilizer in rows versus between rows, soil texture, organic matter content, and applications of manure or fertilizer. Scan sampling area for large bare spots, areas with short plants, areas with better plant growth, and areas with possible indications of salinity (salts may be visible at the soil surface). Each of these areas should be sampled separately.

*Step-by-step procedure:

1. Calibrate EC probe by immersing in a standard salt solution (1.41 dS/m) at 25 °C (77 °F) and turning the adjustment knob on the probe to 1.4 with a screwdriver. Second, insert EC probe (fig. 2) into calibration resistor on probe holder. Record reading. Future readings are taken at the same air temperature.

7. Save soil and water mixture to measure pH, nitrates, nitrites, and phosphorus, if applicable. Nitrate levels can be estimated for soils that are nonsaline and have a pH of less than 7.2 if nitrates make up most of the soluble salts in the EC reading. Use the equation— $140 \times EC_{1:1} \leq \text{soil nitrate nitrogen}$, expressed as ppm. For example, $140 \times 0.03 \text{ dS/m} \leq 4.2 \text{ ppm nitrate nitrogen}$.

8. Turn off probe, thoroughly rinse with water, and replace cap.

*Note that the EC test can be conducted in the field by inserting the EC probe into the soil to the desired depth and saturating the soil with distilled water. This simulates the EC1:1 test.

Interpretations

Record soil EC_{1:1} readings. Complete table 4 by comparing EC readings to values in tables 1, 2, and 3 to determine the relative

level of salinity and the microbial processes and crops that might be impacted by the salinity. Answer discussion questions.

Table 4.—Soil EC level (salinity) of upper part of soil and interpretations

Site	Soil EC _{1:1} (dS/m)	Texture	Degree of salinity	pH	Nitrate estimate (ppm)	Microbial processes impacted	Crops impacted	Notes
No till	0.3	Silt loam	Nonsaline	7.0	42	N/A	N/A	Nitrate level of 42 ppm is adequate for corn.
Conventional till	1.2	Silt loam	Slightly saline	7.8	N/A	Decrease in respiration, decomposition, and nitrification; increase in loss of nitrogen (N ₂ and N ₂ O) through denitrification	Alfalfa and vegetables	Reading taken after nitrogen fertilizer was applied.

Were results of soil EC test expected? Why or why not?

Compare soil EC results to values in tables 1, 2, and 3. Are EC levels ideal for crops or forage plants and for soil microbial processes? Why or why not?

Glossary and References

Glossary

Cation-exchange capacity (CEC).—Capacity of soil to hold cations (positively charged ions) on surface of negatively charged clay and soil organic matter and release them to the soil solution to be used by plants, to be leached, and/or to be used for biological processes. Soils that have a high content of clay or organic matter have a higher CEC than those that have a low content of organic matter or are sandy.

DeciSiemens per meter (dS/m).—Unit of measurement for soil electrical conductivity. Equivalent to millimhos per centimeter.

Denitrification.—Conversion and loss of nitrate nitrogen to the atmosphere as various forms of gas due to a lack of oxygen in soil when it is saturated with water.

EC_e method.—Saturated past method for measuring soil EC, which is the standard laboratory method (adjustment for soil texture not needed). See table 2 for the relationship between EC_{1:1} and EC_e values.

EC_{1:1} method.—Method for measuring soil EC using a 1:1 ratio of soil and water (adjustment

for soil texture needed). See table 2 for the relationship between EC_{1:1} and EC_e values.

Loess.—Soil consisting of eolian sediment, which is an accumulation of windblown silt. Loess typically is homogeneous and highly porous.

Nitrification.—Conversion of ammonium compounds in organic material and fertilizer into nitrites and nitrates by soil bacteria, making nitrogen available to plants.

Nitrogen oxides.—Nitrogen gases that can be generated by human activity and released into the atmosphere. Loss of nitrogen gases from soils increases 10 to 100 times by nitrification when the soils are dry and by denitrification when the soils are saturated. Loss of nitrogen oxide gases also increases when soil EC is more than 1 to 2 dS/m.

Respiration.—Release of carbon dioxide (CO₂) from soil as a result of biological activity (i.e., micro-organisms and roots) and decomposition of organic matter.

Saline/sodic soil.—Saline soils have a high content of soluble salts that negatively affect soil processes, productivity, and overall soil

health. As sodium (Na^+) becomes dominant, saline soils can become sodic. Sodic soils tend to have poor structure, which restricts water infiltration, soil aeration, and drainage.

Till.—Soils that formed in till or glacial till are made up of extremely heterogeneous sediment of glacial origin. These soils consist of clay to mixed clay, sand, gravel, and boulders. Till typically is less porous than loess, and water seeps can form on hillsides in areas where loess overlies till.

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Soil Quality Indicators

Soil Electrical Conductivity

Soil electrical conductivity (EC) measures the ability of soil water to carry electrical current. Electrical conductivity is an electrolytic process that takes place principally through water-filled pores. Cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+ , and NH_4^+) and anions (SO_4^{2-} , Cl^- , NO_3^- , and HCO_3^-) from salts dissolved in soil water carry electrical charges and conduct the electrical current. Consequently, the concentration of ions determines the EC of soils. In agriculture, EC has been used principally as a measure of soil salinity (table 1); however, in non-saline soils, EC can be an estimate of other soil properties, such as soil moisture and soil depth. EC is expressed in deciSiemens per meter (dS/m).

Factors Affecting

Inherent - Factors influencing the electrical conductivity of soils include the amount and type of soluble salts in solution, porosity, soil texture (especially clay content and mineralogy), soil moisture, and soil temperature. High levels of precipitation can flush soluble salts out of the soil and reduce EC. Conversely, in arid soils (with low levels of precipitation), soluble salts are more likely to accumulate in soil profiles resulting in high EC. Electrical conductivity decreases sharply when the temperature of soil water is below the freezing point (EC decreases about 2.2% per degree centigrade due to increased viscosity of water and decreased mobility of ions). In general, EC increases as clay content increases. Soils with clay dominated by high cation-exchange capacity (CEC) clay minerals (e.g., smectite) have higher EC than those with clay dominated by low CEC clay minerals (e.g., kaolinite). Arid soils with high content of soluble salt and exchangeable sodium generally exhibit extremely high EC. In soils where the water table is high and saline, water will rise by capillarity and increase salt concentration and EC in the soil surface layers.

It is generally accepted that the higher the porosity (the higher the soil moisture content), the greater the ability of soil to conduct electrical currents; that is, other properties being similar, the wetter the soil the higher the EC. Soil parent materials contribute to EC variability. Granites have lower EC than marine shales and clayey lacustrine deposits

have higher EC than sandy outwash or alluvial deposits. Saline (ECe \geq 4 dS/m) and sodic (sodium absorption ratio \geq 13) soils are characterized by high EC. Scientific literature reported a relationship between EC values measured with commercial sensors and depths to claypan, bedrock, and fragipan. Microtopographic depressions in agricultural fields typically are wetter and accumulate organic matter and nutrients and therefore have higher EC than surrounding higher lying, better drained areas.

Dynamic - Mineral soils enriched in organic matter, or with chemical fertilizers (e.g., NH_4OH) have higher CEC than non-enriched soils, because OM improves soil water holding capacity, and synthetic fertilizers augment salt content. Continuous application of municipal wastes on soil can increase soil EC in some cases. Electrical conductivity has been used to infer the relative concentration, extent, and movement of animal wastes in soils. Because of its sensitivity to soluble salts, EC is an effective measure for assessing the contamination of surface and ground water. Although EC does not provide a direct measurement of specific ions or compounds, it has been correlated with concentrations of potassium, sodium, chloride, sulfate, ammonia, and nitrate in soils. Poor water infiltration can lead to poor drainage, waterlogging, and increased EC.

Relationship to Soil Function

Soil EC does not directly affect plant growth but has been used as an indirect indicator of the amount of nutrients available for plant uptake and salinity levels. EC has been used as a surrogate measure of salt concentration, organic

Table 1. Classes of salinity and EC (1 dS/m = 1 mmhos/cm; adapted from NRCS Soil Survey Handbook)

EC (dS/m)	Salinity Class
$0 < 2$	Non-saline
$2 < 4$	Very slightly saline
$4 < 8$	Slightly saline
$8 < 16$	Moderately saline
≥ 16	Strongly saline

matter, cation-exchange capacity, soil texture, soil thickness, nutrients (e.g., nitrate), water-holding capacity, and drainage conditions. In site-specific management and high-intensity soil surveys, EC is used to partition units of management, differentiate soil types, and predict soil fertility and crop yields. For example, farmers can use EC maps to apply different management strategies (e.g., N fertilizers) to sections of a field that have different types of soil. In some management units, high EC has been associated with high levels of nitrate and other selected soil nutrients (P, K, Ca, Mg, Mn, Zn, and Cu). Most microorganisms are sensitive to salt (high EC). Actinomycetes and fungi are less sensitive than bacteria, except for halophyte (salt-tolerant) bacteria. Microbial processes, including respiration and nitrification, decline as EC increases (table 2).

Problems with Poor Soil EC Levels

High EC can serve as an indication of salinity ($EC > 4$ dS/m) problems, which impede crop growth (inability to absorb water even when present) and microbial activity (tables 2 and 3). Soils with high EC resulting from a high concentration of sodium generally have poor structure and drainage, and sodium becomes toxic to plants.

Improving Soil EC

Effective irrigation practices, which wash soluble salts out of soil and beyond the rooting depth, can decrease EC. Excessive irrigation and waterlogging should be avoided since a rising water table may bring soluble salts into the root zone. In arid climates, plant residue and mulch help soils to remain wetter and thus allow seasonal precipitation and irrigation to be more effective in leaching salts from the surface. To avoid the adverse effects of high EC (salinity) in irrigation water, the leaching requirement must be calculated for each crop. Leaching requirement is the fraction of water needed to flush excessive salt below the root zone, that is, the amount of additional water required to maintain a target salinity level. Adding organic matter,

such as manure and compost, increases EC by adding cations and anions and improving the water-holding capacity. In some cases, a combination of irrigation and drainage is necessary to lower salt concentration and EC. An EC water ($EC_w \leq 0.75$ dS/m) is considered good for irrigation water. Beyond this value, leaching or a combination of leaching and drainage will be necessary if the water is used.

Measuring Soil EC

The EC pocket meter is used to take measurements in the field. The method is described in the Soil Quality Test Kit Guide. Always calibrate the EC meter before use.

The pocket meter can be augmented by a probe that is placed directly into the soil to measure subsoil EC and NO_3^- and make other estimates. NRCS soil scientists and agronomists use electromagnetic induction meters, not pocket EC meters, to map spatial variability of EC and associated soil properties at field scales. Special sensors are used for EC mapping for precision agriculture.

Time needed: 10 minutes

References:

Corwin DL and SM Lesch. 2005. Apparent soil electrical conductivity measurements in agriculture. Computers and Electronics in Agriculture 46:11-43.

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Doolittle JA, KA Suddeth, NR Kitchen, and SJ Indorante. 1994. Estimating depths to claypans using electromagnetic induction methods.

Table 3. Salt tolerance of crops and yield decrease beyond EC threshold (adapted from Smith and Doran, 1996)

Crop species	Threshold EC 1:1 (dS/m)*	Percent yield decrease per unit EC beyond threshold EC
Alfalfa	1.1 - 1.4	7.3
Barley	4.5 - 5.7	5.0
Cotton	4.3 - 5.5	5.2
Peanut	1.4 - 1.8	29
Potato	1.0 - 1.2	12
Rice	1.7 - 2.1	12
Soybean	2.8 - 3.6	20
Tomato	1.4 - 1.8	9.9
Wheat	3.9 - 5.0	7.1

* Electrical conductivity of a 1:1 soil/water mixture relative to that of a saturated paste extract

Soil Quality Information Sheet

Soil Quality Resource Concerns: Salinization

USDA Natural Resources Conservation Service

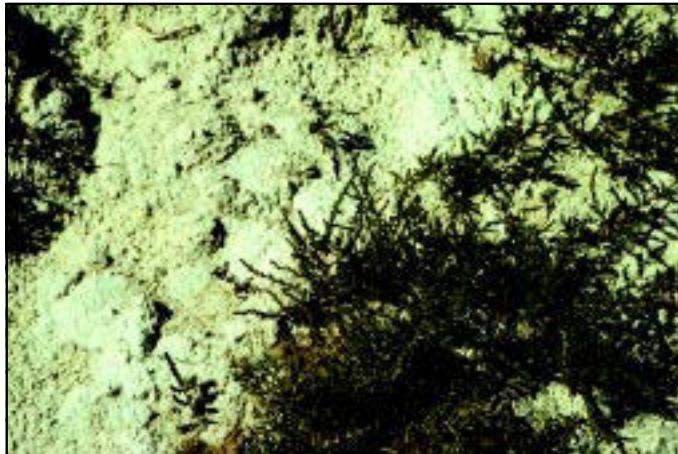
January 1998

What is salinization?

Salinization is the process by which water-soluble salts accumulate in the soil. Salinization is a resource concern because excess salts hinder the growth of crops by limiting their ability to take up water. Salinization may occur naturally or because of conditions resulting from management practices.

Any process that affects the soil-water balance may affect the movement and accumulation of salts in the soil. These processes include:

- hydrology
- climate
- irrigation
- drainage
- plant cover and rooting characteristics
- farming practices



What causes salinization?

Salinization on the soil surface occurs where the following conditions occur together:

- the presence of soluble salts, such as sulfates of sodium, calcium, and magnesium in the soil
- a high water table
- a high rate of evaporation
- low annual rainfall

In semiarid areas, salinization often occurs on the rims of depressions and edges of drainageways, at the base of hillslopes, and in flat, low-lying areas surrounding sloughs and shallow bodies of water. These areas receive additional water from below the surface, which evaporates, and the salts are left behind on the soil surface.

Summer fallow management practices may cause increased salinization by increasing the soil moisture content to the point that water moves to seeps on hillslopes. Salts accumulate as the water evaporates from these seeps.

What are some indicators of soil salinity?

Early signs:

- increased soil wetness in semiarid and arid areas to the point that the soil does not support equipment
- the growth of salt-tolerant weeds
- irregular patterns of crop growth and lack of plant vigor

Advanced signs:

- white crusting on the surface
- a broken ring pattern of salts adjacent to a body of water
- white spots and streaks in the soil, even where no surface crusting is visible
- the presence of naturally growing, salt-tolerant vegetation

Soil salinity can be estimated by measuring the electrical conductivity of the soil solution. Electrical conductivity increases in a solution in direct proportion to the total concentration of dissolved salts.

What are some effects of salinization?

Salts in the soil increase the efforts by plant roots to take in water. High levels of salt in the soil have a similar effect as droughtiness by making water less available for uptake by plant roots.

Few plants grow well on saline soils; therefore, salinization often restricts options for cropping in a given land area.

Salinization degrades the quality of shallow ground water and surface water resources, such as ponds, sloughs, and dugouts.



- Maintain the water table at a low, safe level. Do not over irrigate. In some areas, over irrigation and the lack of natural drainage has raised the water tables, which may require the use of an artificial drainage system. Discharge of salty waters from these drains may contribute to other offsite problems.
- Irrigate to maintain salts at a level below the root zone in the soil.
- Use cropping and tillage systems that promote adequate infiltration and permeability. This includes building organic matter for soil aggregation and avoiding compaction.
- Plant crops that use the available soil moisture. Shallow-rooted crops may not extract excess subsoil moisture that can lead to salinity.
- Remove excess water from recharge areas of seeps by using actively growing, deep-rooted plants. Perennial plants and forages, especially alfalfa, are useful for this purpose because they have a longer growing season and take up more water from a greater depth in the soil than annual plants. Forages may also increase organic matter in the soil and improve soil structure.
- Return manure and crop residue to the soil to increase soil-water retention.
- Reduce summer fallow by continuous cropping.
- Manage snow so that it is evenly distributed and does not pond on thawing.

Discharge management:

- Grow salt-tolerant crops.
- Convert to permanent soil cover with salt-tolerant crops in high risk areas.
- Reduce deep tillage, which may bring up salts from deeper soil horizons.
- Plant forage crops or trees next to bodies of water to increase water use.
- Install artificial drainage systems in severely affected areas only.
- Eliminate seepage from irrigation canals, dugouts, and ponds.

Generally, control measures should take an integrated approach involving cropping, structural methods, and tillage systems.

How can salinity problems be managed?

Reducing the severity and extent of soil salinity is primarily a problem of water management. Water management can be addressed in two ways: (1) by managing the area contributing excess water to the soil (recharge area) or (2) by managing the area where the excess water comes to the surface (discharge area).

Recharge management:

- Decrease excess water from infiltrating into the soil in recharge areas of seeps by diverting surface water to downslope ponds.

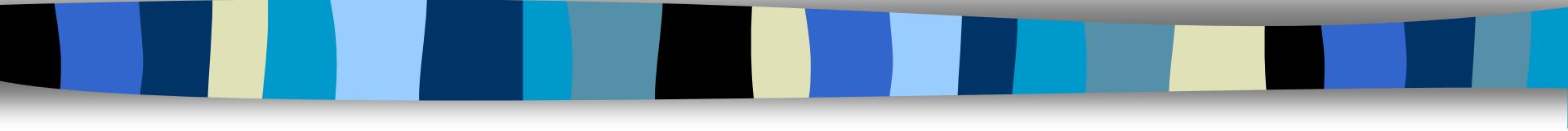
(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

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SALINITY AND SODICITY

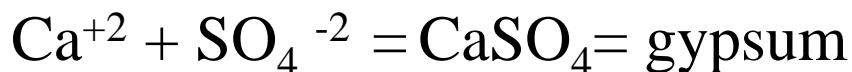


IN WESTERN SOILS

What are Salts?

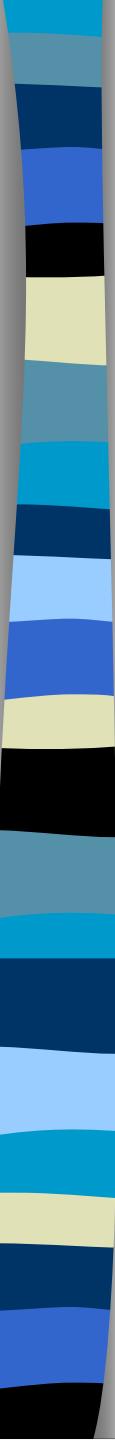
When acids and bases neutralize one another; that is, they react chemically, they lose their distinguishing characteristics, and produce compounds called salts.

Example: $Mg^{+2} + SO_4^{-2} = MgSO_4 \cdot 7H_2O$, is known as Epsom salt, and is used in medicine, in tanning leather, and in fireproofing compositions.



TYPES OF SALT

- TABLE SALT = SODIUM CHLORIDE NaCl
- ROAD DEICER = MAGNESIUM CHLORIDE MgCl_2
- DUST CONTROL= CALCIUM CHLORIDE = CaCl_2
- TUMS or LIME = CaCO_3
- GYPSUM = CaSO_4
- BAKING SODA = NaHCO_3
- AMMONIUM NITRATE = NH_4NO_3
- CALCIUM NITRATE = CaNO_3
- EPSOM SALT = MgSO_4
- NU-SALT SUBSTITUTE = KCl



WHERE DO SALTS COME FROM?

Salts come from the breakdown of rocks through a geochemical process in nature. Production of salt come from salt mines (surface and subsurface), salt wells and the sea.

Typical Saline Seep



Sodium salt is very soluble!

A maximum of 35.7 grams of Sodium Chloride (table salt) will form a solution with 100 ml of water.

A maximum of 0.24 grams of CaSO_4 (gypsum) will form a solution with 100 ml of water.

A maximum of .0081 grams of CaCO_3 (lime) will form a solution with 100 ml of water.

SALT CONDITIONS IN NATURE (2 MAJOR TYPES)

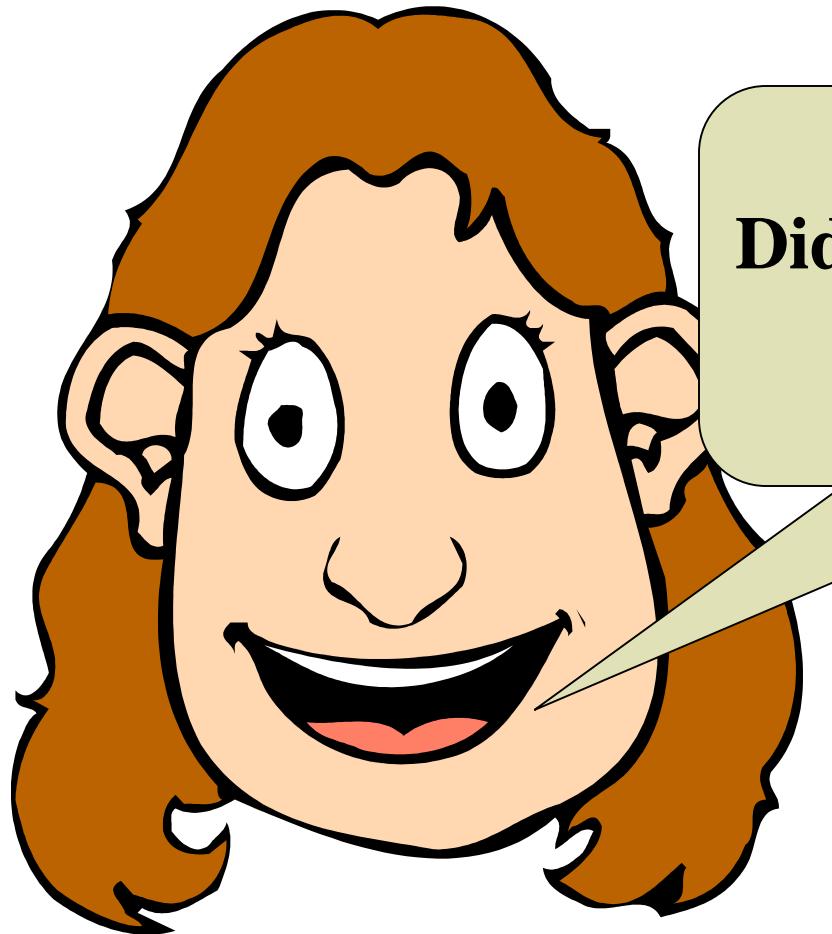
Salinity- Total concentrations of dissolved salts in soil or water. (Ca, Mg, K, Na, Cl, SO₃, HCO₃, NO₃,) *Measured by Electrical conductivity EC's dS/m*

Sodicity- Excess sodium (Na), lower amounts of Ca and Mg on the soil colloid. *Measured by calculating SAR or ESP, unitless*

SAR Is Calculated by:

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}}$$

units are in meq/l



**Did you know that salt is
a good conductor!**





What is the Difference between Salinity and Sodicity?

Salinity = total salts in irrigation water or soil and is measured by EC (dS/m)

Sodicity = excess sodium salts relative to Ca and Mg (or other salts) in irrigation water or soil colloids and is measured by SAR

Classes of Soil Salts

Class	EC	SAR	pH	Soil Structure
Saline	>4dS/m	<13 SAR	<8.5pH	Normal
Sodic	<4dS/m	>13 SAR	>8.5pH	Poor
Saline/ Sodic	>4dS/m	>13 SAR	< 8.5 pH	Normal

Very Important!!

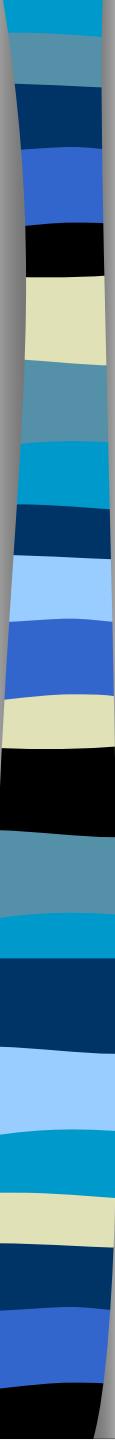
Watch your units in EC!

There are many units being used for example:

an EC of 1.6 mS/cm = 1.6 dS/m

or an EC of 1.6 dS/m = 1.6 mmhos/cm

or an EC of 1.6 dS/m = 1600 microS/m



What is Soil EC ?

- Soil Electrical Conductivity (EC) is the electrolytic conductivity of an extract from saturated soil paste. Electrical conductivity is a measure of the concentration of water-soluble salts in soils. It is used to indicate saline soils.

Why does sodium raise the pH?

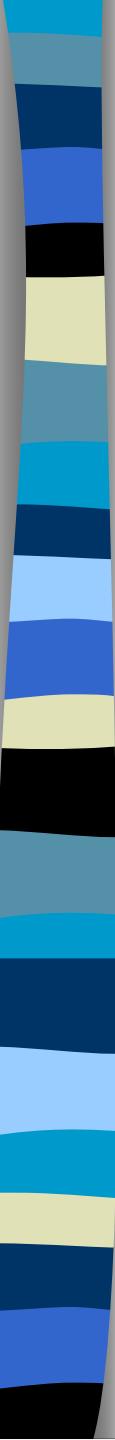
The pH of most western soils is controlled by CaCO_3 . As sodium enters the soil which is more soluble than Ca, the sodium reacts with the CO_3 to form Na_2CO_3 and by adding water gives off Na_2HCO_3 . This gives off the OH anion in soil solution which raises pH.

Ex. pH 9 has >(OH- Anions) vs (H+cations) in soil solution

pH 5 has >(H+cations) vs (OH-anions) in soil solution

Remember pH is the negative log of the H ion.

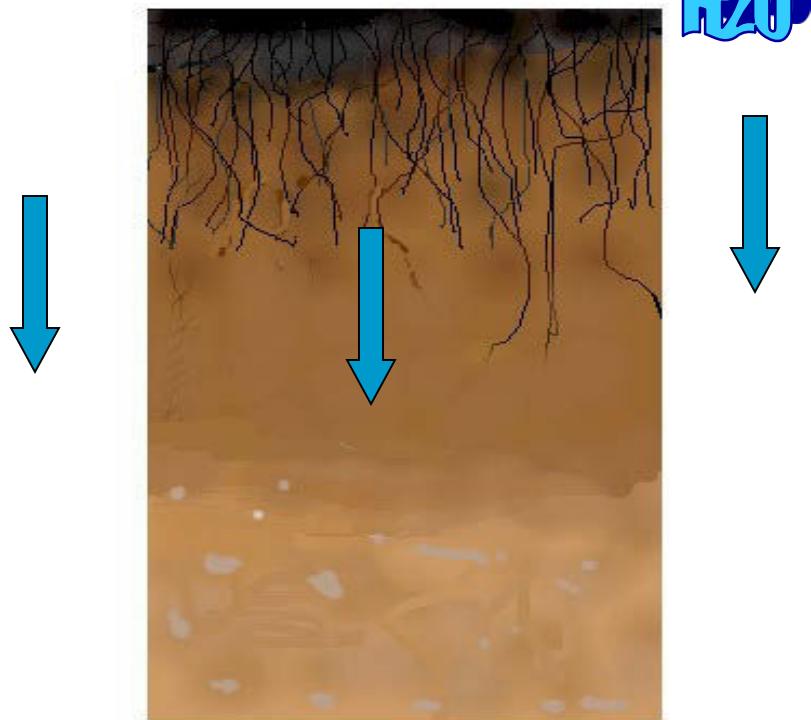
H is positive (cation) and OH is negative (anion)!



