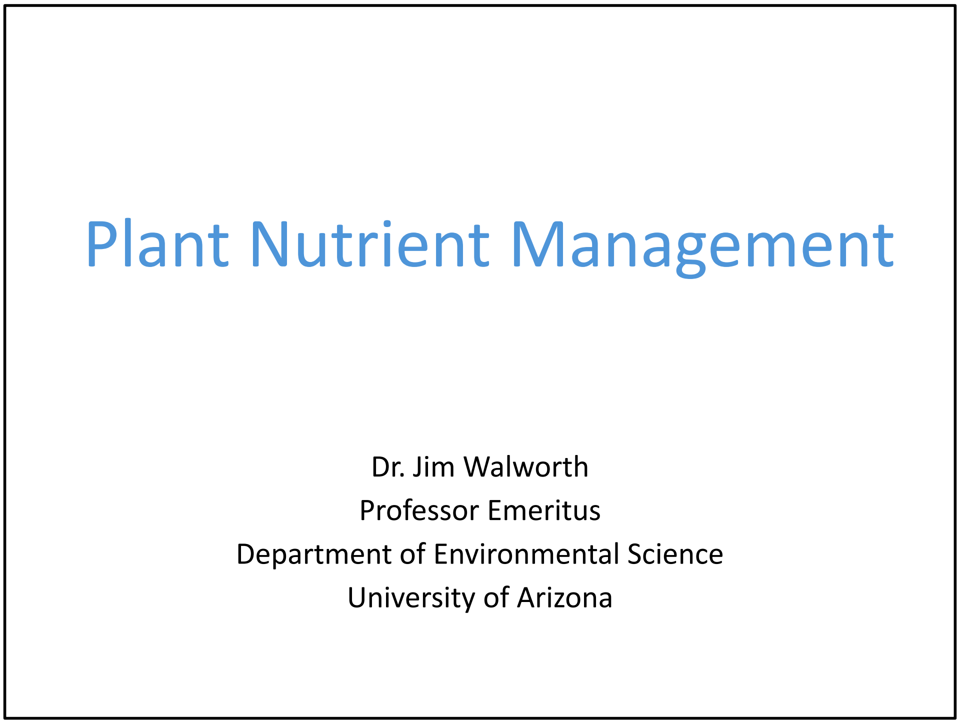

Plant Nutrient Management

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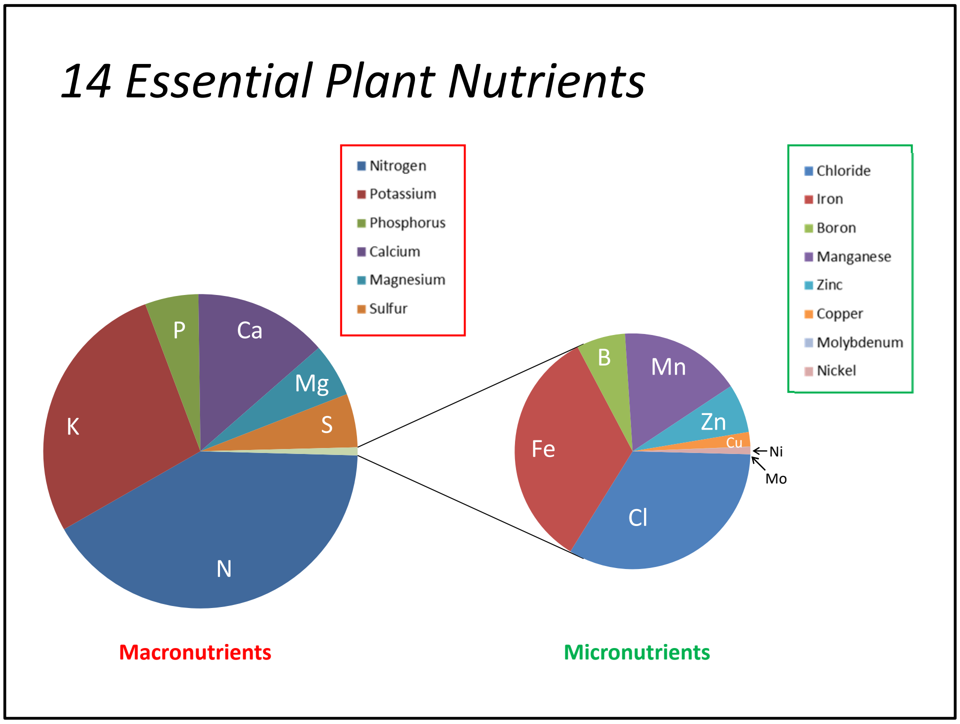


