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Soil & Water Amendments

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The #1 soil additive for controlling soil salts is…

WATER

H_2O and Salts

K^+ $SO_4^=$ Cl^- Na^+ K^+ $SO_4^=$ H_2O Cl^- Na^+

Because salts move with water, it is relatively easy to remove salt from soil simply by leaching water through the soil. Draining water carries the salt out of the soil profile, leaving a non-saline (un-salty) soil.

If the soil salts contain high levels of sodium, this approach alone will not work. These soils require special management.

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Leaching Requirement

- To maintain salt levels and avoid buildup, salt leached must equal salt added
  - The Leaching Requirement is the fraction of water (rain + irrigation) applied that must move below the root zone to control salt buildup.
- Equation: $$LR = \frac{(EC_w)}{5(EC_e - EC_w)}$$

where

EC_w = EC of irrigation water
EC_e = max EC crop will tolerate

In addition to the irrigation water salinity (EC_w), the leaching requirement also depends on the salinity tolerance of the crop being grown (EC_e). The equation above can be used to estimate the leaching requirement.

For example, if our irrigation water had an EC_w of 1.0 dS/m, and the crop tolerance (EC_e) was 2 dS/m, then the leaching requirement would be

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Leaching Requirement

- To maintain salt levels and avoid buildup, irrigate to satisfy crop requirement (ET) and leaching fraction:

$$AW = \frac{ET}{1 - LR}$$

where

AW= crop water requirement
ET = crop requirement (evapotranspiration)
LR = leaching requirement

The amount of water we’d have to add to prevent salt build-up is calculated from the above equation.

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Leaching Requirement

- Example 1: Buffalograss
  - If EC_w = 0.5 dS/m (320 ppm) and EC_e = 3 dS/m

$$LR = \frac{0.5}{5(3.0) - 0.5} = 0.03$$

  - If the weekly turf irrigation requirement is 2 inch, then excess irrigation to remove salts = 2/(1-0.03) = 2.06 inches.

Several examples will illustrate the impact of irrigation water salinity and crop sensitivity (or tolerance) on the irrigation requirement.

Buffalograss, a relatively salt-sensitive turfgrass (we're using a maximum EC that the grass can withstand of 3 dS/m) is irrigated with high quality (low salinity) water. An excess of 0.06 inches are needed per week of the growing season.

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Grass	Turf threshold	Irrigation water	Leaching Requirement	Excess for 2" irrigation
Buffalograss	3 dS/m	0.5 dS/m	0.03	2.06
	3 dS/m	1.5 dS/m	0.11	2.25
	3 dS/m	3.0 dS/m	0.25	2.67
Bermudagrass	16 dS/m	0.5 dS/m	0.01	2.02
	16 dS/m	1.5 dS/m	0.02	2.04
	16 dS/m	3.0 dS/m	0.04	2.08

Here we compare the leaching requirements for two grasses, salt-sensitive Buffalo grass and salt-tolerant Bermuda grass, irrigated with three qualities of irrigation water. Notice that saltier water requires a greater amount of leaching water, and that sensitive plants need much greater leaching than salt-tolerant plants.

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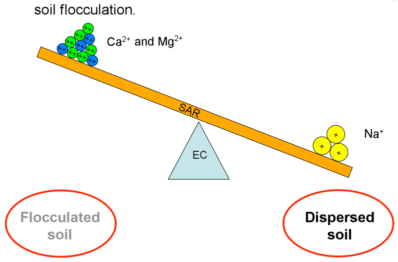
Controlling Na^+ requires increasing concentrations of soluble Ca^{2+} to decrease soil or water SAR, thus favoring soil flocculation.



If the left side of the see-saw is loaded up with calcium or magnesium, and the sodium side (the right side) is unchanged, the left side of the see-saw is heavier and tilts downward. This means the soil is flocculated. This makes sense because both calcium and magnesium are good flocculators.

Also, as calcium and magnesium levels increase, SAR decreases. Therefore, another way to describe this situation is to say that as SAR drops, soil tends to flocculate.

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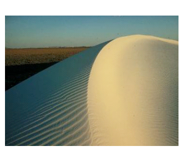
GYPSUM

Calcium sulfate
$CaSO_4 2H_2O$
22 - 23% Ca

Gypsum is the most commonly-used calcium soil amendment and is also used to treat irrigation water.



White Sands National Monument
www.nps.gov/whsa/gallery.htm

Gypsum is a non-toxic, naturally-occurring, mined mineral. White Sands in New Mexico are gypsum dunes. Gypsum is used to make dry wall for houses and to mark athletic fields.