Sodium Hazards

- High concentrations of neutral salts, such as sodium chloride and sodium sulfate, may interfere with the absorption of water by plants because the osmotic pressure in the soil solution is nearly as high or higher than that in the plant cells. Other salts such as CaSO_4 may also effect osmotic pressure.

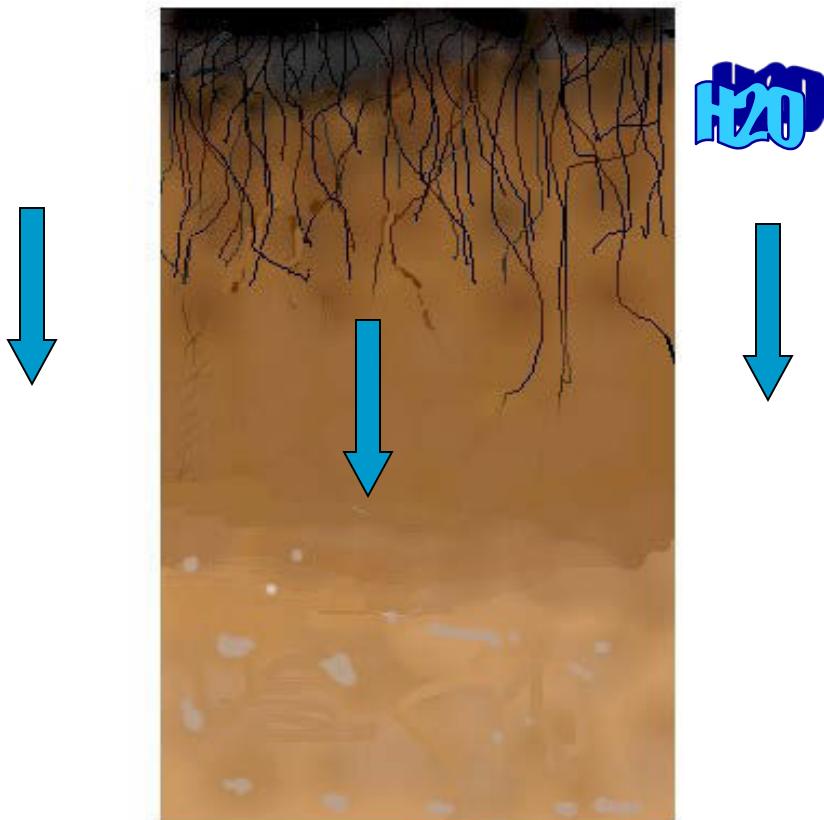
What are the components of a good soil? Non-saline, Non-sodic $EC=1.0$ $SAR=1.5$



- A balanced soil of cation/anions on the exchange sites with $EC=1.0 = \underline{640\text{mg/l}}$
- 23% Ca or 150mg/l
- 7% Mg or 15mg/l
- 11% Na or 70 mg/l
- 4% K or 8 mg/l
- 28% HCO_3 or 180 mg/l
- 25% SO_4 or 160 mg/l
- 14% Cl or 90 mg/l

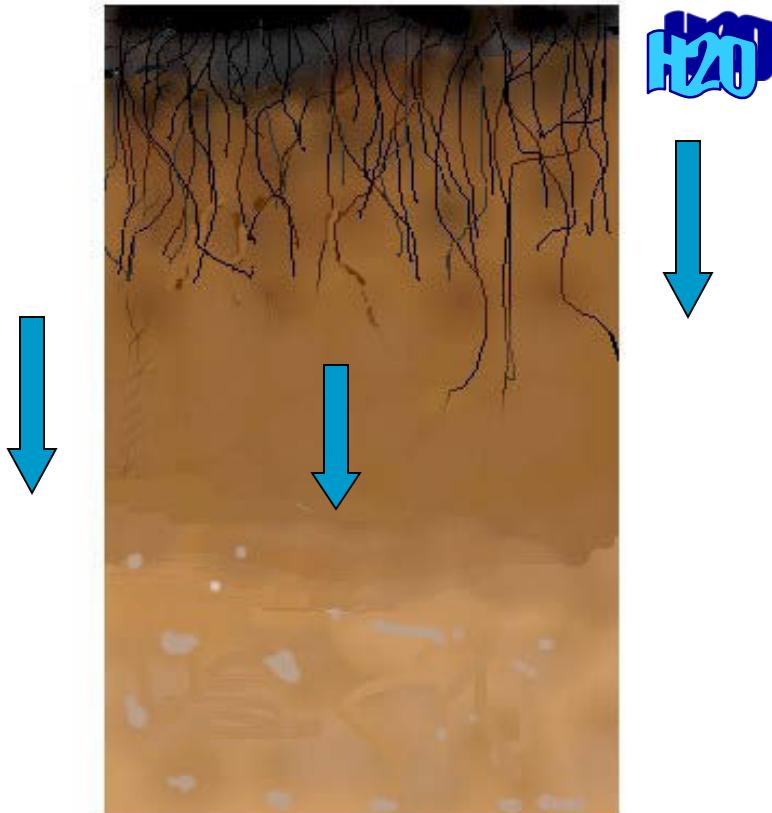
What are the components of a high EC (6.0) /saline soil?

SAR (2.3)



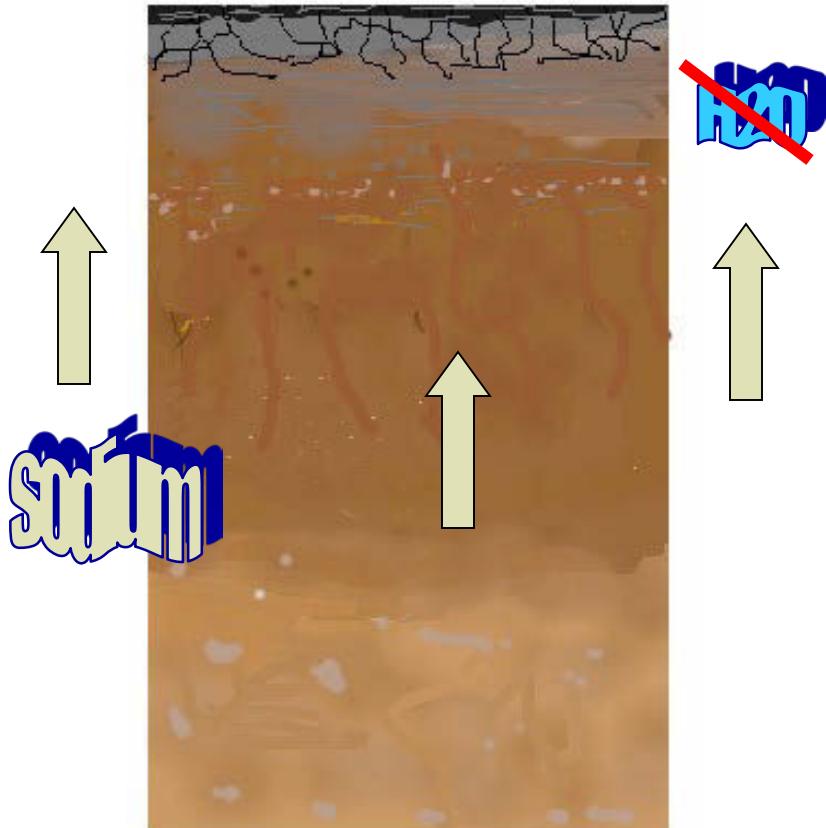
- A Saline soil has a high amount of soluble salts, non-sodic salts 3800 mg/l
- 21% Ca or 800mg/l
- 4% Mg or 160mg/l
- 10% Na or 400mg/l
- 4% K or 150mg/l
- 16% Cl or 610mg/l
- 21% HCO_3 or 790 mg/l
- 23% SO_4 or 890 mg/l

What are the components of a high EC (6.5) /Saline and High Sodic/SAR (27) soil?



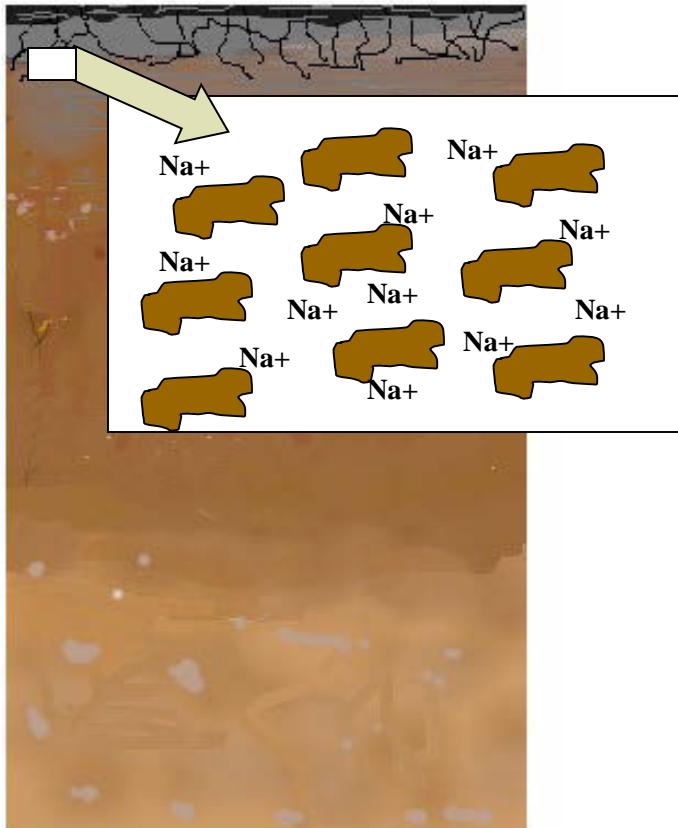
- A high EC/Saline and high Sodic/SAR soil 5200 mg/l
- 6% Ca or 320mg/l
- 0.5% Mg or 60mg/l
- 57% Na or 2900mg/l
- 0.5% K or 150mg/l
- 7% Cl or 360 mg/l
- 15% HCO_3 or 800mg/l
- 14% SO_4 or 720mg/l

What are the components of a low EC (2.0) /Saline and High Sodic/SAR (19) soil?



- A low EC/Saline and high Sodic/SAR soil dispersing & black alkali sfc.
- 1268 mg/l
- 6% Ca or 80 mg/l
- 3% Mg or 40 mg/l
- 71% Na or 900 mg/l
- 0.6% K or 8 mg/l
- 6% SO_4 or 80 mg/l
- 6% Cl or 80 mg/l
- 6% HCO_3 or 80 mg/l

Low EC (2.0) – Saline High Sodic/SAR (19) soil

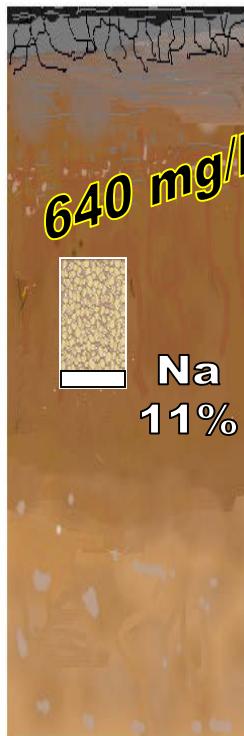


- Na – Sodium only has 1+ charge, compared to Ca and Mg which has 2+. Na does not form bridges (weaker bond) between soil particles therefore the soil structure deteriorates.

TDS Ratio's

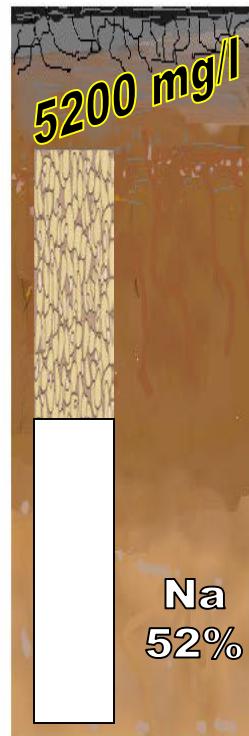
EC/SAR

1.0/1.5



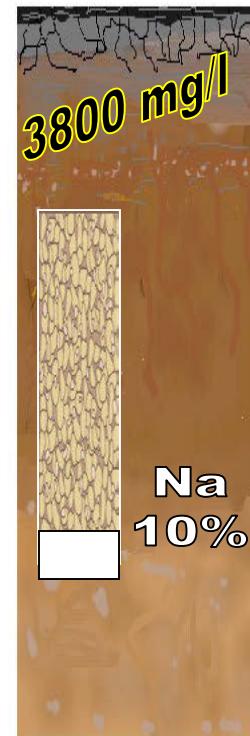
EC/SAR

6.5/27



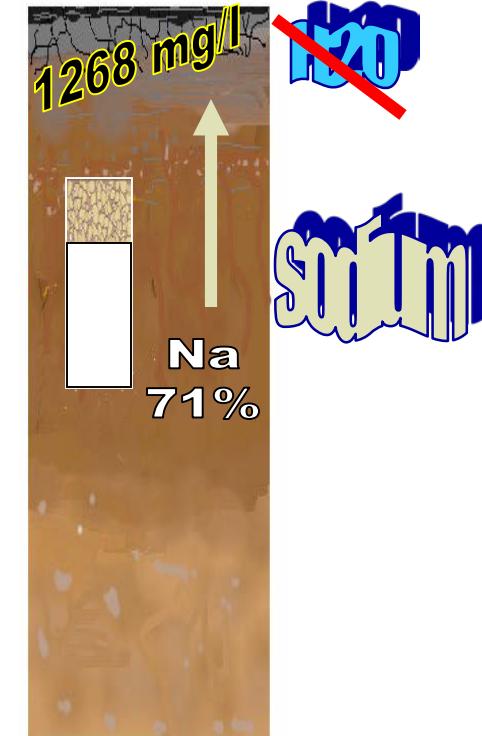
EC/SAR

6.0/2.3



EC/SAR

2.0/19



Example of Sodic and Saline Soil

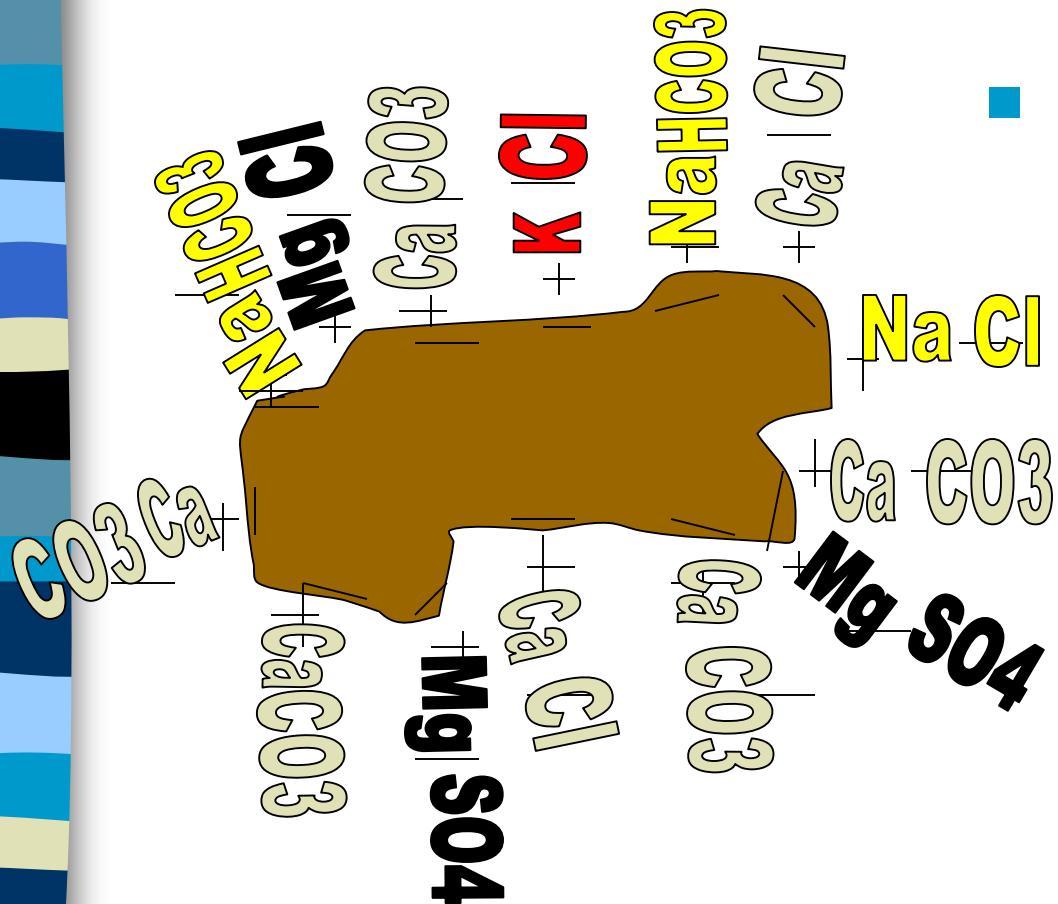


Close Up Of Soil Dispersion

Breakdown of soil particles.



Soil Particles are negatively charged.



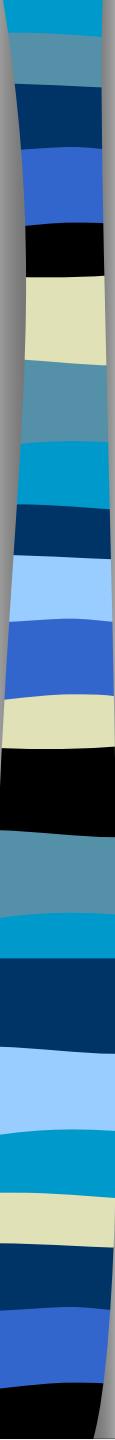
- Soil Particles are negatively charged and attract positive charge

EC Values of Various Water

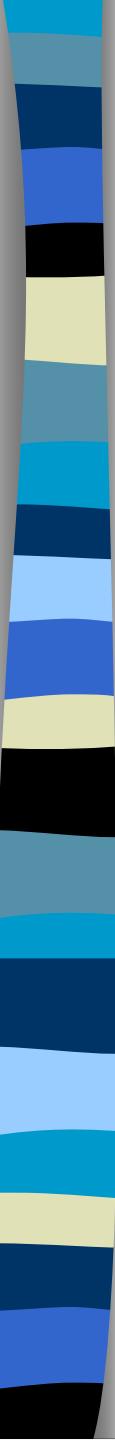
- Absolute Pure water 0.0055 dS/m
- Good City water 0.05 dS/m
- My water (Gillette) 2.2 dS/m
- Ocean water 53.0 dS/m

Crop EC Tolerances

Crop	toler. no loss	Max toler. will have 50% loss
Beans	1.0	3.6
Alfalfa	2.0	8.8
Corn	2.7	7.0
S. Beets	6.7	15.0
Crest. Whtg	3.5	12.0
Wheat	4.7	10.0
Barley	5.3	13.0
M.Brome	3.0	8.0
Tall	7.5	19.0
Wheatgrass		


$$\text{Cations} + \text{Anions} = \text{TDS}$$
$$\text{Ca, Mg, K, Na} \quad \text{Cl, SO}_4, \text{HCO}_3, \text{CO}_3$$

- An EC of 1.0 dS/m = 640 mg/l
- An EC of 2.0 dS/m = 1280 mg/l
- An EC of 4.0 dS/m = 2560 mg/l



Irrigation Water EC ranges

- Non-saline water < 0.75 dS/m
- Slightly saline 0.75-2 d/Sm
- Moderately saline 2-5 dS/m
- Highly saline 5-25 dS/m
- Brine water >45 dS/m

Salts In Irrigation Water

- EC of irrigation water = 2.0 or 1280mg/l or 1280 ppm.

Ac-Ft of water weighs 2,720,000 lbs

Therefore each irrigation of 1.0 ac-ft of water will have $1280 \times 2.72 = 1.7$ tons of salt with each irrigation application.

Reclamation of Saline Soils

- Applying additional water to leach the salts lower in the profile, it is best to use EC water is 0.5 or less.
- E.g. Amt. of drainage/ amt. of water applied
12"ppt with 20" irrigation w/ efficiencies calculated
corn needs 24" $12"+20"=32"$
 $32"-24" = 8"$ $8"/32" = 25\%$ leaching fraction
Rule of Thumb 1.0 ac-ft or 12 inches of extra water applied = would reduce salinity by approx. 90%

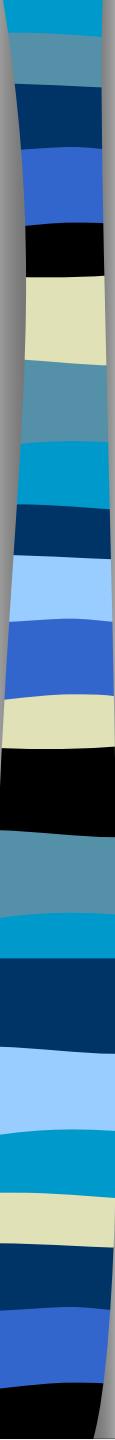
Therefore 8 inches of extra water = 65%

Reclamation of Sodic Soils

Amend soils with a supply of Ca, such as

- Gypsum, CaSO_4
- CaCl_2
- Sulfur
- Sulfuric Acid, H_2SO_4

- Along with Irrigation water



NRCS Practices

- PC-610 Toxic Salt Reductions, used to reduce sodium/boron/chlorides in soils.
- PC- 571 Soil Salinity Mgt., non-irrigated lands

Leaching Fraction-example

- Water has EC of 3.1 dS/m
- Crop is alfalfa, max no yield loss EC of 2.0
- 30 inches of water for alfalfa
- What is the leaching fraction?

$$\begin{aligned} \text{Lf\%} &= \text{EC water} \div [5 \text{ (a constant)} \times \text{Ecdesired}] - \text{Ecwater} \\ &= 3.1 \div [5 \times 2.0] - 3.1 \end{aligned}$$

45% extra water to leach the salts to a acceptable EC of 2.0

Reclamation of Saline Soils

- Leaching excess soluble salts from soil with salt free water
- Use deep rooted vegetation to lower water table and reduce upward movement of salts
- Ensure natural soil drainage is adequate to accommodate leaching water
 - Install artificial drainage if necessary

Reclamation of Saline Soils

- Management of soil salinity
 - Timing of irrigation important
 - Ensure that salts are moved out of root zone of seedlings
 - High quality water necessary
 - Tillage or surface-residue management
 - Mulches or conservation tillage can reduce evaporation and prevent upward movement of soluble salts

Reclamation of Saline-Sodic and Sodic Soils

- First, need to reduce level of exchangeable Na^+ ions, then leach soluble salts
 - To reduce level of exchangeable Na^+ , Ca^{2+} or H^+ used to replace Na^+ on exchange complex
 - Gypsum used to supply the Ca^{2+} or H^+ ions
 - Replaced sodium forms a soluble salt (sodium sulfate) that is easily leached
 - Gypsum must be well mixed with soil and followed by leaching to remove sodium sulfate

Reclamation of Saline-Sodic and Sodic Soils

- Sulfur or sulfuric acid can be used in place of gypsum
- Gypsum and sulfur reverse impermeability of sodic soils
 - ▣ Replacement of Na^+ with Ca^{2+} or H^+ improves soil aggregation and improves water infiltration

FERTFACTS

GYPSUM

INTRODUCTION

Gypsum is the common name of hydrated calcium sulphate, which has the chemical formula $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Gypsum is obtained in two ways, being either:

- mined from naturally-occurring deposits, or
- obtained as a co-product from the manufacture of phosphoric acid. This product is known as Phosphogypsum. Very little Phosphogypsum is now available in Australia.

Gypsum is used as:

- a sulphur fertiliser,
- a calcium fertiliser, or
- at higher rates as a soil conditioner.

Gypsum contains sulphur as sulphate, the form taken up by plant roots. The sulphur in gypsum is readily available, so gypsum can be used where a quick response to sulphur is required.

Gypsum has little if any effect on soil pH. It cannot be used as a substitute for lime to correct soil acidity, i.e. to raise the pH.

Naturally occurring gypsum is a soft crystalline mineral which is found in arid inland areas of Australia. Naturally occurring gypsum ranges from white to yellow, through pink to brown in colour. The gypsum content usually varies between 35% and 85%.

COMPOSITION AND LABEL INFORMATION

1 Analysis

Pure gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) contains 18.6% sulphur (S) and 23% calcium (Ca). Under state legislation in Australia, gypsum is categorised into a number of grades:

Grade 1	- a minimum of 15.0% S and 19.0% Ca
Grade 2	- a minimum of 12.5% S and 15.5% Ca
Grade 3	- a minimum of 10% S and 12.5% Ca

2 Sizing

A fine particle size is important for products that are insoluble or have low solubility.

The percentage of the gypsum that is capable of passing through a 2.0 mm sieve must be stated on the label. The solubility of gypsum is 0.26 kg/100L water at 20°C.

Most naturally occurring gypsums are coarse. Coarse gypsum takes longer to dissolve, which may be either advantageous or disadvantageous. A fine particle size may be of importance where gypsum is dissolved in irrigation water, or a quick response is required.

USES OF GYPSUM

Gypsum can be used as a fertiliser, to supply sulphur (S) and/or calcium (Ca); or as a soil conditioner. It may also be used to improve the infiltration rate of low conductivity irrigation water, and for water clarification.

Use of Gypsum as a Sulphur Fertiliser

Given its low analysis, it is usually uneconomical to use gypsum as a sulphur fertiliser if it has to be transported over any great distance. Its use is usually restricted to those districts in which gypsum is available locally at competitive prices.

Normally, sulphur is applied along with other nutrients, e.g. nitrogen or phosphorus, using fertilisers like ammonium sulphate (Gran-am), ammonium phosphate sulphate fertilisers (Granulock 15) and single superphosphate (SuPerfect and Super).