14 Essential Plant Nutrients

- Nitrogen
- Potassium
- Phosphorus
- Calcium
- Magnesium
- Sulfur

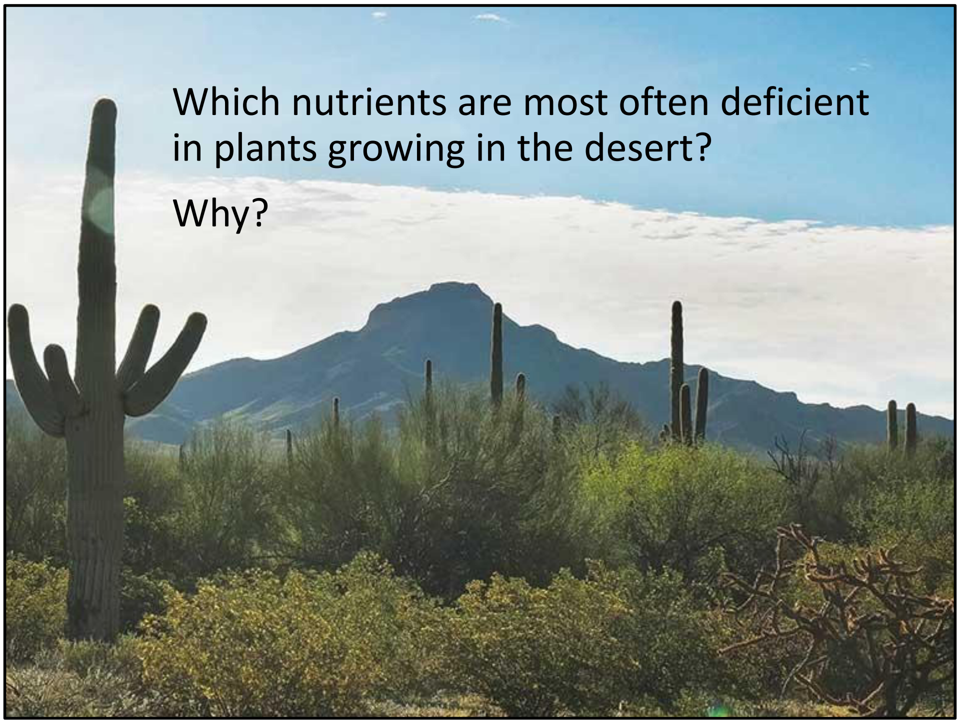
- Chloride
- Iron
- Boron
- Manganese
- Zinc
- Copper
- Molybdenum
- Nickel

Macronutrients

Micronutrients

All plants need each of the 14 essential nutrient to complete a life cycle. The macronutrients are required in larger amounts than the micronutrients, but all nutrients are of equal importance.

We usually express macronutrient concentrations as a percent (%)of a plant’s dry matter. Micronutrients are expressed in parts per million (ppm).



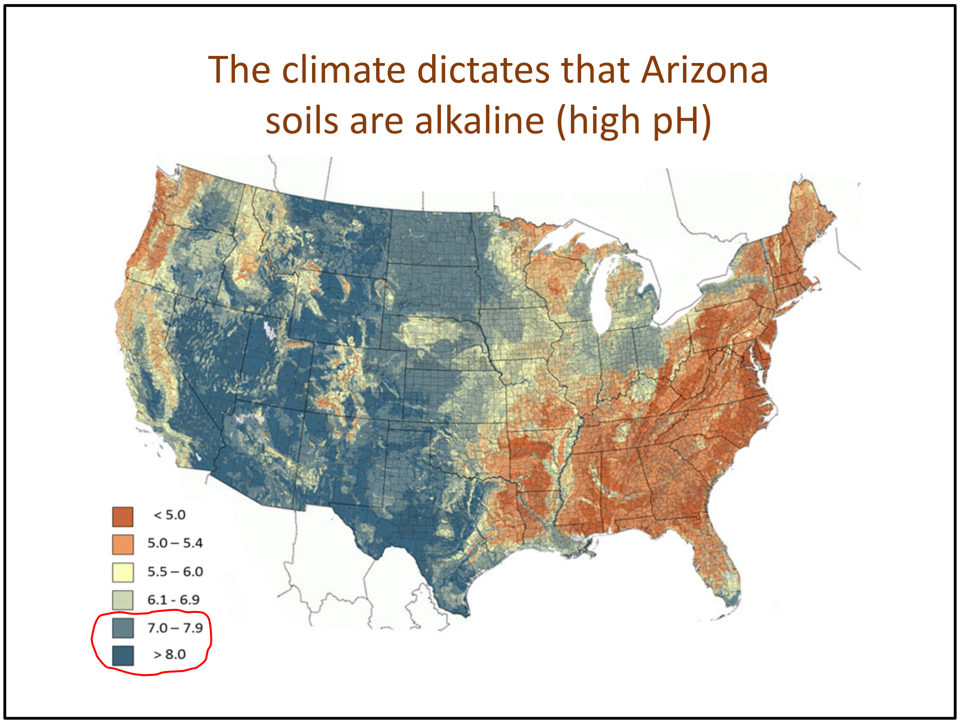
Which nutrients are most often deficient in plants growing in the desert?