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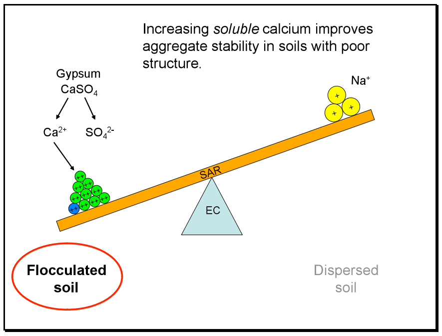

To increase soluble calcium levels, we usually add gypsum, which is calcium sulfate. Gypsum is slightly soluble in soil, so it generally does not cause salt problems. It dissolves slowly, releasing calcium, which will help to flocculate the soil clays.

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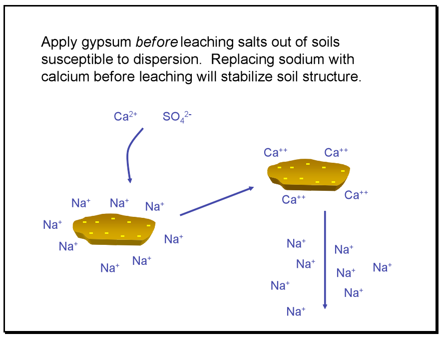

Here is a schematic representation of reclamation of a sodium-affected soil. Calcium from gypsum displaces exchangeable sodium, causing soil particles to flocculate. Then, when the soil is leached, the sodium is washed out. This leaves a flocculated soil.

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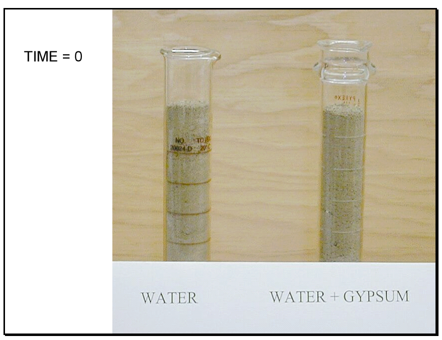

Here is an illustration of the effects of gypsum. The two cylinders are filled with the same high-sodium soil. The cylinder on the left will be watered with distilled water. The soil on the right will be watered with distilled water with gypsum dissolved in it.

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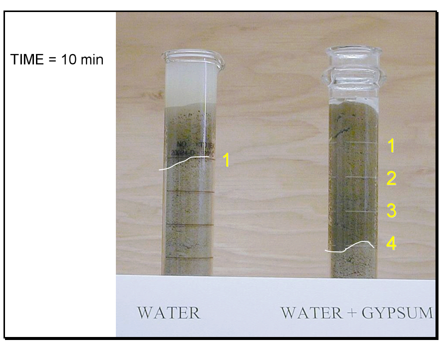

Even after 10 minutes, differences are apparent. Notice the dispersed soil in the water standing in the 'water' cylinder and at the surface of the soil. In the 'gypsum' cylinder the water is moving much more rapidly.

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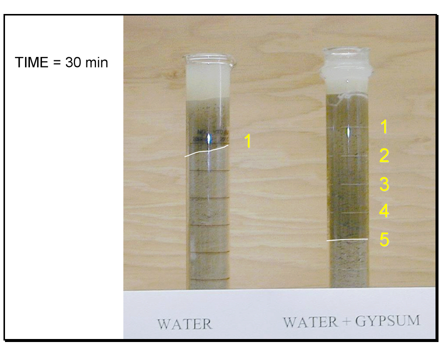

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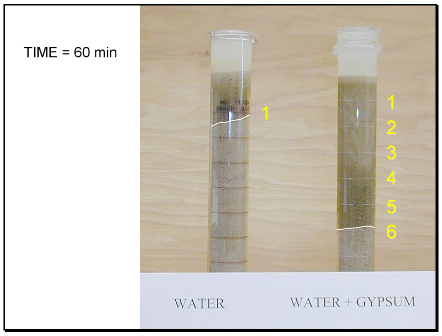

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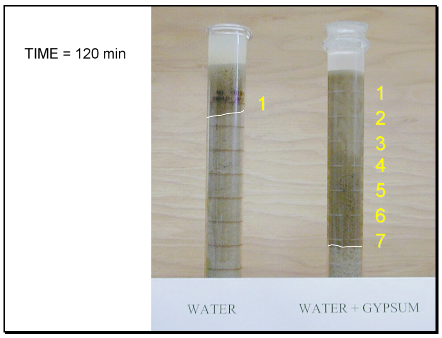

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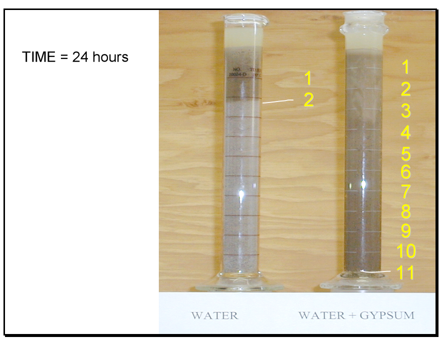

This pattern continues and, even after 24 hours, there has been little movement of water into the cylinder on the left. The soil at the surface is dispersed, and the soil surface is sealed, preventing water infiltration. Even several days later, the water had not moved any more in this cylinder.