Situations where gypsum may be applied as a sulphur fertiliser include:

- In legume-based pastures on basaltic soils with high phosphorus levels, where fertiliser phosphorus is not required and legumes are relied on to fix nitrogen.
- In canola, as a pre-plant application, allowing high analysis nitrogen and phosphorus fertilisers with a low sulphur content to be used at planting and during the growing season.

Notes

It is often necessary to apply gypsum at about 300 kg/ha (45 kg/ha S) as it may be difficult to get application equipment to operate properly and spread gypsum uniformly at lower rates, particularly if the product has a fine particle size.

Use of Gypsum as a Calcium Fertiliser

Gypsum may be used as a calcium fertiliser, but it may not be the product of choice. Lime should be used on acid soils that are low in calcium. Not only does lime supply calcium, it also corrects acidity (raises the soil pH). However, while lime reacts in acid soils, it is ineffective in neutral and alkaline soils.

A typical rate at which gypsum is applied as a calcium fertiliser where the pH does not need amending is 1 - 2.5 t/ha. This would normally be applied during the fallow period, and can remain effective for several years.

Use of Gypsum as a Soil Conditioner

1 Causes of Poor Soil Structure

Poor soil structure can be attributed to many factors, such as over-cultivation, compaction and a loss of soil organic matter. It may also be associated with high concentrations of sodium and/or magnesium in the soil, compared to calcium. When soils with high exchangeable sodium are wet, the clay particles disperse, and the soil loses its defined structure resulting in reduced water infiltration and possible reduced seedling emergence.

The structure of sodic and magnesian soils (soils high in sodium and magnesium) can be improved by applying calcium compounds such as gypsum (calcium sulphate) at high rates. As the gypsum dissolves, it releases calcium ions that displace sodium (or magnesium) on the clay colloids.

Good rainfall (or irrigation) and drainage is necessary to leach the displaced sodium (and magnesium) from the topsoil deeper into the soil profile.

2 Recognition of Gypsum Responsive Soils

To start, much can be learnt from the field, e.g. degree of surface crusting, ease of cultivation, ability to store and use soil moisture, and crop yields. Soil tests can further assist in confirming the cause of soil structural problems.

3 Gypsum Rates

The rate at which gypsum is recommended will depend on the soil type (higher rates are required on heavy clays), the severity of the problem, the depth of incorporation, and the value of the crop.

4 Gypsum Applications and Timing

Gypsum is broadcast on the soil surface. Where gypsum is applied to improve soil structural characteristics, apply it as early as possible prior to sowing a crop or pasture. After application, it should be thoroughly incorporated into the soil.

Gypsum improves soil structure by displacing sodium (and magnesium) on the surface of clay particles with calcium. Gypsum (calcium sulphate) is sparingly soluble, but the sodium (and magnesium) sulphates that form in the soil solution are very soluble.

Rain (or irrigation) is required to leach these soluble salts out of the topsoil deeper into the soil profile, away from zone in which crop roots will be growing. If this does not occur, soil structure may be improved, but crop growth may in fact be made worse due to the salt effect.

5 Before applying Gypsum to Sodic Soil check the Soil EC (Electrical Conductivity).

If a soil test reveals high electrical conductivity, sodium and chloride, gypsum should not be recommended. The best way to ameliorate the soil will be to improve drainage, as most of the sodium will be present as soluble sodium salts and not exchangeable sodium.

6 Use of Lime to improve Soil Structure

Sodic and magnesian soils are typically alkaline, i.e. they have a high pH. Lime is insoluble and therefore ineffective if the pH is high. It only reacts in acid soil where, the solubility of lime is adequate to supply calcium and increase pH. Gypsum has little or no effect on soil pH.

On soils that are both **acid** and **sodic**, lime should be used, or a combination of lime and gypsum. The gypsum will work quicker in improving soil structure than lime, but lime is necessary to increase the soil pH. Lime is of no use on alkaline sodic soils.

Use of Gypsum to Improve Irrigation Water Infiltration Rates

The use of low conductivity irrigation water can cause clay particles at the soil surface to disperse, causing the surface to seal, thereby reducing water infiltration rates. This can occur in soils of otherwise good structure.

As gypsum is sparingly soluble, the use of agitators in the mixing tank can help get it to dissolve.

Use of Gypsum as a Water Clarifier

Gypsum can be used as a clearing (or flocculating) agent for muddy water, e.g. from dams, bores and in rice paddies. It causes the very fine suspended colloidal particles to clump together, forming particles too large to remain in suspension, so they fall to the bottom.

A fine particle size is essential for the gypsum to dissolve quickly. A suggested application rate is 1 kg of gypsum per 5 000 litres of water.

WARNING

The information contained in this publication is for use as a guide only. The use of fertilisers and soil amendments are not the only factors involved in producing a top yielding crop or pasture. Local soil, climatic and other conditions should also be taken into account, as these could affect responses.

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The Myth of Gypsum Magic
"Adding gypsum to your yard or garden will improve soil tilth and plant health"

The Myth

Upon continued prodding from one of my university extension colleagues, I recently watched several episodes of a well-known gardening program on television. My kids joined me, alerted by my animated responses to the host's non-stop torrent of advice. Among many amazing discoveries I learned that by adding gypsum to my yard or garden I would improve my problem soils by changing the particle size and loosening compaction. Further searching on the web revealed that gypsum would also improve drainage, decrease acidity, and eliminate soil salts. Previously, I had heard of gypsum for use in soil reclamation projects, but not for a typical urban landscape. Since gypsum is simply calcium sulfate, could this chemical truly transform soil structure and serve as a fertilizer for yards and gardens?

The Reality

This myth falls into the category of agricultural practices misapplied to ornamental landscapes. Gypsum effectively changes the structure and fertility of heavy clay soils, especially those that are heavily weathered or subject to intensive crop production. Gypsum also improves sodic (saline) soils by removing sodium from the soil and replacing it with calcium. Therefore, one can see improvement in clay soil structure and fertility, and desalinization of sodium-rich soils, by using gypsum.

What other effects will gypsum have on soil and plant health? There are a number of scientific studies on gypsum usage both in the literature and on websites. Briefly, researchers have found:

- Gypsum does not usually change soil acidity, though occasional reports of both increasing and decreasing pH exist;
- Gypsum can increase leaching of aluminum, which can detoxify soils but also contaminates nearby watersheds;
- Gypsum can increase leaching of iron and manganese, leading to deficiencies of these nutrients;
- Gypsum applied to acid soils can induce magnesium deficiency in plants on site;
- Gypsum applied to sandy soils can depress phosphorus, copper and zinc transport;
- Gypsum can have negative effects on mycorrhizal inoculation of roots, which may account for several reports of negative effects of gypsum on tree seedling establishment and survival;
- Gypsum is variable in its effects on mature trees;
- Gypsum will not improve fertility of acid or sandy soils;
- Gypsum will not improve water holding capacity of sandy soils; and
- Gypsum's effects are short-lived (often a matter of months)

With the exception of arid and coastal regions (where soil salts are high) and the southeastern United States (where heavy clay soils are common), gypsum amendment is just not necessary in non-agricultural areas. Urban soils are generally amalgamations of subsoils, native and non-native topsoils, and – in home landscapes – high levels of organic and non-organic chemical additives. They are also heavily compacted and layered (and gypsum does not work well on layered soils). In such landscapes, it is pointless to add yet more chemicals in the form of gypsum unless you need to increase soil calcium levels. This nutrient deficiency can be quickly identified by any soil testing laboratory for less than a bag of gypsum costs. (If you need to improve sulfur nutrition, it's wiser to use ammonium sulfate). To reduce compaction and

improve aeration in nearly any landscape, application of an organic mulch is more economically and environmentally sustainable.

The Bottom Line

- Gypsum can improve heavy clay soil structure and remove sodium from saline soils
- Gypsum has no effect on soil fertility, structure, or pH of any other soil type
- Most urban soils are not improved by additional gypsum
- Before adding gypsum or any chemical to a landscape, have soil analysis performed to identify mineral deficiencies, toxicities, and soil character
- Adding gypsum to sandy or non-sodic soils is a waste of money, natural resources, and can have negative impacts on plant, soil, and ecosystem health

For more information, please visit Dr. Chalker-Scott's web page at <http://www.theinformedgardener.com>.

Gypsum

Benefits and Misconceptions

Each year, usually in the winter and early spring, we receive calls asking about the benefits of applying gypsum to Midwestern or Eastern farm fields. Typically, the grower is looking for a way to reduce soil compaction. This paper is intended to answer many of these questions.

Gypsum is a naturally occurring mineral in many parts of the United States and the world. Gypsum is also often available as a by-product material. Gypsum is hydrated calcium sulfate. The chemical name of gypsum is calcium sulfate dihydrate. The chemical formula for pure gypsum is $\text{Ca}(\text{SO}_4) \cdot 2(\text{H}_2\text{O})$. In the chemically pure form, gypsum contains 23.28% calcium (Ca) and 18.62% sulfur (S) in the readily available sulfate form (SO_4). However, the typical gypsum sources that are commercially available for agricultural often contain impurities which result in a Ca level between 18%-23% Ca and 15%-19%. Gypsum is also available as a byproduct material. Some of the more common byproduct gypsum sources are flue gas desulfurization (FGD) gypsum and waste wallboard (also known as sheetrock or drywall). A few locations may have access to byproduct phosphogypsum from the production of P fertilizer, and some locations may have access to byproduct gypsum sources related to other industrial processes.

Gypsum has many uses in addition to agriculture. A partial list of products and processes that use gypsum includes blackboard chalk, cement, wallboard, Plaster-of-Paris, dental molds, paint filler, toothpaste, molds for casting metals, Tofu coagulation, improving mineral content of brewing water, dietary calcium additives in breads and cereals, and pharmaceuticals.

Table 1. Mineralogical composition of gypsum samples.

Source	Minerals* present
Synthetic gypsum ¹	gypsum, quartz
Natural gypsum ²	gypsum, quartz, dolomite
Cast gypsum ³	gypsum, quartz, anhydrite
Drywall gypsum ⁴	gypsum, quartz, portlandite, calcite

¹ Flue gas desulfurization (FGD) by-product. Samples obtained from the W.H. Zimmer Station in Moscow, OH, owned by Cinergy Corporation

² Mined geologic deposits. Samples obtained from the Kwest Group at Port Clinton, OH

³ Cast gypsum from recycled molds. Samples obtained from Mansfield Plumbing Products, LLC of Mansfield, OH

⁴ Waste wallboard/drywall/sheetrock. Samples obtained from Transfer Services, LLC of Columbus, OH

* gypsum = $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, quartz = SiO_2 , dolomite = $\text{CaMg}(\text{CO}_3)_2$, anhydrite = CaSO_4 , portlandite = $\text{Ca}(\text{OH})_2$, calcite = CaCO_3

Ohio State University Extension Fact Sheet (ANR-20-05) entitled "Gypsum for Agricultural Use in Ohio-Sources and Quality of Available Products" lists some sources and properties of gypsum available in Ohio. This information is probably typical of that found in many places and is presented as an example of material that may be in your area. Please note that the descriptions in table 1 have been edited by Spectrum to clarify the description of the materials.

Table 2. Physical properties and price (as of 12/2004) of gypsum.

Material	Water content ¹ %	Particle size	Price \$/ton	Insoluble residue ² %
Synthetic gypsum	5.55 (3.04) ³	120 µm	7.00	0.4 (0.2)
Natural gypsum	0.38 (0.48)	NA	12.75	12.9 (8.1)
Cast gypsum ⁴	0.15 (0.21)	NA	NA	0.2
Drywall gypsum	10.1 (12.8)	< 0.5 inch	11.00	2.2 (0.3)

¹ Dried overnight at 60 degrees Celsius.
² Following dissolution for three days at pH < 3.
³ Standard deviation included in parentheses.
⁴ Material is not yet available for sale for agricultural application.
NA = not available

Table 3. Selected macro- and micronutrient¹ concentrations in the gypsum samples.

Measure	Unit s	Museum specimen ²	Synthet ic gypsum	Natur al gypsum	Cast gypsum	Drywa ll gypsum	Ideal analysi s ³
Calcium	%	22.6	23.0 (0.0) ⁴	19.1 (2.2)	22.4 (0.0)	21.9 (0.2)	23.3
Magnesium	%	0.01	0.03 (0.01)	1.35 (0.30)	0.05 (0.00)	0.22 (0.01)	
Sulfur	%	18.6	18.7 (0.1)	15.1 (1.2)	19.3 (0.2)	18.1 (0.3)	18.6
Boron	ppm	< 13.1	26.7 (8.7)	9.4 (0.9)	0.4 (0.4)	7.3 (4.5)	
Iron	ppm	< 1	264 (129)	1045 (148)	44 (7)	547 (92)	
Manganese	ppm	0.1	5.5 (2.3)	14.6 (2.9)	9.1 (0.0)	9.4 (1.6)	
Phosphorus	ppm	3.8	16.7 (9.4)	30.6 (7.6)	7.5 (0.3)	51.6 (3.5)	

¹ Micronutrient data obtained by EPA method 3050 (USEPA, 1996).² The museum specimen is included as a pure sample of gypsum.³ Calculated content in a 100% pure product.⁴ Standard deviation included in parentheses.

Table 4. Trace metal content¹ of gypsum from different sources compared with U.S. EPA Part 503 pollutant concentration limits for excellent quality biosolids.

Pollutant (ppm = mg kg ⁻¹)	Museum specimen	Synthetic gypsum	Natural gypsum	Cast gypsum	Drywall gypsum	Part 503 Table 3 ²
Arsenic	< 0.52	0.56 (0.05) ³	< 0.52	< 0.52	0.98 (0.11)	41
Cadmium	< 0.48	< 0.48	< 0.48	< 0.48	< 0.48	39
Chromium	0.01	1.30 (0.85)	1.38 (0.32)	0.07 (0.00)	1.09 (0.09)	1200
Cobalt	< 0.48	< 0.48	0.53 (0.04)	< 0.48	< 0.48	NR ⁴
Copper	< 0.48	1.16 (0.66)	1.33 (0.30)	1.40 (0.21)	0.95 (0.14)	1500
Lead	< 0.48	0.80 (.30)	2.92 (0.30)	0.57 (0.08)	0.70 (0.02)	300
Mercury	< 0.26?	< 0.26	< 0.26	< 0.26	< 0.26	17
Molybdenum	< 0.24	0.51 (0.26)	1.28 (0.04)	< 0.24	< 0.24	----- ⁵
Nickel	< 0.24	0.73 (0.18)	1.42 (0.23)	< 0.24	0.83 (0.12)	420
Selenium	< 1.45	5.51 (3.47)	< 1.45	< 1.45	1.85 (0.04)	36
Zinc	< 0.24	3.88 (2.78)	0.91 (0.49)	< 0.24	3.08 (0.45)	2800

¹ Data obtained by EPA method 3050 (USEPA, 1996).

² Part 503-Standards for the Use or Disposal of Sewage Sludge; 503.13, Table 3. (USEPA, 1993).

³ Standard deviation included in parentheses.

⁴ NR = not regulated.

⁵ Ceiling concentration limit for molybdenum is 75 ppm; 503.13, Table 1. (USEPA, 1993).

"Claimed" Uses for Gypsum

As a soil amendment, gypsum has the following proven benefits.

- Correcting the damaging effects of high soil sodium (Na)
- A source of readily plant-available Ca
- A source of readily plant-available SO₄-S
- Increase the pH of highly acid subsoils
- Reducing Al toxicity of highly acid subsoil
- Possible benefits by lessening the severity of soil surface crusting
- Gypsum can reduce ammonia volatilization from urea and UAN fertilizers

These are the only demonstrated benefits derived from applying gypsum.

Misconceptions about Gypsum

There is a lot of confusion and misrepresentation about the benefits of gypsum for soils and plants. The following list is in response to the most common misconceptions.

- Gypsum will not correct the most common type of soil compaction
- High quality gypsum will not change the soil pH, although contaminants in some by-product gypsum may have some effect (raising or lowering pH) on soils.
- Gypsum will not "de-toxify" most soil problems.

Gypsum Effects on Soil Compaction

Typically, there are three types of soil compaction that prompt growers to ask about using gypsum. They are...

1. Relatively deep and thick layers of compacted soil caused by mechanical compaction of clay-based soils

2. Surface crusting

3. Loss of soil structure caused by high sodium (Na) levels in the soil

1. One of the most common misconceptions is that gypsum will help reduce mechanical soil compaction in clay soils ***that are not damaged by excess Na (sodic soils). There is no research data to support the claim that gypsum has any significant effect on reducing mechanical soil compaction.*** The belief that gypsum will reduce soil compaction probably comes from its effect on crusting and sodic soils. ***It needs to be understood that both soil crusting is caused by a different process than mechanical compaction and that compaction caused by sodic soils is extremely rare in the vast majority of fields in this country.*** Nearly all compaction affecting farms is caused by production practices that mechanically compact the soil, not by a chemical process. ***Mechanical compaction is caused by field operations performed when the land was too wet and/or improper implement selection. It can only be corrected through proper soil management practices, such as deep tillage, not working the field when it is too wet, proper equipment selection, and others.***

Table 5. Application of Flue-Gas Scrubber Desulfurization Sludge (Gypsum)

Wynoose silt loam (F. Thicke, Ph.D. Thesis, 1988, Univ. Illinois)

Product Rate lb/a	3-yr Corn Yield bu/a	4-yr Soybean Yield bu/a	Soil pH 3-yr	Exchangeable 1-yr		1 yr Bulk Density g/cu. cm.
				Ca ppm	Mg ppm	
0	159	36	6.8	1608	407	1.42
1,000	159	38	6.9	1615	371	1.41
10,000	156	36	6.8	1705	368	1.45
50,000	142	35	6.7	2110	330	1.38
100,000	145	33	6.9	3960	294	1.39
Significant	S	S	NS	S	S	NS

Material applied spring 1984, moldboard plow incorporation. Newton, IL

2. Soil crusting forms when the clay in the surface layer of soil becomes dispersed in water, then settles to form a thin, layer of interlocking clay particles on the soil surface. As this layer of deposited clay dries, it hardens and forms a barrier between the soil and the air. Such a crust can significantly reduce the water infiltration rate as well as the exchange of gasses with the atmosphere. This type of soil crust can increase erosion as well as degrade the growing conditions for the crop. As the thickness and strength of the crust increases, it may reach a point at which it physically inhibits seedling emergence. Several researchers have found that increasing the Ca saturation of the surface layer of the soil can reduce the possibility of crust formation as well as the damage caused by crust formation. The benefit of increasing the Ca saturation of the surface soil appears to be more important in soils with a high Mg content. Finely ground gypsum can be effective, at least in the short term, in reducing soil crusting in such soils when applied in the appropriate manner. It is recommended that gypsum applied to prevent or reduce soil crusting be surface applied and not incorporated. North Carolina State University recommends rates between 500 to 2,000 lb. of gypsum per acre for this purpose.

Remember, soil crusting is not the same thing as mechanical soil compaction.

Different processes are at work in the two problems and the fact that gypsum helps to alleviate crusting does not mean that it will improve compacted soils. Also, we found no data that compared the relative effectiveness of gypsum with mechanical cultivation to break soil crust. The effect of raindrop impact on bare soil is one of the factors that increase soil crusting in susceptible soil types. Therefore, the proper management of crop residues to shield the soil from raindrop impact is recommended as part of the soil management system.

3. Gypsum has long been recognized as being effective at improving the soil structure in sodic soils. When soil contains enough excess Na, the soil is unable to form aggregates. The result is similar to crusting, only it involves the entire topsoil layer, not just a fraction of an inch on the surface. Very few fields east of the dryer parts of the Great Plains have sodic soils that might benefit from gypsum. We find some in small areas around old oil wells where large volumes of salt water were pumped out onto the surface of the soil. Some years ago, researchers found that if they applied large amounts of gypsum (1-10 tons/acre) followed by large amounts of irrigation water, the excess Ca from the gypsum displaces the Na in the soil and the excess water leaches the displaced Na below the root zone of the planned crop. This permits a crop to be grown successfully on that land. Of course, the excess Ca will also displace other nutrient cations such as K and Mg, so the fertility program would need to be adjusted to compensate for this loss of nutrients. From this you can see that ***if a soil does***

not have excess Na there is no mechanism for gypsum to provide relief from this source of compaction.

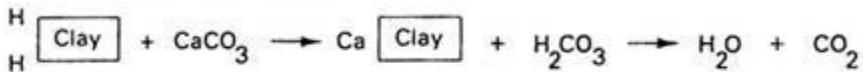
Gypsum Effects On Soil pH

This topic can get a little confusing due to the chemistry and causes of soil acidity, and the different ways in which lime and gypsum react in the soil. **The short answer is that pure gypsum will not affect the pH of the topsoil when surface applied or incorporated by typical methods.** However, gypsum is able to offset some of the toxic effects of extremely acid subsoil, in some soil types. Gypsum may even increase the pH of those subsoils to some degree. These seemingly contradictory statements can be explained by the differences in the chemistry between lime and gypsum, plus the somewhat unique nature of most acid subsoils.

Some people think that gypsum will increase soil pH. This belief is apparently based on fact that gypsum contains a significant amount of Ca. Without getting too deeply into the chemistry of lime, a short description of how lime works will help to illustrate why gypsum will not neutralize soil acid.

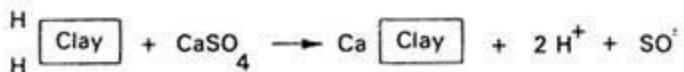
Typical agricultural lime is primarily composed of calcium carbonate (CaCO_3) and magnesium carbonate (MgCO_3). The principle acid-neutralizing power of agricultural lime is caused by the carbonate (CO_3) in both the calcium carbonate (CaCO_3) and magnesium carbonate (MgCO_3), not so much by the Ca nor Mg. Both lime minerals work in the same way to neutralize acid. Soil acid is defined as the hydrogen ion (H^+) content of the soil. To neutralize this acid, any soil amendment must either convert the H^+ into another non-acidic form of H or cause the minerals which generate the H^+ to stop or slow that process. Carbonates act directly upon the H^+ by causing it to combine with carbon dioxide (CO_2) to form water (see illustration). Since gypsum does not change the form of soil H^+ there is no change in soil pH.

LIMING REACTION



Eliminates H^+ as water

GYPSUM REACTION



The beneficial effect of gypsum on some acid subsoil occurs by a different type of chemistry. If acid neutralizing power were the only consideration, then lime would be the material of choice to neutralize acid subsoils. The problem with lime is that it is not very mobile in the soil. Therefore, in order to neutralize acid subsoils in any reasonable amount of time, the lime must be physically mixed into the subsoil. This is not something that most farmers can accomplish. Gypsum can affect subsoil acidity in a shorter time frame because it is much more mobile in the soil and can be leached into the subsoil by irrigation or rainfall.

In extremely acid subsoils (pH 5.0 and lower) excess soluble aluminum (Al^{+++}) is the main problem. Excess soluble Al is toxic to plants. The primary damage from excess Al^{+++} is the death of the root growing points or root pruning. The non-toxic calcium ion (Ca^{++}) generated by gypsum is a competitor with Al^{+++} . When the Ca^{++} from the gypsum reaches the subsoil, it causes some of the Al^{+++} to be leached into greater soil depths (assuming enough water

passes through the subsoil). The more Ca^{++} that leaches through the subsoil, the more Al^{+++} is leached. The same benefit would occur in the topsoil if it were at the same pH. However, in this case, we can use lime in which we get the benefits of acid neutralization plus the effects of Ca and Mg.

Neither the lime nor the gypsum is an instant solution to excess Al^{+++} . Depending on the nature and particle size of lime, it could require up to 18 months for the lime to completely react and neutralize acid topsoil. Gypsum's effects on subsoil can take less time, depending on how fast it can be leached through the subsoil.

Gypsum as a Nutrient Source

Because gypsum is highly soluble, it is an excellent source of Ca and S, especially for acid-loving crops and ornamentals, plus a few crops that are especially responsive to either Ca or S for reasons other than soil pH. Acid soils are by nature low in Ca. Where additional Ca is needed, gypsum is an ideal source for these crops. Potatoes are often grown in acid soil to control common scab. In these conditions, gypsum can improve tuber quality. Commercial Christmas tree producers have greatly improved the quality of their acid-loving species with applications of gypsum. Blueberry producers have also found gypsum to be beneficial with that acid-requiring crop. The list of acid-loving ornamentals is much too long to include here, but any of these plants are likely to benefit from additional Ca that does not increase the soil pH. While peanuts do not require acid soils, they are very responsive to applied Ca as gypsum.

Calculating Gypsum Requirement to Reduce soil Na and to build Soil Ca.

These two uses for gypsum require somewhat more complicated calculations in order to determine the appropriate rate of application. Reducing soil Na levels is by far the more complicated process and the following is only a superficial discussion of correcting this problem. A much more in-depth discussion is presented in Spectrum Analytics paper entitled "A Guide to Interpreting Irrigation Water Analysis", which can be found in the Library at spectrumanalytic.com.

Reducing Soil Sodium

1. Reducing Na to a "generally acceptable" level: The following formula is published by North Carolina State University.

$$\text{Lb. gypsum/acre} = \text{C.E.C.} \times (\% \text{Na sat.} - 5) \times 18$$

2. Reducing Na to a particular saturation percent: The following calculation may be used when there is a specific percent Na saturation target to be achieved.

Example (Assumptions): Soil CEC = 20; Na % saturation = 40%; Na % saturation goal = 10% Gypsum = 80% efficient at displacing excess soil Na

Calculations:

$$(\text{Present \% Na} - \text{Goal \% Na}) = 30\%$$

$$30\% \text{ of } 20 \text{ CEC, which is } 0.30 \times 20 = 6 \text{ meq. of Na}$$

6 meq. of Na \diamond 0.85 Tons of gypsum per meq. of Na = 5.1 Tons gypsum/a (at 100% efficiency)

5.1 Tons/a at 80% efficiency, which is 5.1 Tons/a \diamond 0.80 = 6.38 Tons gypsum/acre final requirement

3. Calculating gypsum to offset Na in irrigation water: (see "[A Guide to Interpreting Irrigation Water Analysis](#)" for an explanation of RSC)

Gypsum requirements can be calculated from the residual sodium carbonate (RSC) value of the irrigation water from the following equation.

RSC \diamond 234 = pounds of gypsum required to offset the excess sodium in 1 acre foot (325,852 gallons) of irrigation water

Remember, gypsum alone does not solve a high Na problem, you must apply adequate irrigation water (or wait for enough rainfall) to leach the displaced Na out of the root zone.