Why?

Although every plant needs all 14 essential nutrients, we will focus on those that are most often lacking, and which therefore require extra management.

Most of the nutrients are supplied naturally in large enough quantities that we seldom see deficiencies. We can simplify management by focusing on only a few nutrients.

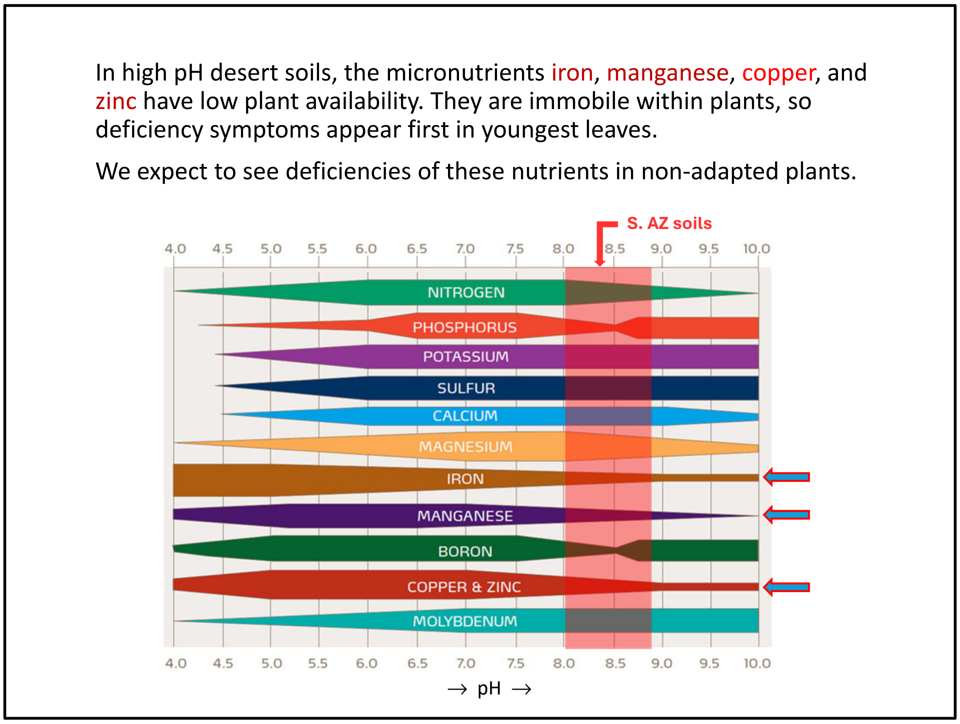
We will focus our discussion on desert soils and conditions.



The climate dictates that Arizona soils are alkaline (high pH)

Soil pH follows annual rainfall closely. Soil pH is highest in low rainfall areas and lowest where rainfall is greatest. We expect to find alkaline soils in arid regions, whereas tropical soils are generally acidic.

In southern Arizona, typical soil pH is roughly 8.0 to 8.5.