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Applying Gypsum

- What form?
  - Powder, prilled, waste
    - Finer-textured materials react with the soil more rapidly, but are hard to handle
  - Consider
    - Price
    - Ease of application
- How?
  - Broadcast on soil surface, preferably incorporated
  - Injected into irrigation water

Gypsum is generally applied as a broadcast treatment, applied evenly over the soil surface. Many gypsum suppliers provide custom application. Gypsum can be incorporated via tillage, or left on the soil surface. Because gypsum is not very soluble, it moves slowly down through the soil profile. Incorporation is not needed to treat the surface soil, but for treating deeper in the soil profile, incorporation is recommended if possible.

Gypsum can be injected into irrigation water, which is particularly effective as a preventative management tool.

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Soil gypsum requirement

Soil Texture	Exchangeable Sodium Percentage 10	15	20	30	40	50
	----------- lbs per 1000 ft^2 -----------					
Coarse	50	100	150	250	350	450
Medium	75	150	250	400	550	700
Fine	100	200	300	500	700	900

The amount of gypsum that should be applied depends on soil physical and chemical properties. In general, finer textured soils require more gypsum than coarse textured soils and those with high ESP or SAR require more than those with lower ESP or SAR levels. This table gives approximate amounts of gypsum to apply. More accurate recommendations can be calculated from soil test results.

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Injecting gypsum into irrigation water

May not be required with every irrigation
- Use a high rate to start correcting problems
- Use lower rates for maintenance

Rate	lbs per acre-foot (pure) gypsum
Low	250
Moderate	700
High	1400

Gypsum is easily injected into irrigation water. This may not be needed for every irrigation event. For maintenance programs, gypsum may be injected every second or third irrigation.

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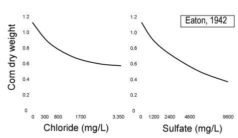
What about sulfate toxicity?



- Plants are sensitive to all soluble salts (e.g. soil salinity).
- Most plants are more sensitive to excess chloride than sulfate.

  A few are more sensitive to sulfate and some, like corn (shown above) and barley are about equally sensitive (when concentrations are expressed per charge).
- Sulfate toxicity is not a significant issue!
- But gypsum can sometimes cause a short-term increase EC.

All salts will adversely affect plants if present at high enough levels. Most soil salts contain the anions chloride and sulfate. These anions have similar toxicities.

Addition of gypsum to soil will increase sulfate levels, but subsequent leaching to remove sodium will also remove chloride and sulfate. Flocculating a soil and leaching will reduce the amount of salts and will reduce the likelihood of salt toxicity. Sulfate toxicity is not a concern when using gypsum.

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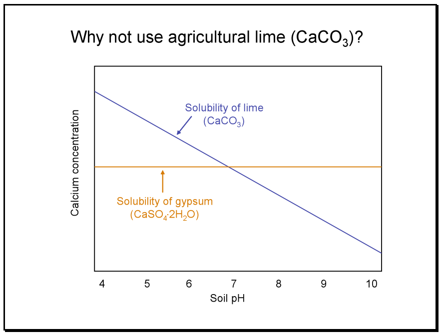

If soil sodium is counteracted by addition of calcium, why not use agricultural lime, calcium carbonate ($CaCO_3$)? In low pH soils, $CaCO_3$ is used to raise soil pH. As can be seen in this diagram, $CaCO_3$ is highly soluble in low pH soils, but the solubility decreases rapidly as soil pH goes up. In alkaline desert soils (most of our soils have pH levels between 8.0 and 8.5) $CaCO_3$ is quite insoluble. Gypsum ($CaSO_4 \cdot 2H_2O$) solubility, on the other hand, is unaffected by soil pH. Even in high pH soils, gypsum is an effective source of calcium.

So, if your soil has a pH of 6.5 or less, lime is a reasonable choice for treating soil sodicity. But if you are managing a high pH soil, lime is useless, and gypsum is the material of choice. A good illustration of this is the fact that most desert soils already contain excess $CaCO_3$, but still have sodium problems because the $CaCO_3$ is insoluble.

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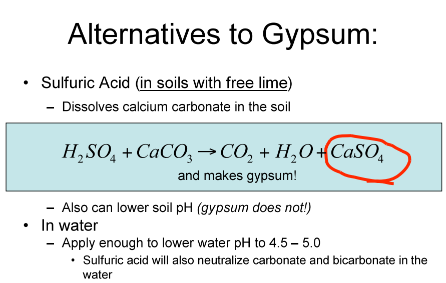

Acidifying agents all work by dissolving soil $CaCO_3$ (free lime), which produces gypsum. Sulfuric acid directly dissolves $CaCO_3$. Any acid will do this. Sulfuric acid is the acid of choice because of relatively low cost and because it adds less salt to the soil than HCl (hydrochloric acid).