Increasing Soil Ca Saturation

This calculation is to simply increase the soil Ca to some desired percent Ca saturation through the use of gypsum. The formula was published by North Carolina State University.

$$\text{Lb. gypsum/acre} = \text{C.E.C.} \diamond (\text{desired \%Ca sat.} - \text{present \%Ca sat.}) \diamond 18$$

The Myth of an Ideal Calcium to Magnesium Ratio

Gypsum is sometimes recommended in order to adjust the soil Ca:Mg ratio to some desired value. The previous formula designed by N.C. State Univ. to Increase the soil Ca saturation could be used to achieve this goal. However, The idea that there is some "ideal" soil Ca:Mg ratio is a myth, and not worth pursuing.

Competition between Ca and Mg for uptake by crops has become a perennial topic of discussion in agriculture. Generally, the discussion centers on the claim by some that there is an "ideal" soil Ca/Mg ratio that should be achieved through fertilization. Often times, the ideal Ca:Mg ratio is somewhere between 5:1 and 8:1. Some of the claimed benefits of this ideal soil Ca:Mg ratio include

- Improved soil structure.
- Reduced weed populations, especially foxtail and quackgrass, plus improved forage quality.
- Reduced leaching of other plant nutrients.
- Generally improved balance of most soil nutrients.

The first publication of an ideal Ca/Mg ratio probably came from New Jersey in 1901. This early work recommended a "total" Ca to "total" Mg ratio in the soil of about 5/4. As we know today, the "total" soil content of CA, Mg, or any nutrient has little relationship to its availability or uptake by crops. It also has literally nothing to do with the general fertility of the soil.

In a 1945, a publication by Bear, again in New Jersey, suggested that an example of an ideal soil was one that had the following saturations of exchangeable cations 65% Ca, 10% Mg, 5% K, and 20% H. The cation ratios resulting from these idealizes concentrations are a Ca:Mg of 6.5:1, Ca:K of 13:1, and Mg:K of 2:1 (or a K:Mg or 0.5:1). It appears that since this time, these ratios have been seized upon by some people as the "ideal" ratios, rather than examples of good ratios.

Since these published figures, we have seen that many top yields of many different crops have been produced in soils with cation nutrient ratios much different than those first published. Also, a significant amount of research has looked at the question of nutrient ratios and almost no results have supported the claim of some "ideal" ratio. Fertile soils commonly have a Ca:Mg ratio between 5:1 and 8:1. However, this does not mean that the specific Ca:Mg ratio is required, best, or even related to yield. Research results show that this ratio can be as narrow as 2:1 or as wide as 11:1 without negative effects, assuming that there is an adequate amount of each nutrient in the soil.

In the mid-1980's the University of Wisconsin conducted research into the effect of Ca:Mg ratio on alfalfa growth. They found that while the Ca:Mg ratio in the plant tended to reflect the soil Ca:Mg ratio, the plant content of these nutrients was affected much less and in no case did the soil or plant ratio affect yield. In this work the plant Ca and Mg contents were never below the respective critical levels for each nutrient, even though the soil Ca:Mg ratios ranged from 2.28:1 to 8.44:1. They concluded that, assuming there are adequate levels of Ca and Mg present in the soil, variations in the Ca:Mg ratio over the range of 2:1 up to 8:1 have no effect on yield.

In 1999 the University of Missouri, Delta Research Center published the results of an investigation into the effects of soil Ca:Mg ratio on cotton. They amended plots with gypsum or epsom salts to create soil Ca:Mg ratios between 3.8:1 and 11.7:1. They found that cotton yields were not significantly different between treatments.

McLean, et al in Ohio, could find no specific cation ratios that predicted sufficiency or shortages of K, Mg, or Ca in several crops (Table 1). Notice that for all crops the Ca:Mg ratios of both the high and low yielding groups have essentially the same ranges. There is no trend or bias in the relationships between the Ca:Mg ratio and the relative yields of any crop. This indicates that the soil Ca:Mg ratio had little or no effect on yield and the researchers concluded the same.

Table 1

Cation Ratio	Yield Group	Ranges of Soil Ca/Mg Ratio			
		Corn	Soybeans	Wheat	Alfalfa
Ca/Mg					
	High	5.7 - 20.6	5.7 - 14.9	5.7 - 14.0	6.8 - 26.8
	Low	5.4 - 18.8	2.3 - 16.1	6.8 - 21.5	5.7 - 21.5

The obvious conclusion is that crop yields are not significantly affected by the soil Ca/Mg ratio as long as both nutrients are present in adequate amounts.

According to Dr. Stanley Barber, the noted soil scientist at Purdue University, "There is no research justification for the added expense of obtaining a definite Ca:Mg ratio in the soil. Research indicates that plant yield or quality is not appreciably affected over a wide range of Ca:Mg ratios in the soil."

The Role of Gypsum in "De-Toxifying" Soils

Gypsum is sometimes recommended based on the ability of soluble Ca to counteract the effects of toxic levels of micronutrients and heavy metals in the soil. There is a significant amount of evidence that soluble Ca can in fact be beneficial in counteracting these problems. However, the practical and economic benefits of this chemistry to most growers are doubtful for the following reasons.

- Land with toxic levels of these metals, are extremely rare. Where the land is highly polluted, much more drastic remedies are required.
- Research on problems shows that where gypsum provides some benefit, it is relatively small.
- Nearly all toxicities found in farm soils or landscapes are related to extremely acid soils. Lime is the proper solution to those problems.

Some of the more common micronutrient toxicity questions are addressed in the following sections.

Boron Toxicity: Like the misunderstandings about gypsum's role in soil compaction, its role in alleviating B toxicity appears to be related to its use in reclaiming sodic soils. It is not uncommon for areas with high Na soils and irrigation water, to also have high levels of B in both the soil and water. In these areas, some or much of the B occurs in the form of easily soluble sodium metaborate. Applications of gypsum have been shown to convert much of the sodium metaborate to the much less soluble calcium metaborate. Where the dominant form of soil B is not sodium metaborate, which included most Midwestern and Eastern soils, the beneficial effects of gypsum for reducing excess soil B may be limited.

Another factor that may have increased the reputation of gypsum in alleviating B toxicity is the role of soil pH in reducing B availability. It is well known that a high soil pH (> 7.2) can greatly reduce the availability of soil B. Since the most common cause of high pH is excess applications or soil content of calcium carbonate (lime), the role of Ca might get confused with the separate role of pH.

Having said this, it is commonly accepted that there is a relationship between Ca and B in both soils and plant physiology. Clemson University has reported that "The relationship between boron and several other nutrients has been established. Calcium, potassium, and nitrogen can affect boron nutrition. The calcium-boron relationship is the most important. Soils high in calcium will require more boron. Lower rates of boron will be required for soils low in calcium, and chances of boron toxicity are greater." Based on this statement, if the chances of B toxicity are greater in low Ca soils, then it would seem logical that high soil Ca should reduce the chances of B toxicity. We were unable to find research results that proved the ability of gypsum to prevent or correct B toxicity to crops. It appears that in the event of an accidental application of excess B fertilizer, an emergency application of gypsum may offer a small chance of some benefit to the crop. However, it should not be expected to perform miracles.

Copper: In preparing information for this paper, we ran across several claims of gypsum being instrumental in reducing the negative effects of excess soil Cu. After an extensive literature search on this subject, we found only one reference to this claim. In Reference 10 a list of recorded interactions of Cu with other elements in plant tissues listed the following reference... "Ca was shown to reduce Cu uptake in nutrient solution culture in lettuce". A

second reference to the effects of Ca on Cu uptake by a crop said... "Increasing Ca in solution culture improved reduced growth due to Cu toxicity in mungbean".

The most common recommendation for amending soils exhibiting Cu toxicity was to lime the soil to a pH of 6.5 or a little higher. For example, the University of Florida says "diagnosis of copper toxicity can only be treated by liming the field for the next crop". While it is possible that the Ca in high application rates of gypsum may have some beneficial effect on copper contaminated soils, we believe that growers should not expect dramatic improvements, if any at all, from gypsum. Based on these findings we conclude that, if a soil contains toxic levels of Cu, applications of gypsum will have only marginal benefits at best. All known options for alleviating Cu toxicity have significant other negative effects. The best management approach is to avoid contaminating the soil with Cu in the first place.

Iron: Direct Fetoxicity is extremely rare, therefore there is little need to apply gypsum to correct a problem that does not exist, regardless of any potentially beneficial effect that gypsum may have.

Manganese: Manganese toxicity is virtually always associated with excessively acid soils. The solution to this is to correct the soil pH with lime. Therefore, there is no place for gypsum in this situation.

Zinc: Zinc toxicity is also extremely rare in most soils and plant production situations. Therefore, any benefit that gypsum may have on reducing Zn toxicity is a solution to a problem that generally does not exist. One exception to this is in peanut production. Peanuts are exceptionally sensitive to Zn and can develop toxic reactions at soil Zn levels much lower than other plants. However, any benefits that gypsum may have for alleviating Zn toxicity in peanuts is probably already being taken advantage of by peanut growers. Peanuts are very responsive to having abundant amounts of soluble Ca in the soil zone where the nuts are forming. Knowing this, most growers already apply gypsum to each crop to insure a quality crop. Therefore, they are unlikely to gain from higher rates of gypsum.

Calcium's Role in Reducing Ammonia Volatilization from Urea and UAN Fertilizers

Beginning in the early 1980's Dr. Lloyd Fenn, of Texas A&M University began publishing the results of his research into using soluble calcium additives to reduce ammonia volatilization from urea applied to calcareous soil. It is beyond the scope of this paper to evaluate all of the work done in this area. However, we will give a brief outline of the work.

It is well known that surface applying urea to calcareous soil often results in unacceptable N volatilization losses. Doctor Fenn found that including soluble Ca in the N application significantly reduced the amount of N lost in these conditions. Additionally, he found that there were similar, but often smaller, benefits from applications of soluble K and Mg with the urea. Doctor Fenn's work was confirmed by other researchers.

In order to be effective, the additional cations (Ca, K, or Mg) that were applied had to be very easily soluble, or already in solution. Most of the work appears to have used calcium chloride as the Ca source. The ratio of the cation to amount of ammonium N was critical to success, plus. The application timing of the cations and N was important as well.

Our files on this research did not have any examples where gypsum was used as the Ca source. However, it would seem that if calcium chloride works, high quality gypsum might also work reasonably well under the same conditions and methods. The problem with

recommending the practice of using co-applied cations with urea (or other urea containing fertilizers) to reduce N loss is that first you must have a significant N loss to prevent. The benefits of this practice will be limited to the estimated value of the N losses (in nutrient costs and/or yield loss) that were prevented. Conditions where there is little chance of significant N loss include the following.

- Where urea is applied to cool soils, such as winter wheat topdress
- Where the urea will be physically incorporated
- Where urea is likely to be leached into the soil with about $\frac{1}{2}$ inch of rainfall within a short time
- Where the soil pH is somewhat acid and there is little or no crop residue or other soil cover to prevent the urea granules from good soil contact.

Of course the cost of the added cations must also be considered. Some publications suggest that to be effective, the final Ca:N ratio must be about 1:4. However, other investigators found that the required Ca:N ratio needed to be approximately 2:1 for significant effect on N loss. If a 1:4 ratio was effective in most situations, this practice might be economical. However, if the 2:1 ratio is needed, it is hard to see where the benefits will be.

Since we can't easily or accurately predict the potential volatilization losses or their effects on yield, nor have researchers been able to give us a reliable Ca:N ratio, we really can't predict the economics of this practice. It is probably instructive to note that this work has been known by agronomists since its first publication and since then few agronomists have found it valuable enough to recommend.

A Final Note

Many growers will see promotions for gypsum use that emphasize the many beneficial roles that Ca plays in both plants and soils. Most of them are probably true, to one degree or another. However, the fact that these claims may be true does not mean that a grower needs gypsum or any other Ca source. The vast majority of soils contain abundant Ca and applying more will gain nothing for the crop or the grower. Before spending scarce money on inputs based on nothing more than claims, the grower must accurately evaluate his crops needs. This requires the proper use of soil tests, plant analysis, and some time spent evaluating research results and/or on-farm field trials. Scarce input dollars must be spent where there are the greatest chances for the largest returns on investments. In most cases, the best returns will be from the proper use of more conventional, such as lime, fertilizer, seed, etc.

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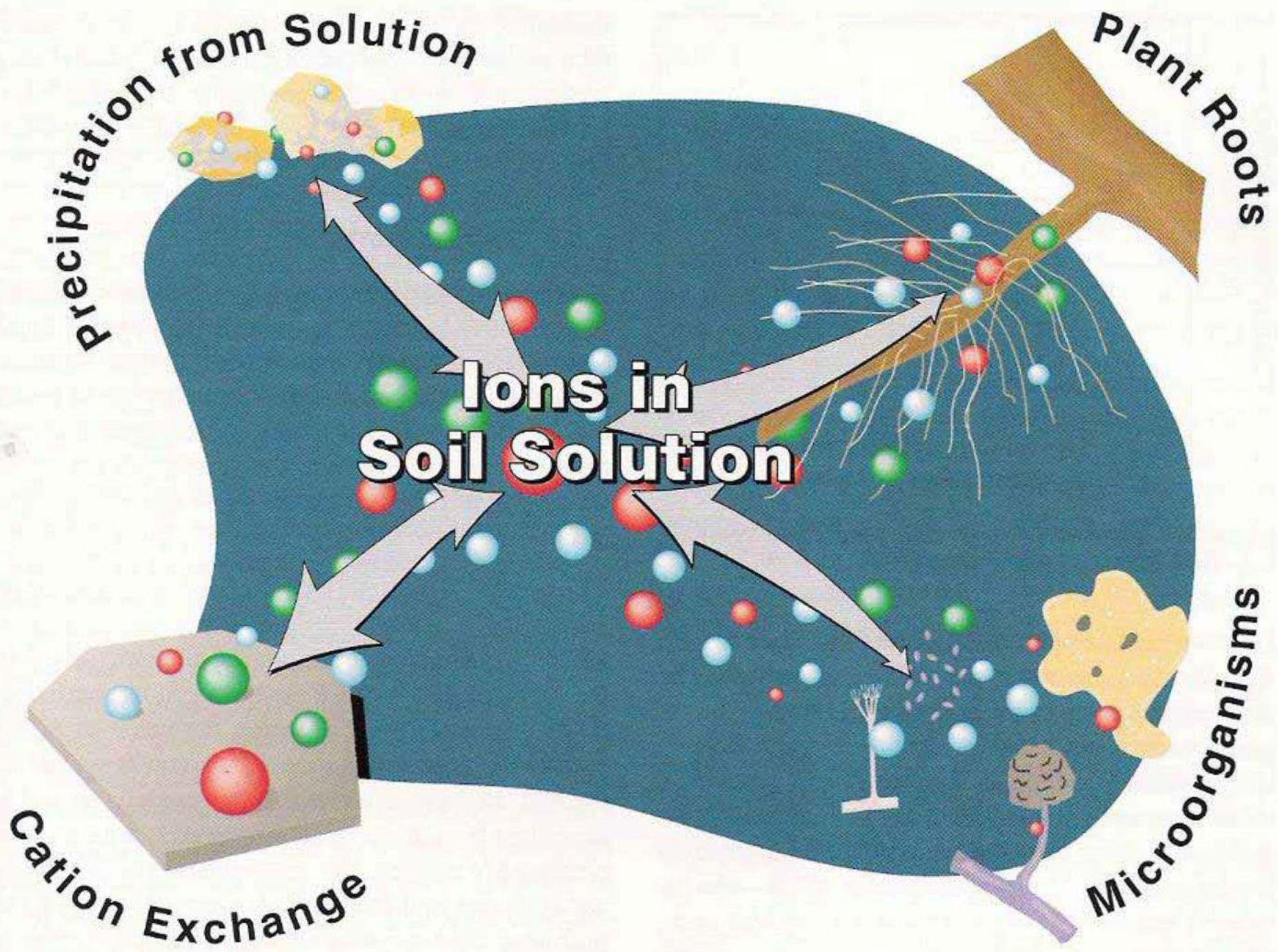
SOIL CHEMICAL RESPONSES TO FGD GYPSUM AND THEIR IMPACT ON CROP YIELDS



**Malcolm E. Sumner
Regents' Professor Emeritus
University of Georgia**

CHEMICAL REACTIONS OF GYPSUM IN SOILS

- Aqueous phase**
 - Ion pair formation
 - Ion activities in solution
- Solid phase**
 - Cation and anion exchange reactions
 - Mineral dissolution/precipitation reactions
- Chemical effects in dispersion/flocculation**



AQUEOUS PHASE REACTIONS

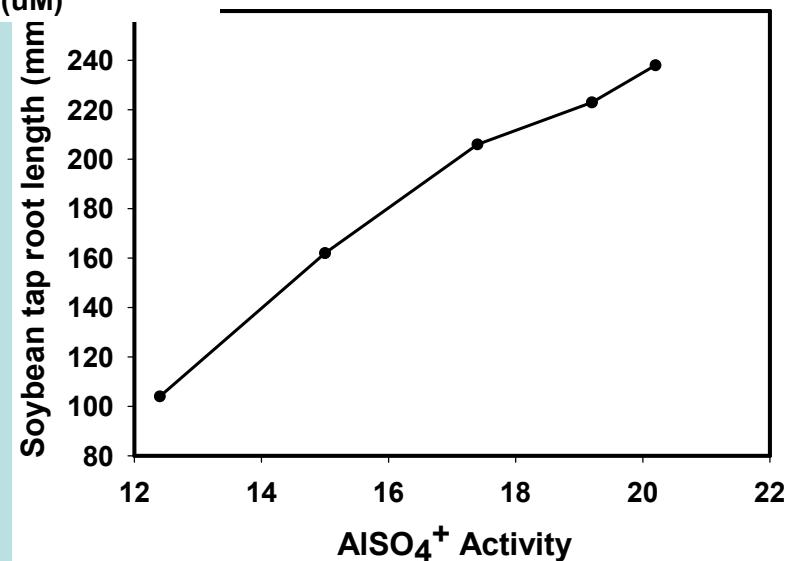
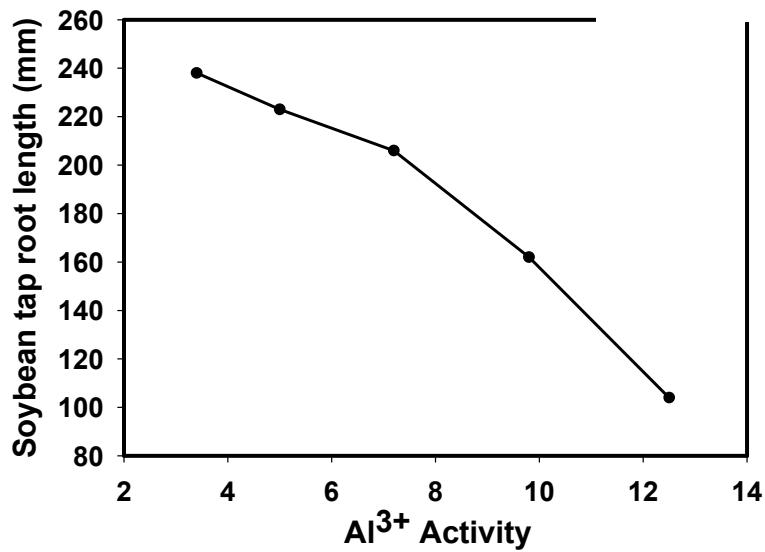
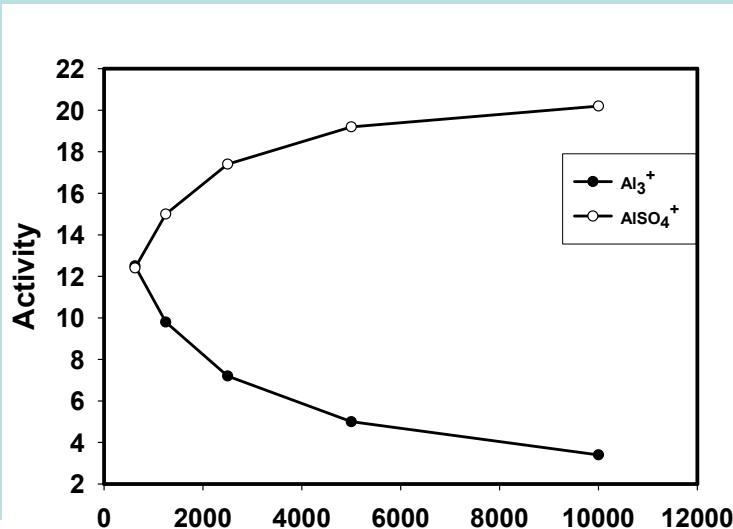
- Ion pair formation



Toxic
aluminum

Gypsum

Much less
toxic

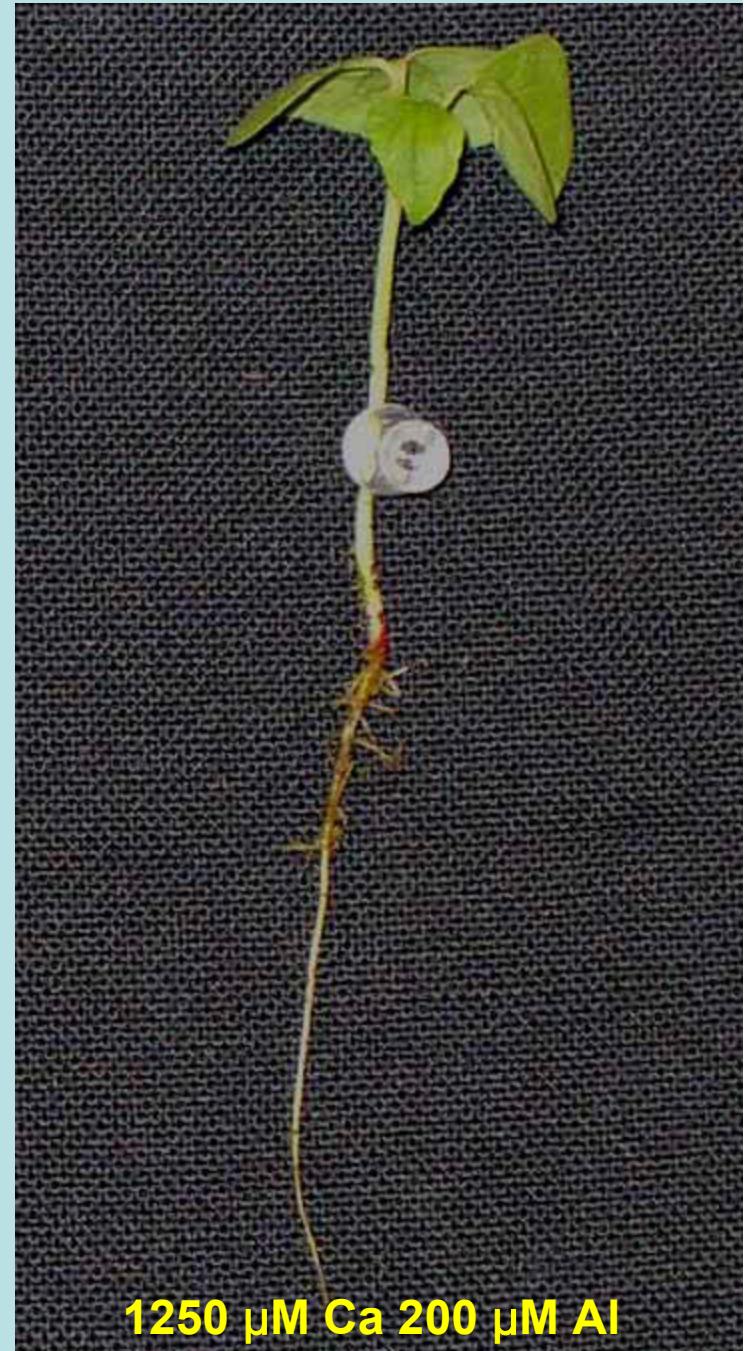


Evidence for Ion Pair Detoxification



50 μM Ca 200 μM Al

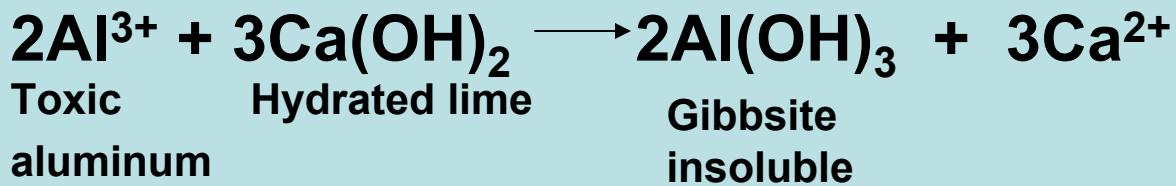
1 inch



1250 μM Ca 200 μM Al

SOLID PHASE REACTIONS

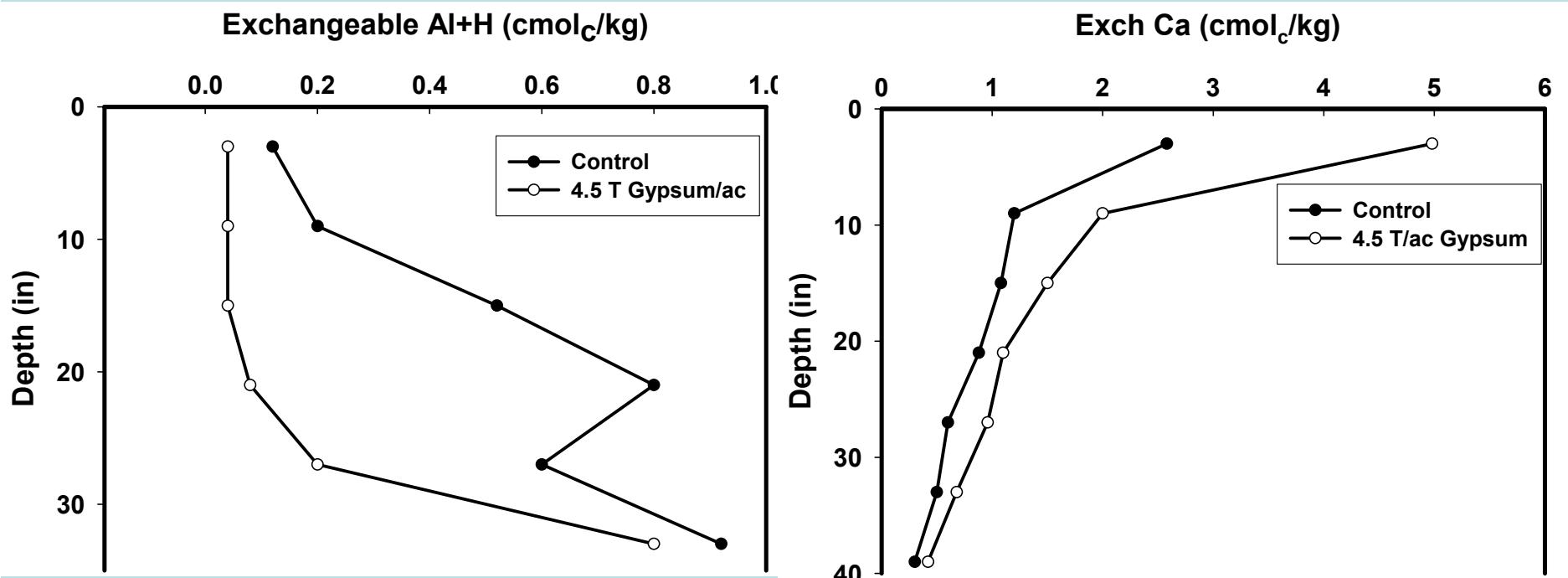
- “Self-limiting Effect” (Ligand exchange $\text{OH} \rightleftharpoons 2\text{SO}_4$)