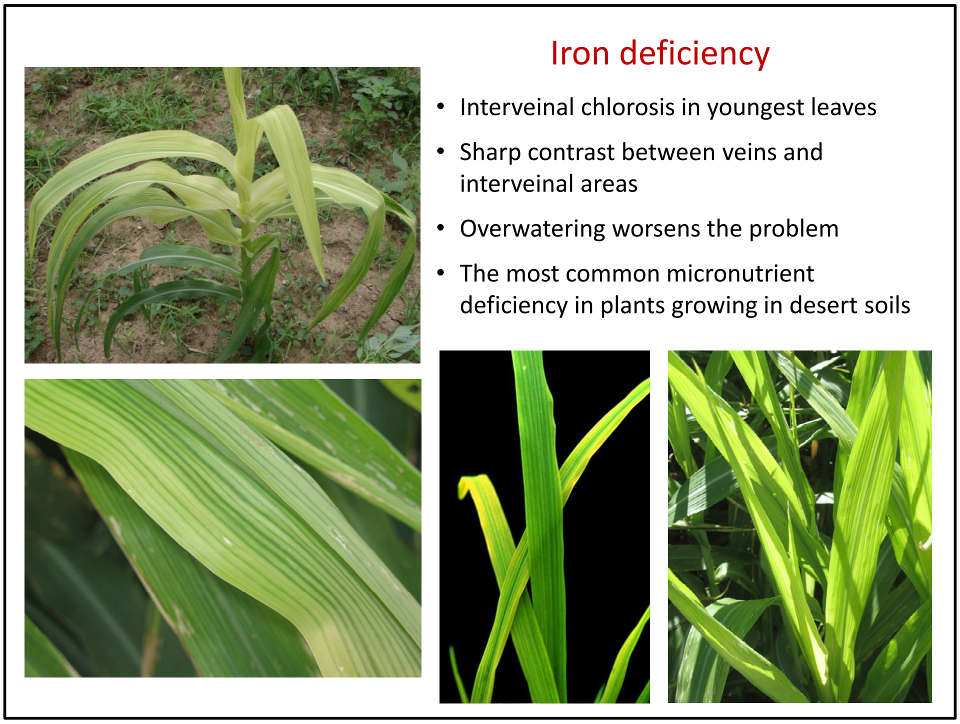
In high pH desert soils, the micronutrients iron, manganese, copper, and zinc have low plant availability. They are immobile within plants, so deficiency symptoms appear first in youngest leaves.

We expect to see deficiencies of these nutrients in non-adapted plants.

Plants don’t care much about pH, but they’re affected by pH indirectly because soil pH controls other soil properties, such as nutrient availability.

Here the width of each nutrient band represents its relative availability to plants. We can see that iron, manganese, copper, and zinc exhibit reduced plant availability in high pH soils like those of the Sonoran desert. We can anticipate that deficiencies of these nutrients are likely, particularly in non desert-adapted plants.

Native plants do not need less of these nutrients, but have developed mechanisms for extracting them from alkaline soils. Plants from tropical regions are most likely to develop iron, manganese, and zinc deficiencies. We’ll focus on those nutrients. Copper deficiency is less common, so we’ll skip over it in our discussion.