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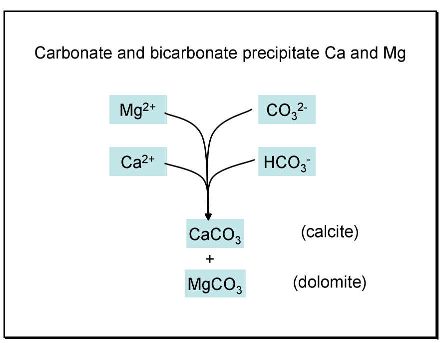

Levels of carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) in irrigation water also should be monitored. These anions form insoluble compounds when they come into contact with calcium and magnesium. By effectively reducing calcium and magnesium levels in the soil, they increase the sodium adsorption ratio.

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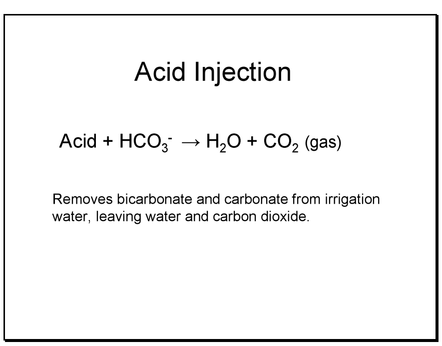

Acid injected into irrigation water removes carbonates and bicarbonates by converting them to carbon dioxide (CO_2) gas. Sulfuric acid (H_2SO_4) is often used for this purpose.

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Alternatives to Gypsum: Sulfur burners

$S + O_2 \rightarrow SO_2$

$SO_2 + H_2O \rightarrow H_2SO_3$ (sulfurous acid)

Sulfur burners eliminate the need for handling dangerous sulfuric acid

Sulfur burners convert elemental sulfur powder into sulfurous acid by combustion. They provide a safe way to inject acid into irrigation water.

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Alternatives to Gypsum:

- Elemental Sulfur (in soils with free lime)
  - Microbes make sulfuric acid

$$S + \tfrac{1}{2}O_2 + CO_2 + 2H_2O \rightarrow H_2SO_4 + CH_2O$$

  - Dissolves calcium carbonate and makes gypsum
  - Use 20% as much as gypsum
  - Takes time
    - several weeks
    - faster in warm soils

Elemental sulfur is converted by soil microbes to sulfuric acid, which then converts $CaCO_3$ to gypsum. Because this is a microbial reaction, it may take weeks to months to be completed.

Most other acidifying agents create acids through chemical reactions, so they react more quickly than sulfur.

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Relative effectiveness of amendments for supplying calcium

Amendment	Chemical composition	Solubility in water (lbs/100 gal)	Amount (lbs) equivalent to 1 lb of gypsum
Gypsum	$CaSO_4 \cdot 2H_2O$	2.0	1.0
Sulfur	S	0	0.2
Sulfuric acid	H_2SO_4	Very high	0.6
Calcium carbonate	$CaCO_3$	0.01	0.6
Calcium chloride	$CaCl_2 \cdot 2H_2O$	810	0.9
Ammonium thiosulfate	$(NH_4)_2S_2O_3$	850	0.5 - 1.4
Potassium thiosulfate	$K_2S_2O_3$	1290	1.1
Aluminum sulfate	$Al_2(SO_4)_3 \cdot 18H_2O$	725	1.3

Organic additives can also help flocculate soils if applied in large enough quantities.

The alternatives to gypsum fall into two groups: calcium sources (gypsum, calcium carbonate, and calcium chloride), and acidifying agents (all the others in the above table). As we have just seen, and as you can also see from this table, calcium carbonate is a poor choice because of the very low solubility. Calcium chloride is very soluble, but adds more salt than gypsum, so it can actually increase salinity problems.

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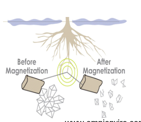
There must be an easier way!



Unfortunately, there are no shortcuts, no magic additives or treatments to get rid of sodium or other salts.

It would be great if there were a chemical you could add to soil or water to get rid of salt, or a gizmo that could be used to treat water to mitigate the effects of salt, but THERE IS NOT! No soil or water additives get rid of salt. We can do various things to change the calcium/sodium balance of soils but, ultimately, salts must be flushed out of soil with leaching water. Irrigation water can be treated to remove salts, with reverse osmosis or distillation, however these are prohibitively expensive for irrigation water. Additives can be used to treat irrigation water, changing the pH, or elevating levels of dissolved calcium.

Proper salt and sodium management can help you to avoid serious long-term problems.