- pH increases
 - Negative charge increases

(Reeve & Sumner, 1972)

EFFECT OF GYPSUM ON EXCHANGEABLE AI & Ca



Evidence for Self-Limiting Effect

(Sumner, 1990)

I (mol/L)	pH		Δ pH
	CaSO ₄	CaCl ₂	
0.0300	4.54	4.20	+0.34
0.0140	4.72	4.44	+0.28
0.0028	4.95	4.74	+0.21
0.0014	5.08	4.91	+0.17
0.0007	5.19	5.06	+0.13

Gypsum Increases Negative Charge

(Sousa et al., 1986)

Depth (cm)	Negative charge (cmol _c /kg)	
	Control	Gypsum (6t/ha)
0-15	2.87	3.65
15-30	1.11	1.42
30-45	1.04	1.15
45-60	0.74	1.13
60-75	0.83	1.13
75-90	0.58	0.91
90-105	0.40	0.65

Responsive Soils Exhibit “Salt Sorption”

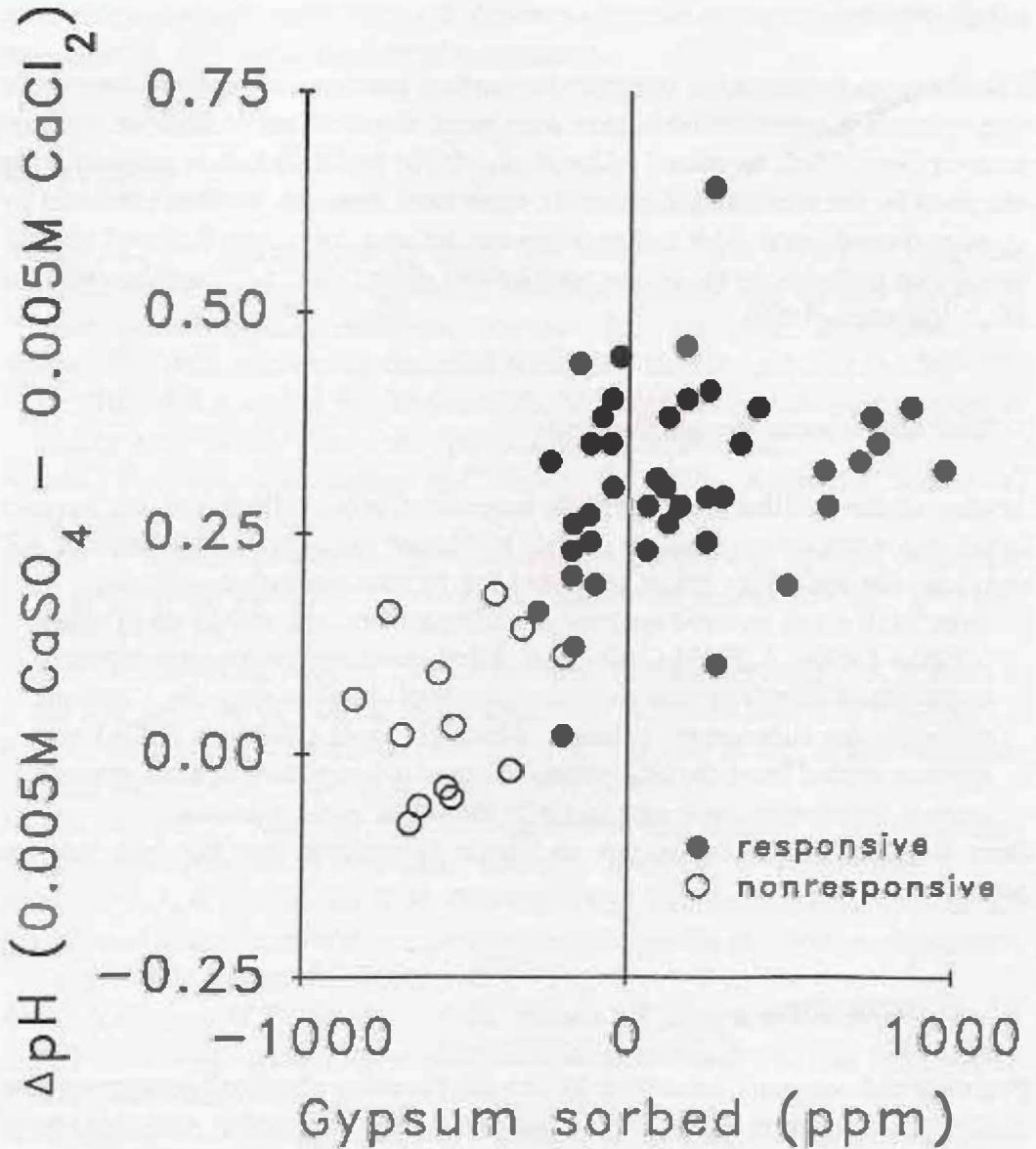
Treatment	EC µS/cm	$\Sigma \text{Cat}_{\text{sol}}$	$\Sigma \text{Cat}_{\text{displ}}$	$\Sigma \text{An}_{\text{sol}}$	$\Sigma \text{An}_{\text{displ}}$
CaSO_4 soln	1830	23		23	
$\text{CaSO}_4 + \text{soil}$	35	2.7	1.2	3.0	1.0

Test for Gypsum Responsive Soils

(Sumner, 1994)

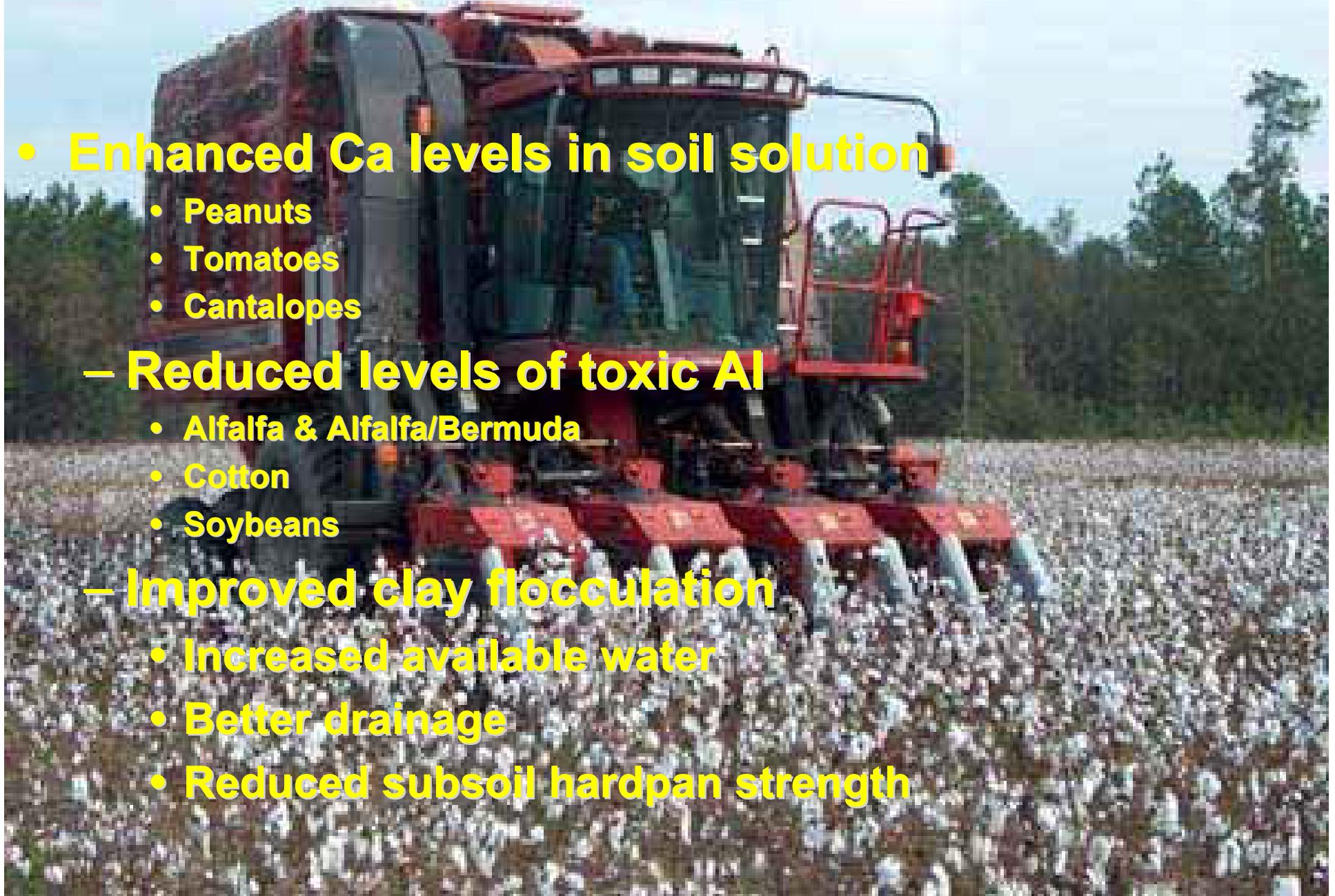
- Measure pH in 0.005 M CaSO_4 and 0.005 M CaCl_2
- Calculate $\Delta\text{pH} (\text{CaSO}_4 - \text{CaCl}_2)$
- Measure EC of 0.005 M CaSO_4 before and after addition of soil
- Calculate amount of gypsum adsorbed
- Plot ΔpH vs gypsum adsorbed





IMPACT ON CROP YIELDS

- Enhanced Ca levels in soil solution
 - Peanuts
 - Tomatoes
 - Cantalopes
- Reduced levels of toxic Al
 - Alfalfa & Alfalfa/Bermuda
 - Cotton
 - Soybeans
- Improved clay flocculation
 - Increased available water
 - Better drainage
 - Reduced subsoil hardpan strength

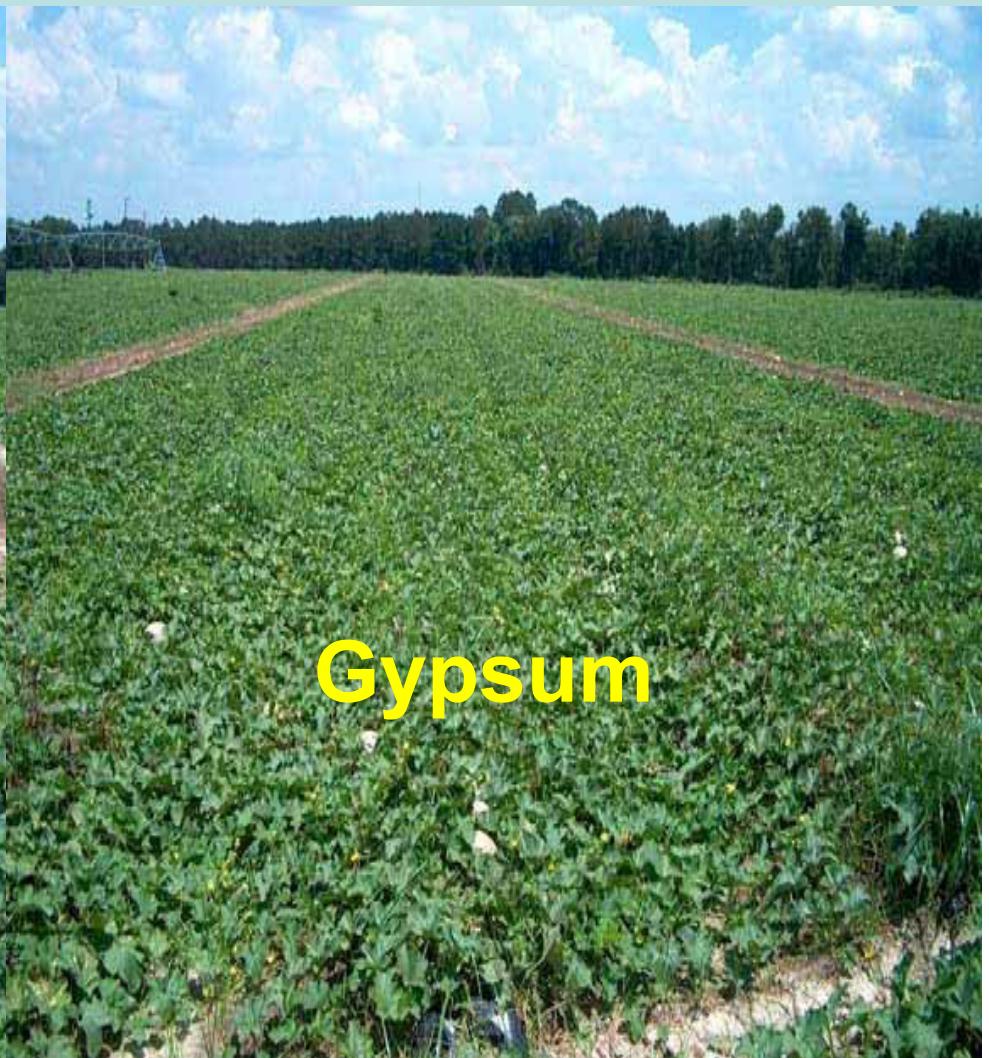


CROP RESPONSES TO GYPSUM

Enhanced Soluble Ca Levels in Soils

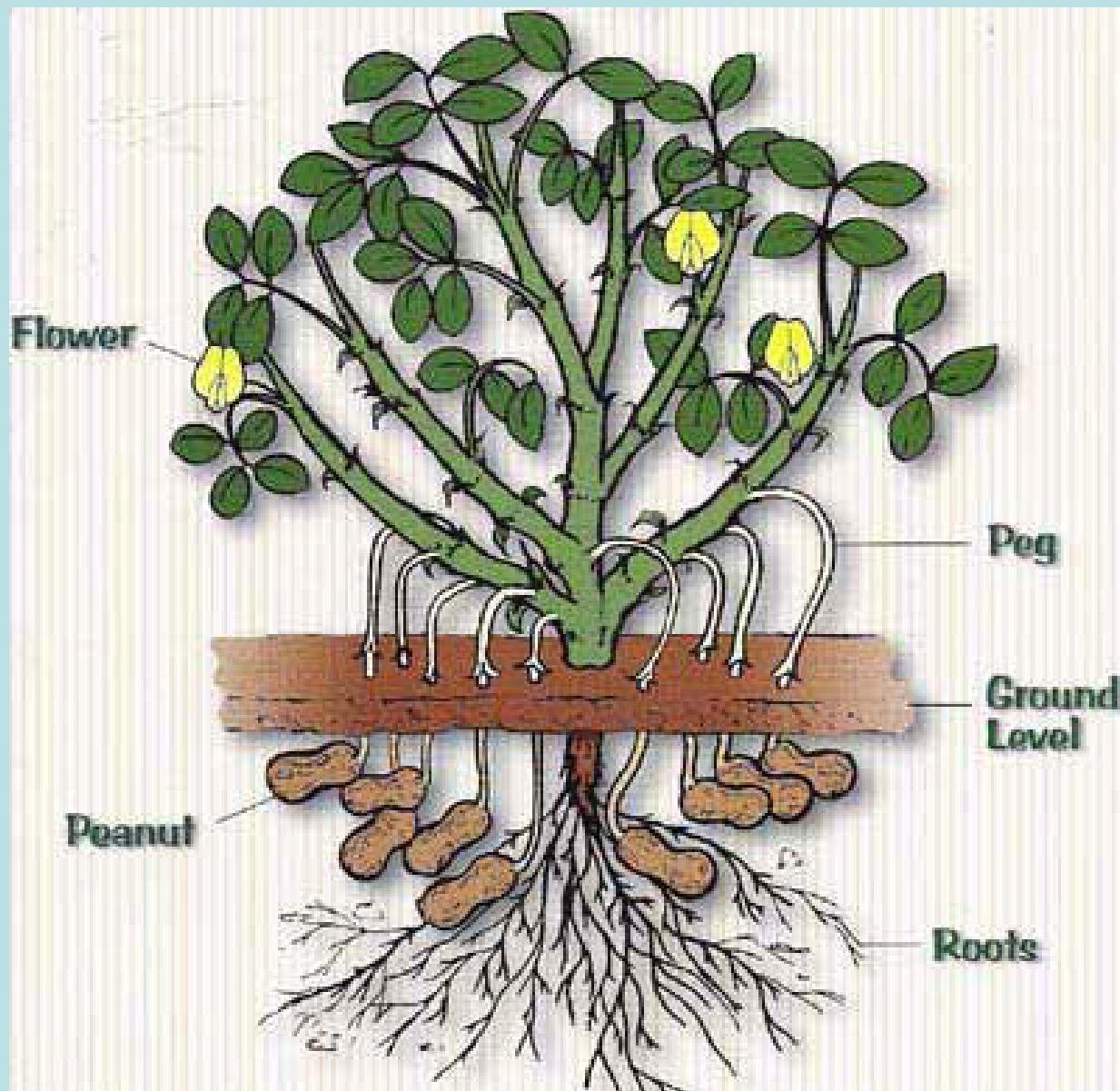


No gypsum



Gypsum

PEANUTS

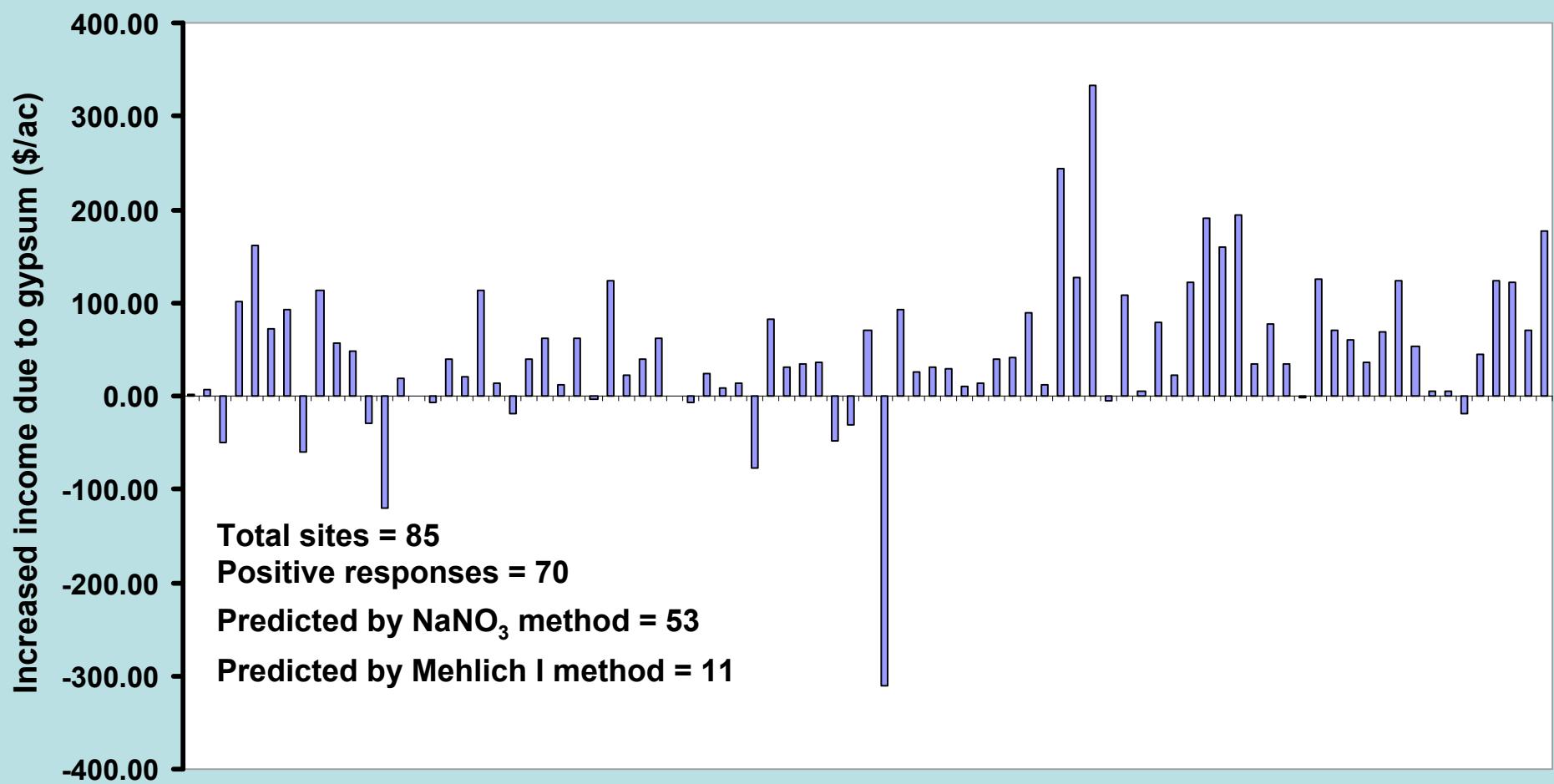


PEANUTS

Treatment	Yield T/ac	SMK* %	Value \$/ac	Seed Ca %
Control	2.1a	71a	375.12	0.049
0.5 T FGD gypsum/ac	2.6b	75b	481.96	0.059

* SMK = Sound mature kernels

Summary of Peanut Responses to Gypsum

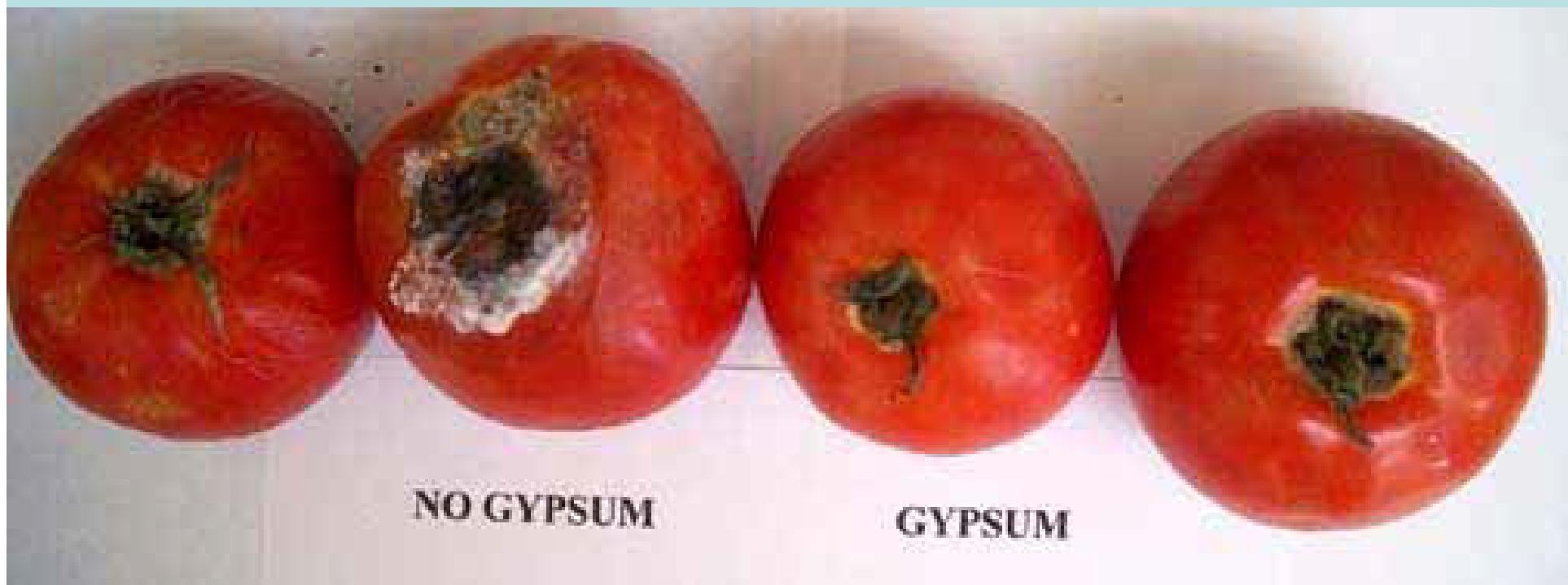


GYPSUM AND TOMATOES

Treatment	Yield	Skin Ca	Fruit rejection*
	T/ac	%	%
Control	26.5a	0.21a	95
5 T FGD gypsum/ha	37.5b	0.34b	15

* After storage for 4 weeks @ 4 °C

Effect of Storage at Room Temperature for 4 Weeks - 2006



GYPSUM AND CANTALOUPES

Treatment	Yield T/ha	Wt/fruit kg	Skin Ca %	Fruit rejection*
Control	6.71a	2.12a	1.07a	89
1.25 T FGD gypsum/ha	10.17b	2.14a	1.24b	15

* After storage for 4 weeks @ 4 °C

No Gypsum

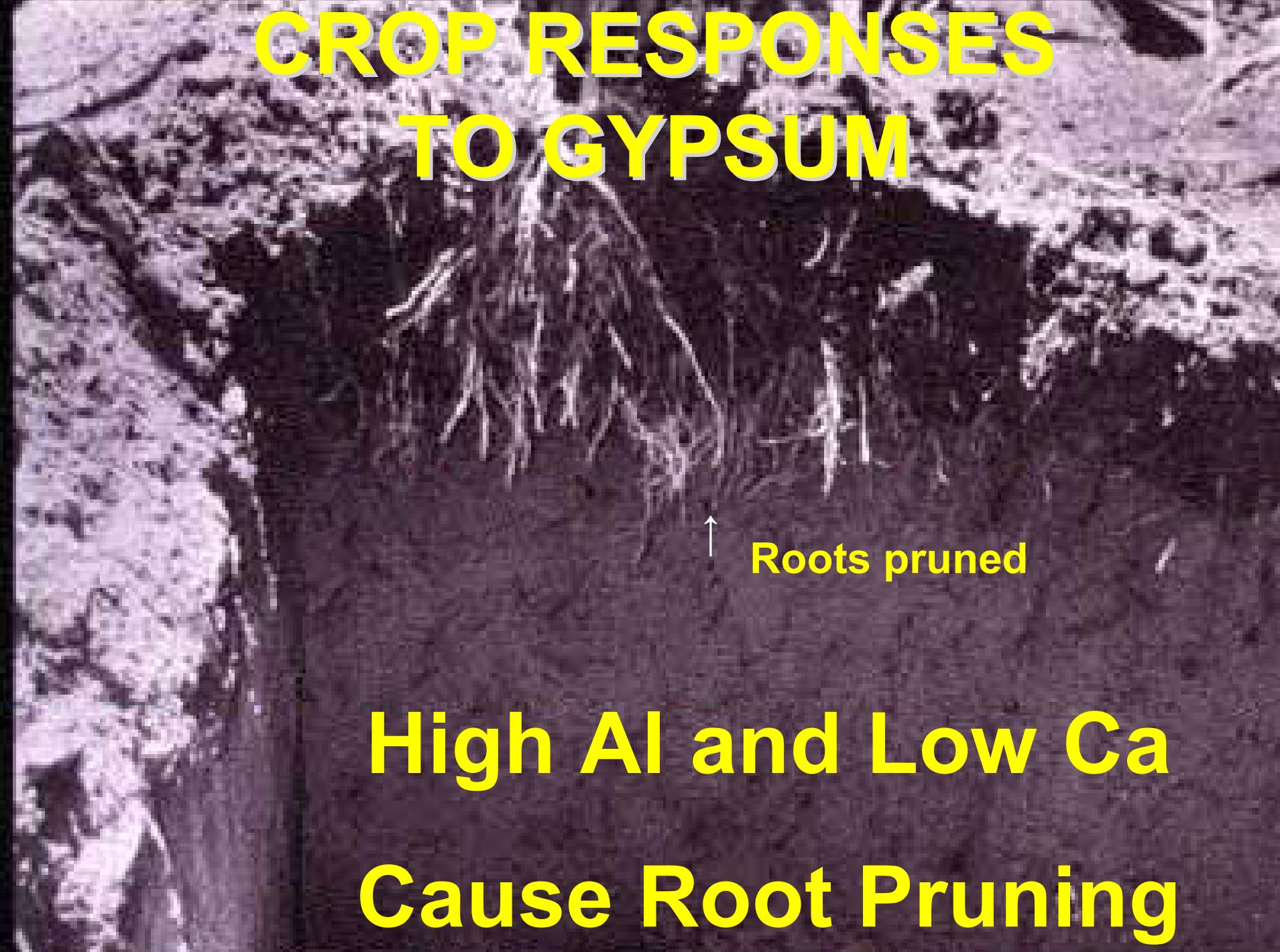


Fruit Quality after 4
Weeks of Storage @
 40°F

0.5 T Gypsum/ac



CROP RESPONSES TO GYPSUM

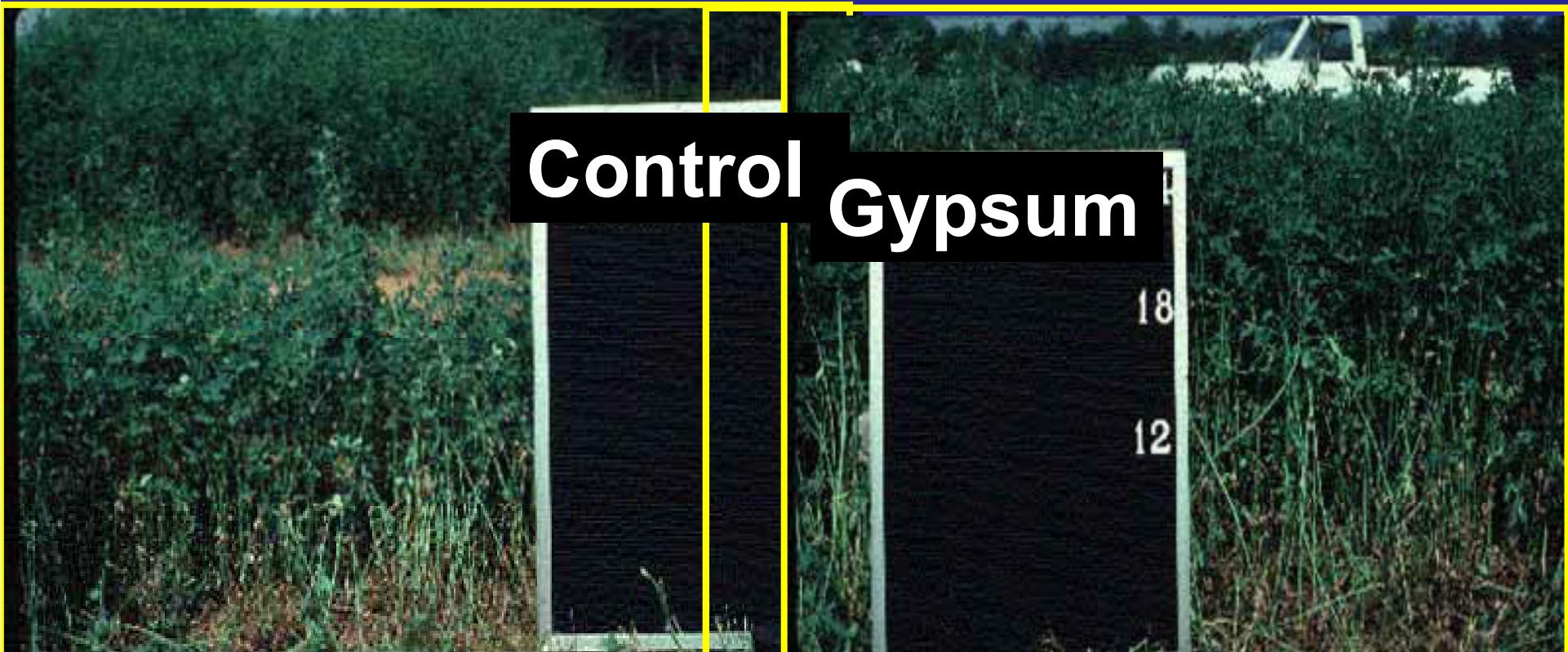


↑ Roots pruned

High Al and Low Ca
Cause Root Pruning

CROP RESPONSES TO GYPSUM

Reduced Levels of Toxic Al
Increased levels of soluble Ca



Control Gypsum

Root Development

Control



Gypsum

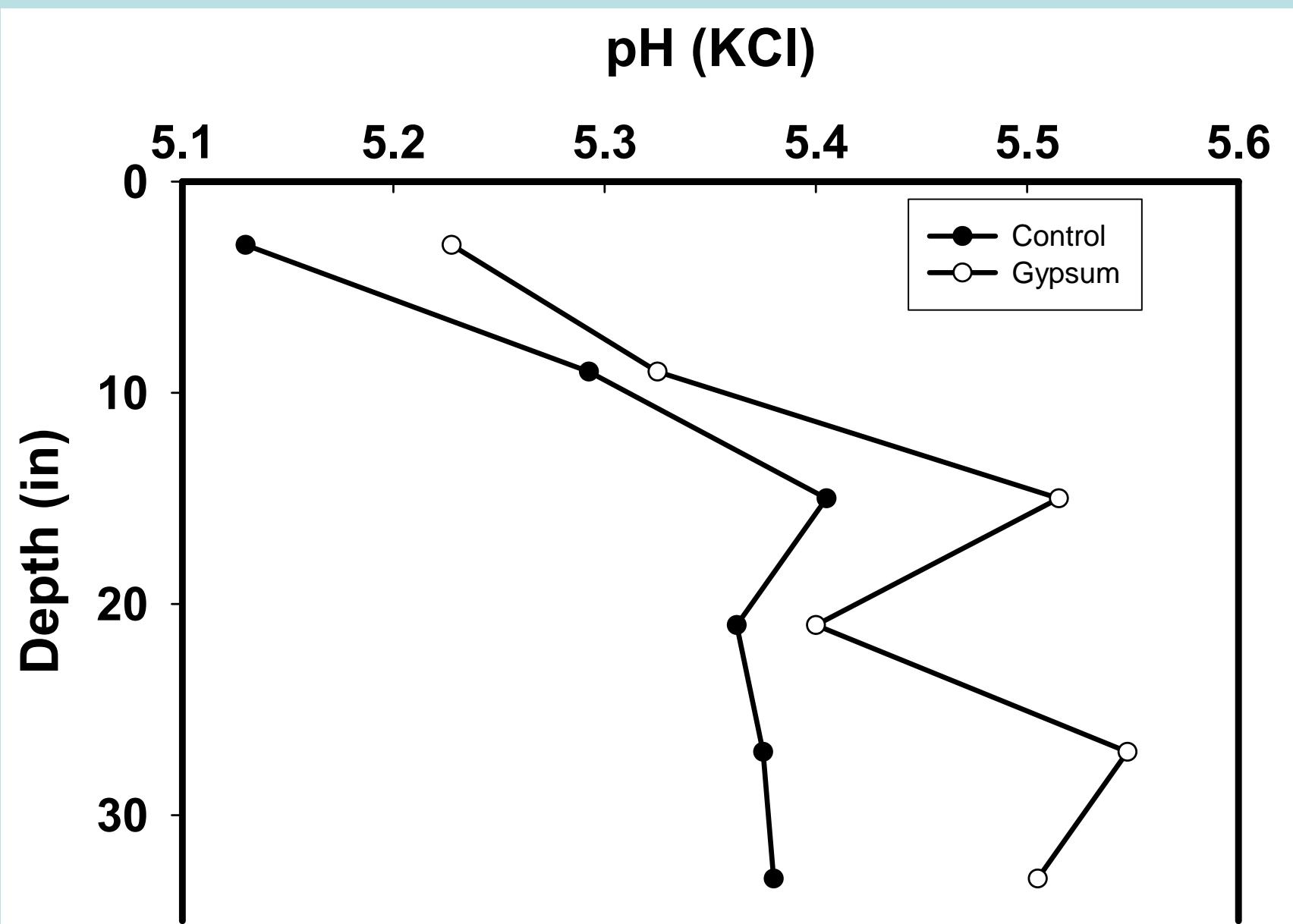


Alfalfa

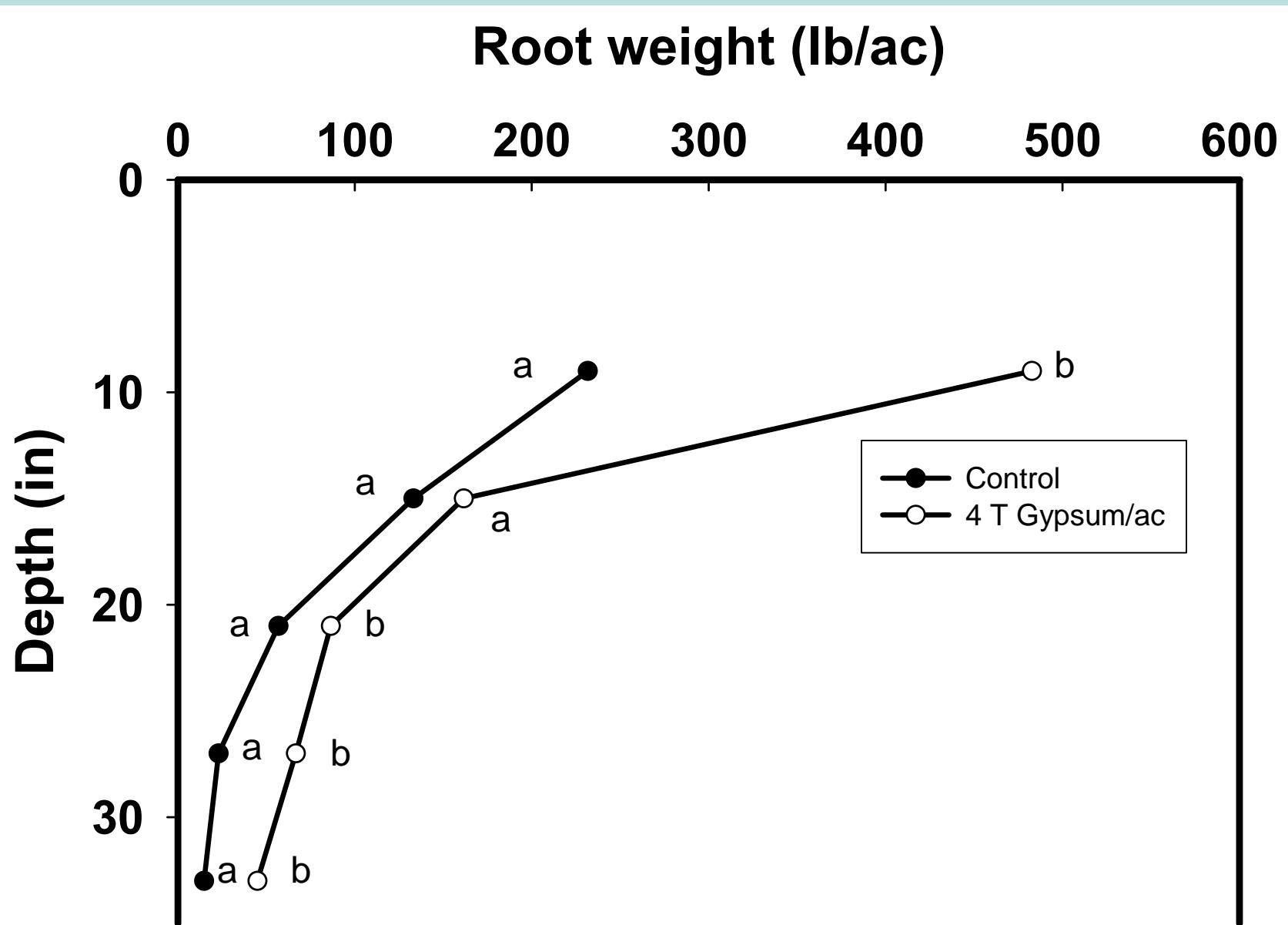
ALFALFA-BERMUDA

Treatment	Hay yield (lb/ac)				
	Cut 1	Cut 2	Cut 3	Cut 4	Total
Control	1.31	1.00	1.29	0.88	4.48
4.5 T Gypsum/ac	1.53	1.06	1.38	1.01	4.98

ALFALFA-BERMUDA

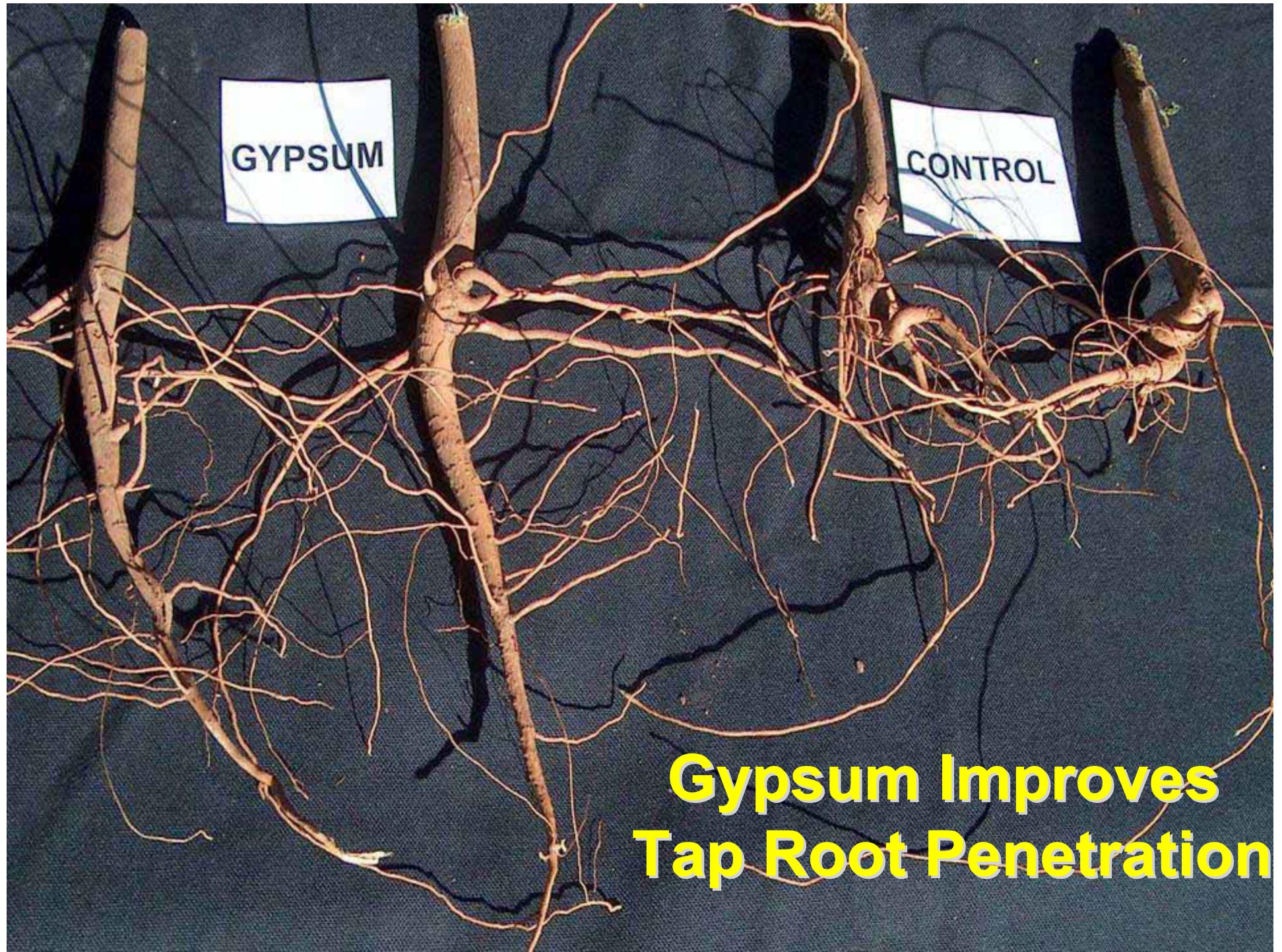


ALFALFA-BERMUDA



COTTON RESPONSE TO GYPSUM

Treatment	Cotton lint yield (lb/ac)				
	2000	2001	2002	2003	2004
Control	309	767	889	338	663
Gypsum	308	985	1113	383	772
Difference	0	218	224	45	109
Value (\$)	0	269.50	276.10	55.00	134.20
Cumul.	-125.00	144.50	420.60	475.60	609.80
Income (\$)					



**Gypsum Improves
Tap Root Penetration**

SOYBEANS



Soybeans



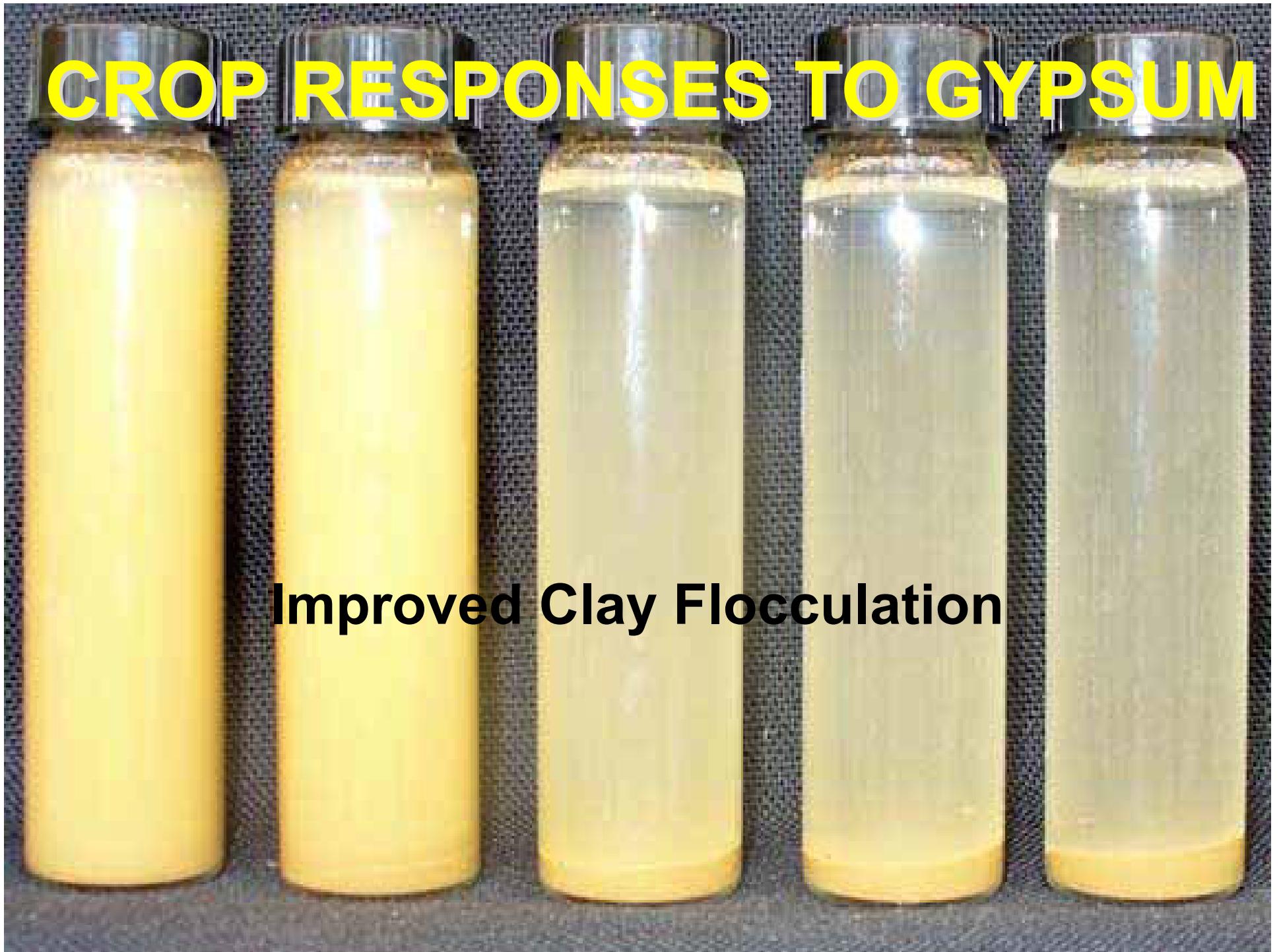
No Gypsum



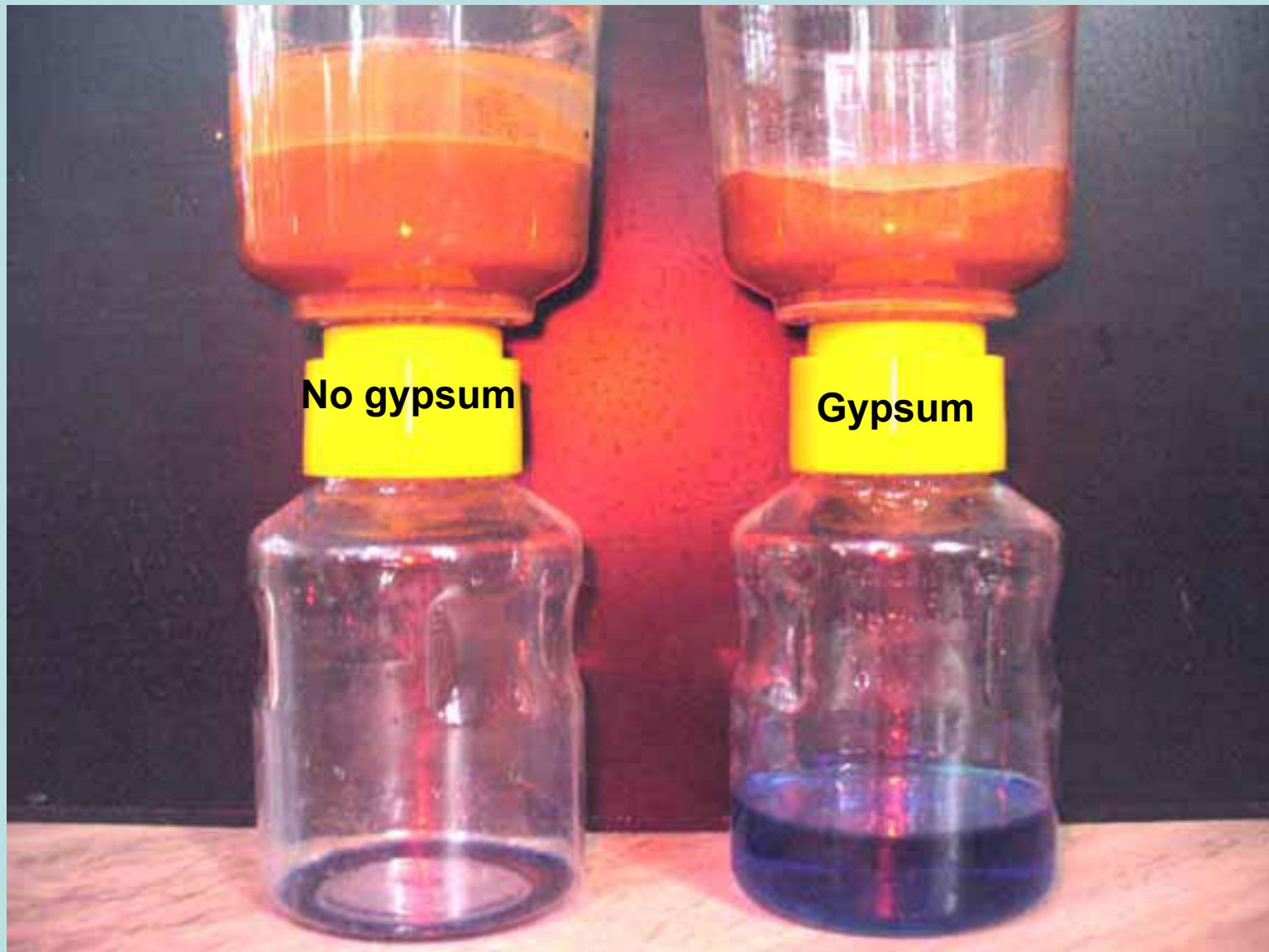
Gypsum

CROP RESPONSES TO GYPSUM

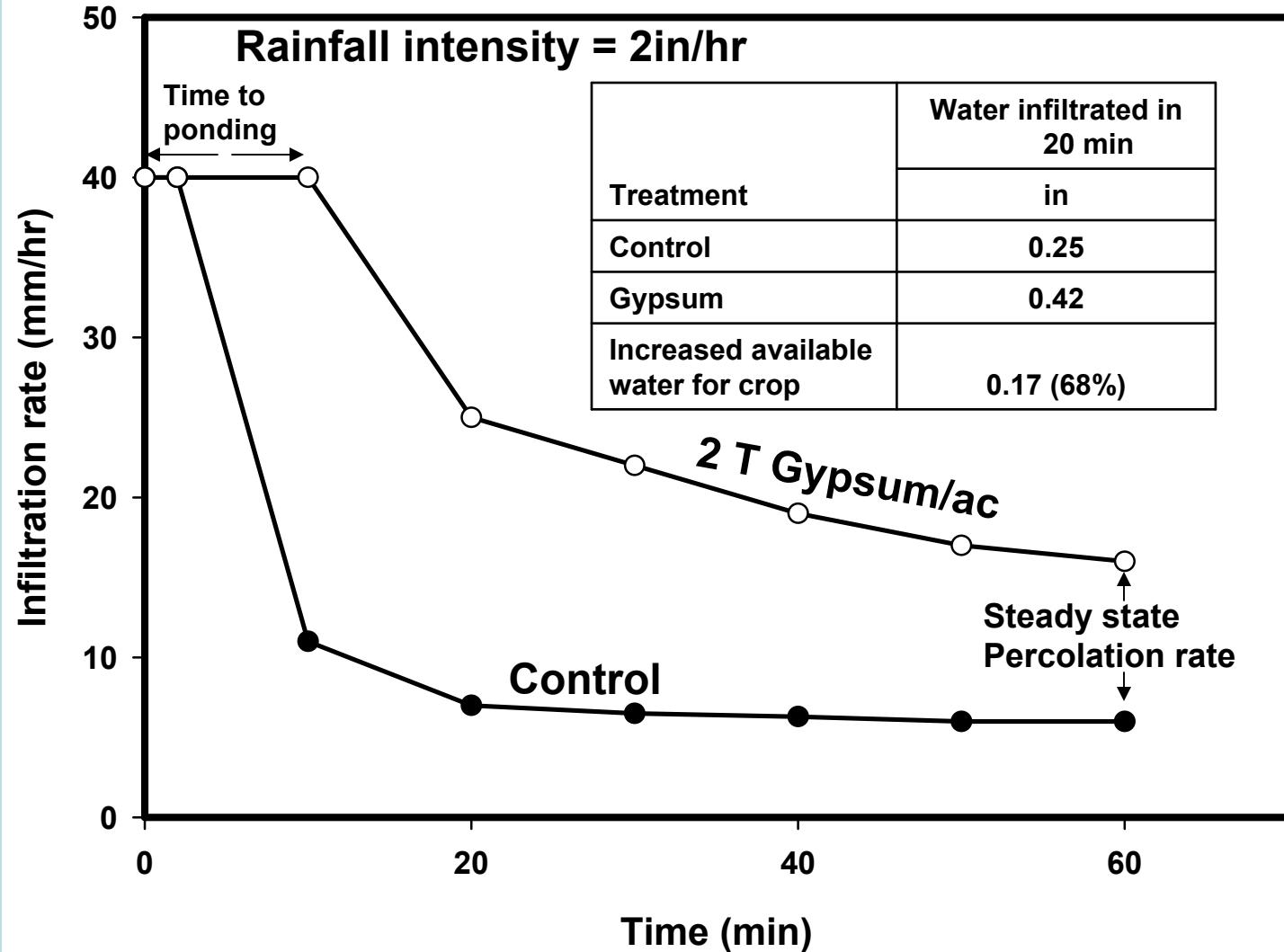
Improved Clay Flocculation



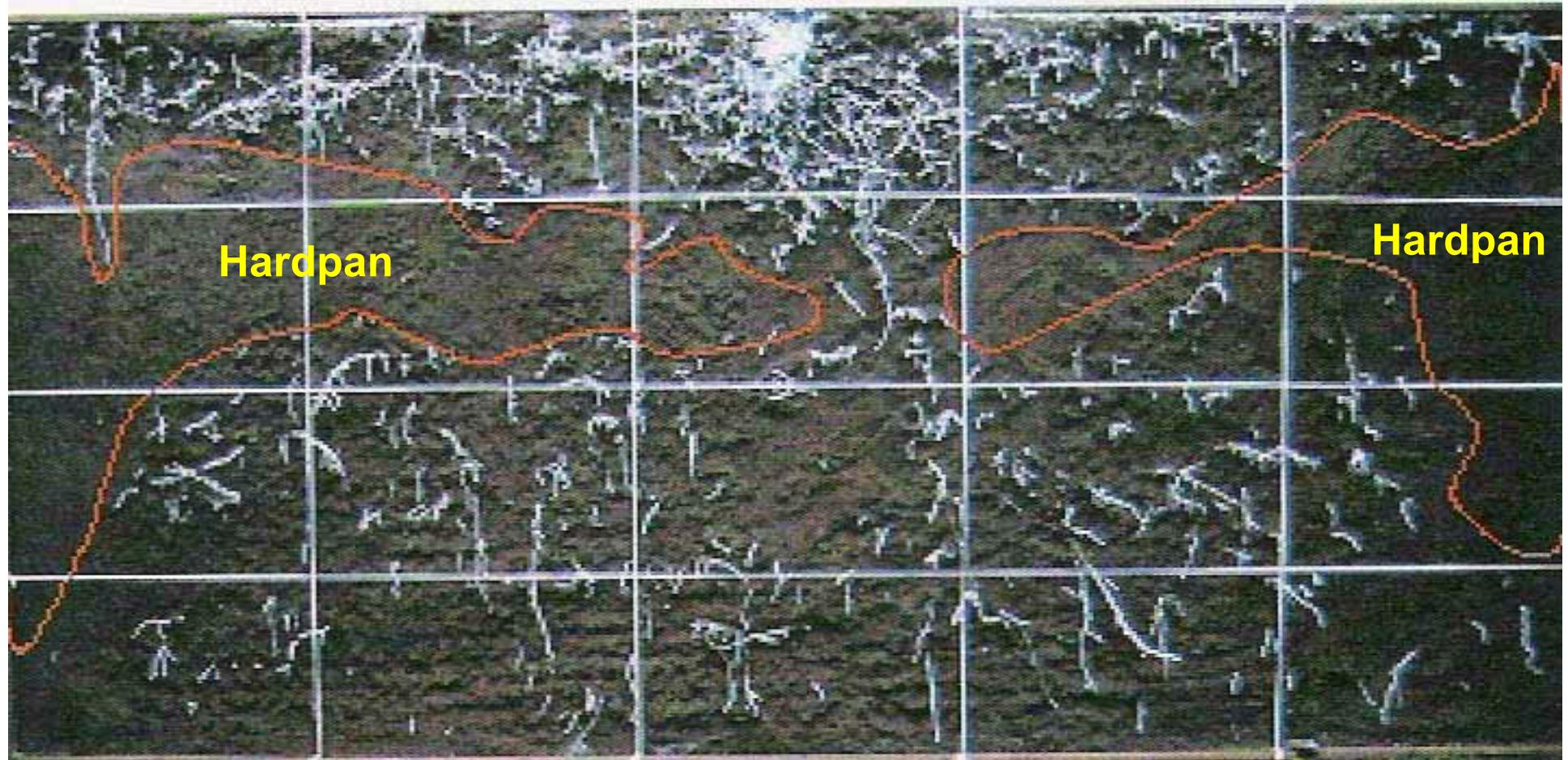
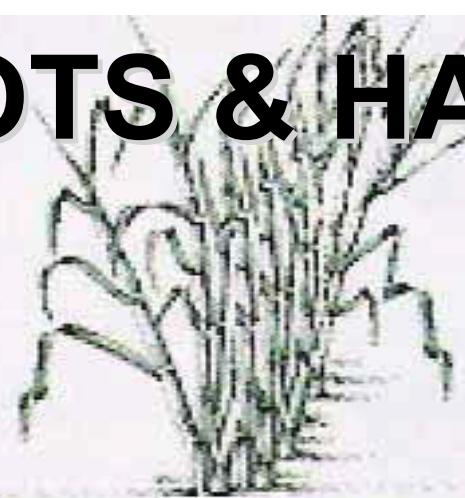
GYPSUM IMPROVES PERCOLATION



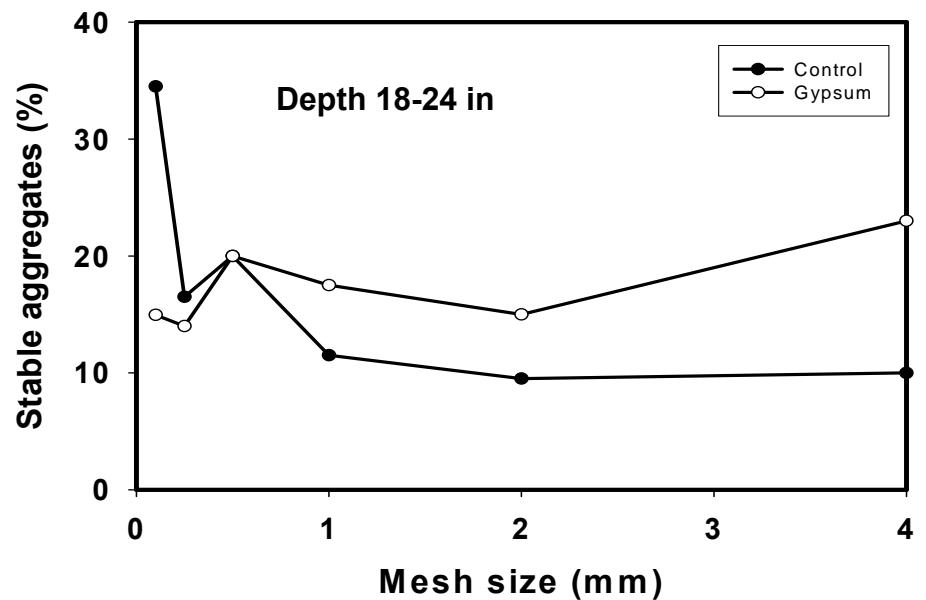
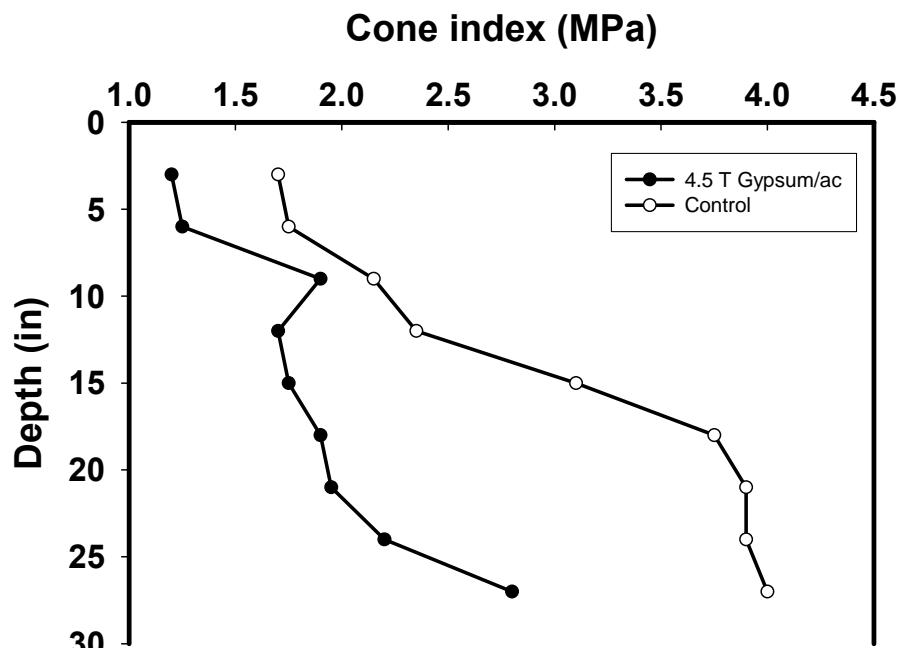
GYPSUM INCREASES INFILTRATION & PERCOLATION RATES IN CLAY SOIL



ROOTS & HARDPAN



GYPSUM SOFTENS SUBSOIL HARDPANS & IMPROVES AGGREGATION





Gypsum

CONCLUSIONS

- **Gypsum**
 - Supplies essential elements (Ca & S) to crops
 - Reduces levels of toxic Al in subsoils
 - Promotes clay flocculation
 - Softens subsoil hardpans
 - Improves aggregation
- **Result**
 - Crop yields and quality improved

No gypsum

Thank you for your attention





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I 785

Spectrum Analytic, Inc.

GUIDE TO INTERPRETING IRRIGATION WATER ANALYSIS



Soil Analysis
Plant Analysis
Fertilizer Analysis
Manure Analysis

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Introduction

While a few aspects of irrigation water quality have a direct impact on plants, the primary goal of water analysis is to judge the effect of the water on the soil, and ultimately on the plants grown on the soil. As such, much of the interpretation of the water analysis is based on a prediction of the consequences for the soil. The interpretation of the test results is, in many cases, dependant on the intended use of the water. Some plant species and production systems may have much different requirements or tolerances. The interpretation guide lists some of these conditions and will help you evaluate your results.

Water Salinity

Water salinity is a measure of the total dissolved salts. Saline water poses several hazards:

- As the salinity of the soil is increased by the use of water containing appreciable soluble salts, plants have increasing difficulty absorbing water.
- A primary cause of water salinity is excess sodium (Na). As Na accumulates in the soil it can compete with other nutrients for uptake by the plants and may become directly toxic.
- Excess sodium in natural soil can lead to the loss of soil structure, causing the loss of soil permeability and leading to poor plant growth.
- Water with too little dissolved salts can also be a problem in that it may lead to soil permeability problems.
- Where irrigation is applied by overhead sprinklers, excess water salinity can lead to foliage damage.

SALINITY HAZARD LEVELS*						
Application	Units	None	Increasing	Significant	High	Severe
All seedlings	mmho/cm	<0.2	0.2-0.7	0.8-1.0	1.1-1.5	>1.5
Container plants	mmho/cm	<0.5	0.5-0.7	0.8-1.0	1.1-2.0	>2.0
Nurseries**	mmho/cm	<0.2	0.2-0.7	0.8-1.25	1.26-3.0	>3.0
Field crops	mmho/cm	<0.75	0.75-1.0	1.1-2.0	2.1-3.0	>3.0
Hydroponics Field crops	mmho/cm	<0.75	0.75-1.0	1.1-2.0	2.1-3.0	>3.0
Soil Permeability***	mmho/cm	>0.5				<0.4

* See appendix A for more specific information

** Some common salt sensitive plants include Contoeaster horizontalis, Photina fraseri, Ilex cornuta, Vinca minor, Hibiscus rosasinensis, Nanadina domestica, Azalea, Bardenia, and Limonium perezii. This list is not comprehensive

*** The University of California has found that irrigation with exceptionally “pure” water has caused soil permeability problems with some vineyard soils in Eastern CA

Water pH, Alkalinity, Bicarbonates, and Carbonates

Water pH

The pH is a measurement of the relative acidity or basicity of the water. The pH range is from 0 to 14. Values from 0 to 6.9 are acidic and those from 7.1 to 14 are basic or alkaline, with 7.0 being neutral. The pH scale is logarithmic, meaning that a change of 1.0 unit is a ten-fold change in either acidity or basicity. Therefore, changes of less than 1.0 unit may be significant. This characteristic of the water has a significant influence on other characteristics or reactions in the soil and water, as well as the way plants perform. A water pH between 6.0 and 7.0 is normally considered to be the most desirable for irrigation. When the pH is outside of this range, it indicates that special actions may need to be taken to improve crop performance.

Alkalinity

This indicates the ability of the water to increase the pH of the soil or growing media, and the buffering power (resistance to change) of the water itself. In other words, the ability of the water to act as a liming agent. Alkalinity is defined as the combined effect of bicarbonates (HCO_3^-) plus the carbonates (CO_3^{2-}). High alkalinity indicates that the water will tend to increase the pH of the soil or growing media, possibly to a point that is detrimental to plant growth. Low alkalinity could also be a problem in some situations. This is because many fertilizers are acid-forming and could, over time, make the soil too acid for some plant. If the water is also somewhat acidic, the process would be accelerated.

Another aspect of alkalinity is its potential effect on sodium (Na^+). Soil or artificial growing media irrigated with alkaline water may, upon drying, cause an excess of available sodium. Several potential problems could result.

- The excess available sodium could become directly toxic to some plants
- The salinity of the soil could be increased to the point that plant growth is damaged.
- Excess sodium could damage the structure of natural soil to the point that air and water infiltration are prevented, and root growth is restricted.

Among the components of water alkalinity, bicarbonates are normally the most significant concern. Typically, bicarbonates become an increasing concern as the water increases from a pH of 7.4 to 9.3. However, bicarbonates can be found in water of lower pH. Carbonates become a significant factor as the water pH increases beyond 8.0 and are a dominant factor when the pH exceeds about 10.3. High levels of bicarbonates can be directly toxic to some plant species. Bicarbonate levels above 3.3 me/l (200 ppm) will cause lime (calcium and magnesium carbonate) to be deposited on foliage when irrigated with overhead sprinklers. This may be undesirable for ornamental plants. Similar levels of bicarbonates may also cause lime deposits to form on roots, which can be especially damaging to many tree species. High water alkalinity can be corrected with acid injection (see [appendix D](#)).

Danger from high alkalinity is governed in part by the volume of soil or artificial media involved. For example, greenhouse transplant production (plugs) have very little soil media and are less tolerant of a given alkalinity level than most other container production systems. Field production will typically be the most tolerant. An example of this effect is illustrated in the guidelines published by the Univ. of Massachusetts.

SUGGESTED ALKALINITY GUIDELINES (ppm CaCO_3)

Container Size	Acceptable Alkalinity	Concern Level
Plugs	60-100	<40, >120
Small Pots	80-120	<40, >140
4 -5 Pots	100-140	<40, >160
>6 Pots	120-180	<60, >200

At Spectrum Analytic, we have chosen the following guidelines, based on multiple sources of information. However, these levels should be viewed in light of the pH requirements of the crop. Alkalinity hazards may be slightly higher for acid-loving crops, and less for high pH tolerant crops.

ALKALINITY HAZARD LEVELS						
Application	Units	None	Increasing	Significant	High	Severe
Field crops	me/l CaCO ₃	<1.0	1.0-2.0	2.0-3.0	3.0-4.0	>4.0
	ppm CaCO ₃	<50	50-100	100-150	150-200	>200
Greenhouse and Nurseries*	me/l CaCO ₃	<1.0	1.0-1.5	1.5-2.0	2.0-3.0	>3.0
	ppm CaCO ₃	<50	50-75	75-100	100-150	>150
Greenhouse "Plugs"	me/l CaCO ₃	<1.0	1-1.25	1.25-1.5	1.5-2.0	>2.0
	ppm CaCO ₃	<50	50-63	63-75	75-100	>100

* Some floriculture crops may have an upper alkalinity limit of 2 me/l or 100 ppm CaCO₃ equivalent.

BICARBONATES (HCO₃) HAZARD LEVELS						
Application	Units	None	Increasing	Significant	High	Severe
Field crops	me/l HCO ₃	<1.0	1.0-2	2.0-3.0	3.0-4.0	>4.0
	ppm HCO ₃	<61	61-122	122-183	183-244	>244
Greenhouse and Nurseries*	me/l HCO ₃	<1.0	1.0-1.5	1.5-2.0	2.0-3.0	>3.0
	ppm HCO ₃	<61	61-92	92-122	122-183	>183
Greenhouse "Plugs"	me/l HCO ₃	<1.0	1.0-1.25	1.25-1.5	1.5-2.0	>2.0
	ppm HCO ₃	<61	61-76	76-92	92-122	>122

*Bicarbonate levels above 3.3 me/l (200 ppm) will cause lime (calcium and magnesium carbonate) to be deposited on foliage when irrigated with overhead sprinklers. This may be undesirable for ornamental plants. Similar levels of bicarbonates may also cause lime deposits to form on roots, which can be especially damaging to many tree species. Acid injection into the irrigation water is needed to correct this condition. (See appendix D).

Carbonates (CO₃)

Carbonates in water typically consist of precipitated calcium (CaCO₃) or magnesium carbonate (MgCO₃). They are the same compounds as the active portions of lime and have a similar effect on soil and plant growth as lime. Generally, water that contains appreciable carbonates will have already exceeded desirable bicarbonate levels. The carbonate content of water is considered in conjunction with bicarbonates for several important evaluations such as alkalinity, the sodium adsorption ratio (SAR), adjusted sodium adsorption ratio (SAR adj.), and residual sodium carbonate (RSC). Carbonates will not be a significant component of water at a pH below 8.0, and will likely dominate at a pH above 10.3.

Sodium Adsorption Ratio (SAR)

The SAR is used to predict the danger of sodium (Na) accumulation in the soil. While some plants, such as table beets, spinach, celery, and possibly others have a relatively high requirement for, or tolerance of Na, most plants have minimal needs for, or tolerance of high Na levels. The SAR relates the relative concentration of Na to the combined concentration of Ca and Mg. Another hazard that excess Na presents in natural soils is the danger of loss of soil structure with the resulting reduction in soil permeability and aeration. The interpretive guidelines for SAR are as follows.

SAR HAZARD LEVELS*					
Application	None	Increasing	Significant	High	Severe
Most Production Systems	<1	1-2	2-4	4-5	>5
Hydroponics	<3	3-7	7-8	8-9	>9

*The SAR, and SAR adj. can be reduced by

1. Increasing the calcium content of the water or soil by adding gypsum or another soluble calcium salt (see appendix B).
2. The SAR and SAR adj. can be reduced by reducing the bicarbonate (HCO_3) level. This is normally accomplished by acidifying the irrigation water.

Adjusted Sodium Adsorption Ratio (SAR adj.)

The SAR adj. (sometimes symbolized as Adj R_{Na}) is a modification of the original SAR calculation. It serves the same purposes, but is modified to include the effects of bicarbonates and carbonates, in addition to Ca and Mg. It is generally considered to be more useful information.

SAR adj. HAZARD LEVELS*					
Application	None	Increasing	Significant	High	Severe
Direct plant Impact	<3	3-6	6-8	8-9	>9
Permeability of Natural Soil	<6	6-7	7-8	8-9	>9

*The SAR, and SAR adj. can be reduced by

1. Increasing the calcium content of the water or soil by adding gypsum or another soluble calcium salt (see appendix B).
2. The SAR adj. can be reduced by reducing the bicarbonate (HCO_3) level. This is normally accomplished by acidifying the irrigation water.

Residual Sodium Carbonate

Residual sodium carbonate (RSC) exists in irrigation water when the carbonate (CO_3) plus bicarbonate (HCO_3) content exceeds the calcium (Ca) plus magnesium (Mg) content of the water. Where the water RSC is high, extended use of that water for irrigation will lead to an accumulation of sodium (Na) in the soil. The results of this include 1) Direct toxicity to crops, 2) Excess soil salinity (EC) and associated poor plant performance, and 3) Where appreciable clay or silt is present in the soil, loss of soil structure and associated decrease in soil permeability.

RSC HAZARD					
Units	None	Increasing	Significant	High	Severe
me/l	<1.24	1.25-1.7	1.7-2.1	2.1-2.5	>2.5

*See appendix B for gypsum recommendations to counter a high RSC.

Lime Deposition Potential

Lime Deposition Potential (LDP) is used by fruit producers to avoid or minimize or avoid the occurrence of lime spots on fruit or tree roots. Fruit deposition is unsightly and detracts from the value of the crop, while root deposition can be harmful to the trees. While no data exists supporting the use of this evaluation for other plants, it would seem useful in other circumstances where clean fruit or foliage is important, or with root deposition on most tree species.

LDP HAZARD LEVELS						
Application	Unit	None	Increasing	Significant	High	Severe
“Overhead Irr. or Evaporative Cooling”	CaCO ₃ (me/l)	<2	2.1-2.5	2.6-3.0	3.1-4.0	>4.0
	CaCO ₃ (ppm)	<100	101-125	126-150	151-200	>200

Individual Elements or Compounds

Nutrient Elements

The status assignments are related to the amounts typically found in acceptable irrigation water and not necessarily related to adequacy for crop growth. Some micronutrients (B, Cu, Fe, Mn, and Mo) may be present in sufficient or excessive amounts for some species.

RELATIVE STATUS							
Element	Application	Units	V. Low	Low	Medium	High	V. High
pH	All, 5.0 – 7.0 is normally acceptable. Some species benefit from more acid conditions.						
pH	micro-irrig. blockage		<6.5	6.5-7.2	7.2-7.6	7.7-8.0	>8.0
Nitrogen, Total (N)	All	ppm	<18	19-36	37-54	55-90	>90
Nitrate-N (NO₃-N)	All	ppm	<15	16-30	31-45	46-75	>75
Ammonium-N (NH₄-N)	All	ppm	<3	4-6	7-9	10-15	>15
NH₄-N + NO₃-N	Hydroponics	ppm	<5	6-13	14-21	22-30	>30
Phosphorus (P)	All	ppm	<1	1-1.9	2-2.9	3-5	>5
Potassium (K)	All	ppm	<3	3.1-4.5	4.6-6.0	6.1-10.0	>10
Calcium (Ca)*	All	ppm	<40	41-80	81-120	121-150	>150
Magnesium (Mg)	All	ppm	<8	9-16	17-24	25-30	>30
Sulfate-S (SO₄-S)	All	ppm	<24	25-50	51-240	241-300	>300
Boron (B)**	Greenhouse, Nursery	ppm	<0.25	0.26-0.5	0.51-0.8	0.81-2.0	>2.0
Boron (B)**	Field crops	ppm	<0.75	0.76-1.17	1.18-1.6	1.61-2.0	>2.0
Boron (B)	Hydroponics	ppm	<1.0	1.1-1.25	1.26-1.6	1.61-2.0	>2.0
Copper (Cu)	All	ppm	<0.05	0.06-0.10	0.11-1.20	0.21-0.30	>0.30
Iron (Fe)	All	ppm	<0.20	0.21-0.30	0.31-0.40	0.41-0.50	>0.50
Iron (Fe)	micro-irrig. blockage	ppm	<0.20	0.21-0.63	0.64-1.0	1.1-1.5	>1.5
Manganese (Mn)	All	ppm	<0.50	0.51-0.75	0.76-1.0	1.1-2.0	>2.0
Manganese (Mn)	micro-irrig. blockage	ppm	<0.10	0.11-0.57	0.58-1.0	1.1-1.5	>1.5
Molybdenum (Mo)	All	ppm	<0.005	.006-0.01	0.011-.020	.021-0.05	>0.05

*See appendix B for gypsum recommendations.

** See appendix E for more information on boron tolerance by crops.

Non-Nutrient Elements

The following elements, when in excess can be damaging to plant growth

TOXICITY HAZARD

Element	Application	Units	None	Increasing	Significant	High	Severe
Sodium (Na)*	Foliar	ppm	<69				
Sodium (Na)*	Woody Ornamentals	ppm	<30	31-35	36-45	46-50	>50
Sodium (Na)*	Others	-----		Use SAR or SAR adj.			
Sodium (Na)	Foliar	ppm	<69		“No specific calibration available”		
Chloride (Cl)**	Foliar	ppm	<40	41-60	61-80	81-100	>100
Chloride (Cl)**	Soil	ppm	<70	71-140	141-240	241-345	>345
Chloride (Cl)	Hydroponics	ppm	<70	71-140	141-240	241-345	>345
Aluminum (Al)	Long Term Irrig.	ppm	<1	1.1-3.0	3.1-4.0	4.1-5.0	>5.0
Arsenic (As)	Long Term Irrig	ppm	<0.1		“No specific calibration available”		
Beryllium (Be)	Long Term Irrig	ppm	<0.1		“No specific calibration available”		
Cadmium (Cd)	Long Term Irrig	ppm	<0.01		“No specific calibration available”		
Chromium (Cr)	Long Term Irrig	ppm	<0.1		“No specific calibration available”		
Cobalt (Co)	Long Term Irrig.	ppm	<0.05		“No specific calibration available”		
Fluoride (Fl)***	Long Term Irrig.	ppm	<1		“No specific calibration available”		
Lead (Pb)	Long Term Irrig.	ppm	<5		“No specific calibration available”		
Lithium (Li)	Long Term Irrig.	ppm	<2.5		“No specific calibration available”		
Nickel (Ni)	Long Term Irrig.	ppm	<0.2		“No specific calibration available”		
Selenium (Se)	Long Term Irrig.	ppm	<0.02		“No specific calibration available”		
Vanadium (V)	Long Term Irrig.	ppm	<0.1		“No specific calibration available”		

*See appendix B for gypsum recommendations to offset excessive Na.

** Small amounts of chlorides can be toxic or detrimental to blueberries, tobacco, certain Southern soybean varieties, and possibly other plants.

*** 1 ppm of Fluoride, which is the level added to most fluoridated water, is safe for most plants, but not for members of the lily family and the genera Chamaedorea, Chlorophytum, Ctenanthe, Dracaena, Marantha, and Spathiphyllum. Other unidentified plants may also be sensitive. Fluoride toxicity causes scorch on the tips of older leaves.

Appendix A

Relative Soil Salt Tolerances of Agricultural and Horticultural Crops

CROP	THRESHOLD SALINITY OF SOIL EXTRACT	REPORTED DECREASE IN YIELD WHEN SOIL CROSSES SALINITY THRESHOLD*
SENSITIVE	mmhos/cm	% yield loss
Bean, Edible	1.0	19
Carrot	1.0	14
Strawberry	1.0	33
Onion	1.2	16
Almond	1.5	19
Blackberry	1.5	22
Boysenberry	1.5	22
Plum, Prune	1.5	18
Apricot	1.6	24
Orange	1.7	16
Peach	1.7	21
Grapefruit	1.8	16

MODERATELY SENSITIVE		
Turnip	0.9	9.0
Radish	1.2	13
Lettuce	1.3	13
Clover	1.5	12
Grape	1.5	9.6
Orchardgrass	1.5	6.2
Pepper	1.5	14
Sweet Potato	1.5	11
Broadbean	1.6	9.6
Corn	1.7	12
Flax	1.7	12
Potato	1.7	12
Sugarcane	1.7	5.9
Cabbage	1.8	9.7
Celery	1.8	6.2
Corn (forage)	1.8	7.4
Alfalfa	2.0	7.3
Spinach	2.0	7.6
Cowpea (forage)	2.5	11

CROP	THRESHOLD SALINITY OF SOIL EXTRACT	REPORTED DECREASE IN YIELD WHEN SOIL CROSSES SALINITY THRESHOLD*
MODERATELY SENSITIVE (continued)		
Cucumber	2.5	13
Tomato	2.5	9.9
Broccoli	2.8	9.2
Vetch, common	3.0	11
Rice, paddy	3.0	12
Squash, scallop	3.2	16

MODERATELY TOLERANT		
Wildrye, beardless	2.7	6.0
Sudangrass	2.8	4.3
Wheatgrass, std crested	3.5	4.0
Fescue, Tall	3.9	5.3
Beet, Red	4.0	9.0
Harding Grass	4.6	7.6
Squash, zucchini	4.7	9.4
Cowpea	4.9	12
Soybean	5.0	20
Trefoil, Birdsfoot	5.0	10
Ryegrass, perennial	5.6	7.6
Wheat, durum	5.7	5.4
Barley, forage	6.0	7.1
Wheat	6.0	7.1
Sorghum	6.8	16

TOLERANT		
Date Palm	4.0	3.6
Bermudagrass	6.9	6.4
Sugarbeet	7.0	5.9
Wheatgrass, fairway, crested	7.5	6.9
Wheatgrass, Tall	7.5	4.2
Cotton	7.7	5.2
Barley	8.0	5.0

*yield losses in a particular field could be significantly different than these reported values

Trees, Scrubs, and Ornamentals

The following information was obtained from Colorado State University, Cooperative Extension, and Tri-River Area

Deciduous Trees

HIGH TOLERANCE - UP TO 8 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
Acer plantanoides, Norway maple	Gleditsia triacanthos, Honeylocust
Aesculus hippocastanum, Common Horsechestnut	Quercus Alba, White Oak
Ailanthus altissima, Tree of Heaven	Quercus robur, English Oak
Amelanchier canadensis, Shadblow	Quercus rubra, Red oak
Crataegus crus-galli, Cockspur Hawthorn	Robinia pseudoacacia, Black Locust
Elaeagnus angustifolia, Russian Olive – (possibly up to 10 mmhos)	Ptelea trifoliata, Wafer Ash

MODERATELY HIGH TOLERANCE - UP TO 6 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
Acer negundo, Box-elder	Betula alleghaniensis, Yellow Birch
Acer ginnala, Amur maple	Betula papyrifera, Paper Birch
Betula lenta, Sweet Birch	Fraxinus americana, White Ash
Betula populifolia, Grey Birch	

MODERATELY HIGH TOLERANCE - UP TO 6 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
Populus alba, White Poplar	Prunus virginiana, Choke Cherry
Populus deltoides, Eastern Cottonwood	Salix alba 'Tristis', Golden Weeping Willow
Populus grandidentata, Large-toothed Aspen	Salix alba 'Vitellina', Golden Willow
Populus nigra Lombardy, Poplar	Salix nigra, Black Willow
Populus tremuloides, Trembling Aspen	Sophora japonica, Japanese Pagoda Tree
Prunus padus, European Bird Cherry	Ulmus pumila, Siberian Elm
Prunus serotina, Black Cherry	

MODERATE TOLERANCE - UP TO 4 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
Catalpa speciosa, Northern Catalpa	Fraxinus pennsylvanica, Green Ash
Celtis occidentalis, Hackberry	Ginkgo biloba, Maidenhair Tree
Celtis reticulata, Netleaf hackberry	Koelreuteria paniculata, Goldenrain
Cercis occidentalis, Western Redbud	Maclura pomifera, Osage-Orange
Fraxinus anomala, Singleleaf Ash	Pyrus species, Pear
Fraxinus excelsior, European Ash	Ulmus americana, American Elm

SLIGHT TOLERANCE - UP TO 2 mmhos/cm (mS)	
Names Scientific, Common	Names Scientific, Common
<i>Quercus palustris</i> , Pin Oak	Malus species and cultivars, Apple and Crabapple

SENSITIVE OR INTOLERANT	
Names Scientific, Common	Names Scientific, Common
<i>Acer rubrum</i> , Red Maple	<i>Plantanus acerifolia</i> , London Plane
<i>Acer saccharinum</i> , Silver Maple	<i>Sorbus aucuparia</i> , European Mountain-Ash
<i>Acer saccharum</i> , Sugar Maple	<i>Tilia Americana</i> , American linden
<i>Cercis canadensis</i> , Eastern Redbud	<i>Tilia cordata</i> , Littleleaf Linden
<i>Juglans nigra</i> , Black Walnut	

Coniferous Trees

HIGH TOLERANCE - UP TO 8 mmhos/cm (mS)	
Names Scientific, Common	Names Scientific, Common
<i>Juniperus chinensis</i> , Pfitzer juniper	<i>Pinus mugo</i> , Mugho Pine
<i>Picea glauca</i> `densata', Black Hills Spruce	<i>Pinus nigra</i> , Austrian Pine

MODERATELY HIGH TOLERANCE - UP TO 6 mmhos/cm (mS)	
Names Scientific, Common	Names Scientific, Common
<i>Pinus ponderosa</i> , Ponderosa Pine	<i>Thuja occidentalis</i> , American Arborvitae
<i>Pinus thunbergiana</i> , Japanese Black Pine	

SLIGHT TOLERANCE - UP TO 2 mmhos/cm (mS)	
Names Scientific, Common	Names Scientific, Common
<i>Picea abies</i> , Norway Spruce	<i>Psedotsuga menziesii</i> , Douglas Fir
<i>Pinus strobus</i> , Eastern White Pine	<i>Taxus cuspidata</i> , Japanese Yew
<i>Pinus sylvestris</i> , Scotch Pine	

SENSITIVE OR INTOLERANT	
Names Scientific, Common	Names Scientific, Common
<i>Abies balsamea</i> , Balsam Fir	<i>Tsuga canadensis</i> , Canadian Hemlock
<i>Pinus resinosa</i> , Red or Norway Pine	

Scrubs

VERY HIGH TOLERANCE - UP TO 10 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Atriplex canescens</i> , Fourwing Saltbush	<i>Ceratoides lanata</i> , Common Winterfat
<i>Atriplex convertifolia</i> , Shadscale Saltbush	<i>Chrysothamnus greenei</i> , Greene Rabbitbrush
<i>Atriplex corrugata</i> , Mat Saltbush	<i>Chrysothamnus linifolius</i> , Flaxleaf Rabbitbrush
<i>Atriplex nuttalli</i> , Nuttall Saltbush	<i>Ephedra</i> , Mormon Teas
<i>Atriplex nuttalli cuneata</i> , Castle Valley Clover	<i>Ephedra torreyana</i> , Torrey Epheara
<i>Atriplex nuttalli gardneri</i> , Gardner Saltbush	<i>Kochia americana</i> , Greenmolly Summercypress
<i>Baccharis emoryi</i> , Emory Baccharis	<i>Sarcobatus vermiculatus</i> , Black Greasewood
<i>Baccharis glutinosa</i> , Seep-Willow	<i>Tamraix pentandra</i> , Westamen Tamarisk

HIGH SALT TOLERANCE - UP TO 8 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Caragana arborescens</i> , Siberian Peashrub	<i>Rhus trilobata</i> , Squawbush
<i>Chrysothamnus albidus</i> , Alkali Rabbitbrush	<i>Rhus typhina</i> , Staghorn Sumac
<i>Cytisus scoparius</i> , Scotch Broom	<i>Rhamnus frangula</i> , Glossy Buckthorn
<i>Elaeagnus commutata</i> , Silverberry	<i>Shepherdia canadensis</i> , Buffaloberry
<i>Elaeagnus multiflora</i> , Cherry Elaeagnus	<i>Spiraea vanhouttei</i> , Van Houtte Spirea
<i>Euonymus japonica</i> , Spindle Tree	<i>Symporicarpus albus</i> , Snowberry
<i>Halimodendron halodendron</i> , Salt-tree	<i>Syringa amurensis</i> japonica, Japanese Tree Lilac
<i>Hippophae rhamnoides</i> , Sea Buckthorn	<i>Syringa vulgaris</i> , Common Lilac
<i>Juniperus chinensis</i> , Pfitzer Juniper	<i>Potentilla fruticosa</i> 'Jackmanii', Jackman's potentilla
<i>Lonicera tatarica</i> , Tararian honeysuckle	<i>Tamarix gallica</i> , Tamarisk
<i>Rhamnus cathartica</i> , Common Buckthorn	

MODERATELY HIGH TOLERANCE - UP TO 6 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Artemisia frigida</i> , Fringed Sagewort	<i>Juniperus communis</i> , Common Juniper
<i>Artemisia spinescens</i> , Bud Sagebrush	<i>Philadelphus coronarius</i> , Sweet Mockorange
<i>Artemisia tridentata</i> , Basin Big Sagebrush	<i>Purshia glandulosa</i> , Desert Bitterbrush
<i>Buxus microphylla</i> , Japanese Boxwood	<i>Pyracantha fortuneana</i> , Pyracantha
<i>Chrysothamnus nauseosus</i> , Rubber Rabbitbrush	<i>Rhus glabra</i> , Smooth Sumac
<i>Chrysothamnus visci diflorus</i> , Couglas Rabbitbrush	<i>Rhus trilobata</i> , Skunkbush Sumac
<i>Ephedra nevadensis</i> , Nevada Mormontea	<i>Shepherdia rotundifolia</i> , Roundleaf Buffaloberry
<i>Forsythia x intermedia</i> , Showy Border Forsythia	<i>Spirea 'Froebel's'</i> , Froebel's spirea

SLIGHT TO MODERATE - UP TO 4 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Artemisia cana</i> , Silver Sagebrush	<i>Rosa woodsii</i> , Wood's Rose
<i>Berberis fremontii</i> , Fremont Barberry	<i>Salix exigua</i> , Coyote Willow
<i>Robinia neo-mexicana</i> , New Mexican Locust	

SLIGHT TOLERANCE - UP TO 2 mmhos/cm (mS)	
Names Scientific, Common	Names Scientific, Common
<i>Chaenomeles speciosa</i> , Flowering Quince	Rosa rugosa, Rugosa Rose - may be slightly tolerant
<i>Ligustrum vulgare</i> , Common Privet	<i>Viburnum opulus</i> , High Bush Cranberry

SENSITIVE OR INTOLERANT	
Names Scientific, Common	Names Scientific, Common
<i>Cornus racemosa</i> , Grey Dogwood	Rosa, Rose
<i>Cornus stolonifera</i> , Red-osier dogwood	

Vines

HIGH TOLERANCE - UP TO 8 mmhos/cm (mS)	
Names Scientific, Common	Names Scientific, Common
<i>Lonicera tataricum</i> 'Zabelii', Zabel's Honeysuckle	<i>Parthenocissus quinquefolia</i> , Virginia Creeper

SLIGHT TOLERANCE - UP TO 4 mmhos/cm (mS)

Names Scientific, Common
Lonicera japonica, Japanese Hall's Honeysuckle

Flowers

HIGH TO MODERATE - 6 TO 8 mmhos/cm (mS)	
Names Scientific, Common	Names Scientific, Common
<i>Aquilegia micrantha</i> , Cliff Columbine	<i>Psilosotrophe bakerii</i> , Paperflower
<i>Machaeranthera xylorrhiza</i> , Common Woody Aster	<i>Stanley pinnata</i> , Prince's Plume - a good indication that the soil is high in selenium

MODERATE SALT TOLERANCE - 4 TO 6 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Fallugia paradoxa</i> , Common Apache	<i>Yucca elata</i> , Soaptree Yucca
<i>Oenothera caespitosa</i> , Tufted Evening Primrose	<i>Yucca glauca</i> , Small Soapweed
<i>Sphaeralcea coccinea</i> , Scarlet Globemallow	

SLIGHTLY TOLERANT - 2 TO 4 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Argemone</i> spp., Prickly Poppies	<i>Gallardia pennatifida</i> , Cutleaf Blanketflower
<i>Calochorutus</i> spp., Mariposa Lilly	<i>Mentzelia</i> spp., Blazing Stars
<i>Chrysopsis villosa</i> , Hairy Goldenaster	<i>Physaria australis</i> , Twinpod

Grasses and Other Ground Covers

HIGH TOLERANCE - 14 TO 18 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Agropyron elongatum</i> , Tall Wheatgrass	<i>Elymus triticoides</i> , Beardless wildrye
<i>Agropyron smithii</i> , Western Wheatgrass	<i>Lotus corniculatus</i> , Birdsfoot trefoil - a legume
<i>Distichlis</i> , Saltgrass	

HIGH TOLERANCE - 14 TO 18 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Puccinellia</i> , alkaligrass	<i>Sporobolus airoides</i> , Alkali sacaton

MODERATELY HIGH - 8 TO 12 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Bromus marginatus</i> , Mountain brome	<i>Melilotus officinalis</i> , Yellow sweet clover
<i>Lolium perenne</i> , Perennial ryegrass	<i>Trifolium fragiferum</i> , Strawberry clover
<i>Melilotus alba</i> , White sweet clover	

MODERATE - 8 TO 4 mmhos/cm (mS)

Names Scientific, Common	Names Scientific, Common
<i>Agropyron cristatum</i> , Crested Wheatgrass	<i>Dactylis glomerata</i> , Orchardgrass
<i>Agropyron riparium</i> , Streambank Wheatgrass	<i>Elymus giganteus</i> , Mammoth wildrye
<i>Agropyron trachycaulum</i> , Slender Wheatgrass	<i>Elymus junceus</i> , Russian wildrye
<i>Arrhenatherum elatius</i> , Tall meadow oatgrass	<i>Festuca arundinacea</i> , Tall Fescue
<i>Bromus inermis</i> , Smooth brome	<i>Medicago sativa</i> , Alfalfa
<i>Buchloe dactyloides</i> , Buffalograss	<i>Phalaris arundinacea</i> , Reed Canarygrass

LOW SALT TOLERANCE

Names Scientific, Common	Names Scientific, Common
<i>Alopecurus pratensis</i> , Meadow foxtail	<i>Poa pratensis</i> , Kentucky Bluegrass
<i>Festuca rubra</i> , Red fescue	<i>Trifolium pratense</i> , Red clover
<i>Festuca elatior</i> , Meadow fescue	<i>Trifolium repens</i> , White clover

Appendix B

Calculating Gypsum Requirement

As with most recommendations in agriculture, more than one method of recommending gypsum has been developed. The various methods may not always agree, so we have reported several of them here.

Gypsum is recommended for two primary purposes. They are...

- To remove excess sodium (Na)
- To build soil Ca levels when a pH change is not desired.

Method 1

The following calculations may be used to calculate gypsum (22% Ca) rates in lb./A.

- To reduce Na saturation: Lb. gypsum/acre = C.E.C. x (%Na sat. - 5) x 18
- To build Ca saturation: Lb. gypsum/acre = C.E.C. x (desired %Ca sat. - present %Ca sat) x 18

Method 2

EXAMPLE: Assume that the soil CEC is 20 (meq/100 grams) and the Na concentration is 40%. You want to lower the Na concentration to 10%, or eliminate 30% of the Na saturation (30% of 20 meq/100 grams = 6 meq of exchangeable Na/100 grams of soil). Multiply the milliequivalents of exchangeable Na by 0.85 tons of gypsum to get the required application of gypsum ($6 \times 0.85 = 5.1$ tons of gypsum/acre). Typically, commercial gypsum is not 100% efficient in displacing Na, and some authorities suggest using an 80% efficiency factor. Doing this results in our example changing as follows... $5.1 \div 0.80 = 6.38$ tons per acre.

If your irrigation water has a gypsum content, or your soil contains gypsum, you can deduct these amounts from the required rate of gypsum to apply.

Method 3

Gypsum requirements can also be predicted from the residual sodium carbonate (RSC) value of the irrigation water. This calculation is...

RSC x 234 = pounds of gypsum required to offset the excess sodium in 1 acre foot (325,852 gallons) of irrigation water

Remember, gypsum alone does not solve a high Na problem; you must apply adequate irrigation water or receive enough rainfall to leach the displaced Na out of the root zone.

Appendix C

Leaching Requirement

High salt soils should be leached periodically to remove excess salts from the root zone. **The leaching requirement, as commonly defined, is the percent of applied water that must pass through and beyond the root zone, in excess to the water needs of the crop, to keep the EC (soluble salts, or electrical conductivity in mmhos/cm) of the drainage water below a given level.** In general, the higher the EC of the water, the higher the leaching requirement. The following tables give a more precise method for calculating the leaching requirement under various conditions, however, a “rule-of-thumb recommend” suggested by Washington State University publication EB 0909 is worth repeating for those who do not chose to do the calculations. According to their rule -of-thumb...

- 6 inches of leaching water for every 1 ft. of plant root zone will leach 50% of the salt
- 12 inches of leaching water for every 1 ft. of plant root zone will leach 80% of the salt
- 24 inches of leaching water for every 1 ft. of plant root zone will leach 90% of the salt

Additional suggestions are...

- Intermittent irrigation is more effective than steady irrigation or ponding and periodic drying may improve infiltration rates which, in turn, increase efficiency of leaching.
- To prevent puddling when leaching with sprinkler systems, the application rate should not exceed ½ of the intake rate of the soil. At least 10 pounds of additional pressure should be kept at the sprinklers than is recommended for normal irrigation.
- Keep fertility levels high while crops are growing, since the leaching process removes valuable plant nutrients as well as undesirable salts. Leach when the least amount of nitrogen will be lost or consider leaching before or after the cropping season.

The salt content of the water used to leach a field also plays a role in determining the amount of water required to reduce soil salts. In general, the higher the EC of the irrigation water, the higher the higher the leaching requirement. The following data illustrates this point. In this data, the Leaching Requirement is the percentage of applied water that must pass beyond the effective rooting depth of the crop in order to keep the EC of the drainage water below a given level

EC of Water (mmhos/cm)	Leaching Requirement (%)
0.3 or less	5
0.4	6
0.6	7.5
1.0	12.5
1.4	17.5
1.8	22.5
2.2	27.5
2.3 or more	Not suitable for irrigation

Washington State Univ. bulletin EM 3552

A formula for calculating the Leaching Percentage (LP), reported by the USDA, NRCS is...

$$LR = EC_{iw} \times [(5 \times EC_e) - EC_{iw}]$$

Where: **LR** = Leaching Requirement in the percent of irrigation water that must pass beyond the effective rooting zone of the crop.

EC_{iw} = Electrical conductivity of the irrigation water in mmho/cm

EC_e = Electrical conductivity of the soil in mmho/cm

The result of this formula is a decimal that must be multiplied by 100 to convert it to a percent.

Appendix D

Acidification Procedures to Neutralize Water Alkalinity

Acidification reduces the amount of bicarbonates and carbonates in water. The acidification process results in the formation of carbon dioxide (CO_2) and water (H_2O). The more commonly used acids are Sulfuric (H_2SO_4), Phosphoric (H_3PO_4), Nitric (HNO_3), and Citric ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$). When deciding which acid to use, you should evaluate...

- Safety and ease of use
- Relative cost
- Plant nutrients that will be included with the acid N, P, or S)
- Availability of the acid

Acids come in varying strengths, some of which are extremely strong and must be used with great caution and care. When handling any acids, the following procedures must always be followed.

- Wear eye protection, acid-resisting gloves, footwear, and an acid-resistant apron
- Always add acid to water. Do not do the reverse
- Always use acid resistant containers

Calculating the Amount of Acid to Use

- a. calculate the amount of alkalinity to be neutralized by the following formula

$$\text{Current alkalinity} - \text{Desired alkalinity} = \text{Alkalinity to be neutralized}$$

- b. Use the following table to determine the amount of various acids to use

CHARACTERISTICS OF ACIDS			
Acid Type	Typical Strength	Nutrient Content (ppm) ^a	Neutralizing Power ^b
Phosphoric	75% ^c	25.6 P, as PO_4	45.0 ^d
Sulfuric	93% ^e	43.6 S, as SO_4	136.0
Sulfuric (battery)	35%	16.4 S, as SO_4	51.2
Nitric	63%	14.6 N, as NO_3	52.3

a. Nutrient content when 1 fl. oz. is added to 100 gal. of water. Make appropriate adjustments to fertilizer program
 b. Amount of alkalinity (ppm CaCO_3) neutralized when 1 fl. oz. of acid is added per 100 gallons of water.
 c. Phosphoric acid comes in many strengths, but 75% is common. Use heavy free grade or food grade, if possible
 d. Assumes about 1/3 of acid is effective since phosphoric acid does not completely dissociate.
 e. 93% sulfuric acid is also known as 66 be' (Baume') acid. Battery acid electrolyte is recommended by some and is about 35% strength

Appendix E

Boron Hazard

	BORON CONTENT OF IRRIGATION WATER		
	ppm-B	ppm-B	ppm-B
EXCELLENT	< 0.33	< 0.67	< 1.00
GOOD	0.33-0.67	0.67-1.33	1.00-2.00
PERMISSIBLE	0.67-1.00	1.33-2.00	2.00-3.00
DOUBTFUL	1.00-1.25	2.00-2.50	3.00-3.75
UNSUITABLE	1.25 +	2.50 +	3.75 +

RELATIVE CROP TOLERANCE TO BORON		
SENSITIVE	SEMI-TOLERANT	TOLERANT
Pecan	Sunflower	Sugarbeet
Black Walnut	Cotton	Table Beet
Navy Bean	Radish	Alfalfa
Pear	Field Pea	Gladiolus
Apple	Barley	Onion
Peach	Wheat	Turnip
	Corn	Cabbage
	Sorghum	Lettuce
	Oat	Carrot
	Pumpkin	
	Sweet Potato	

NOTE: 0.02 ppm B (0.002 meq/l), or more, in the irrigation water may be required to sustain adequate plant growth (in the absence of fertilizer B). No data exists on unlisted crops.