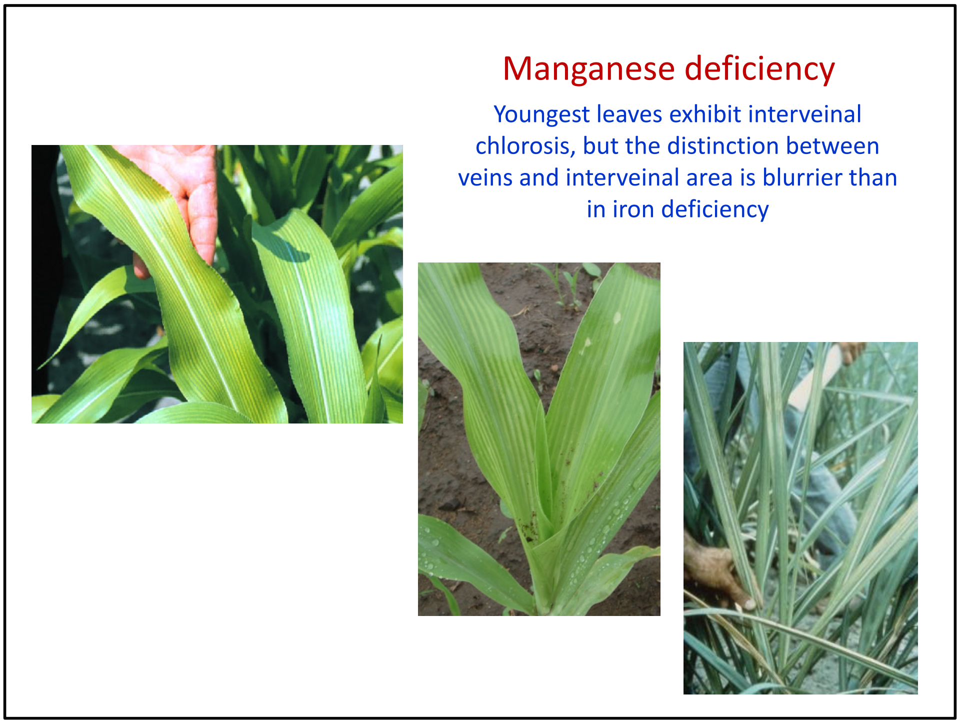
Iron deficiency

- Interveinal chlorosis in youngest leaves
- Sharp contrast between veins and interveinal areas
- Overwatering worsens the problem
- The most common micronutrient deficiency in plants growing in desert soils

Symptoms of deficiencies of iron, manganese, and zinc are very similar. All consist of interveinal chlorosis (yellowing) of the younger leaves. The interveinal area is the space between the leaf veins. In iron deficiency, the contrast between the green veins and the yellow interveins is very sharp and distinct.

Deficiencies of these nutrients appear first in young leaves because they are immobile within the plant and cannot be moved from older leaves into actively growing parts of the plant.

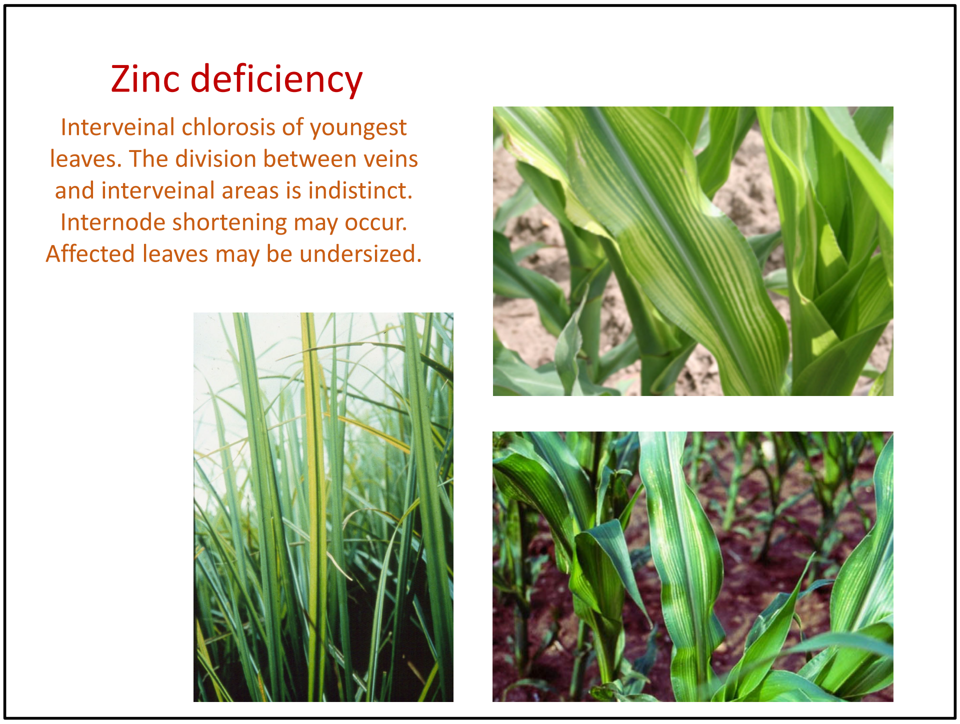
Iron deficiency is much more common than manganese or zinc deficiency. It can be exacerbated by overwatering.



Manganese deficiency

Youngest leaves exhibit interveinal chlorosis, but the distinction between veins and interveinal area is blurrier than in iron deficiency

Manganese deficiency is distinguished by slightly less contrasty or crisp distinction between veins and interveinal areas than iron deficiency. Otherwise, iron and zinc deficiencies are very similar and it can be extremely difficult to distinguish between the two.



Zinc deficiency

Interveinal chlorosis of youngest leaves. The division between veins and interveinal areas is indistinct. Internode shortening may occur. Affected leaves may be undersized.

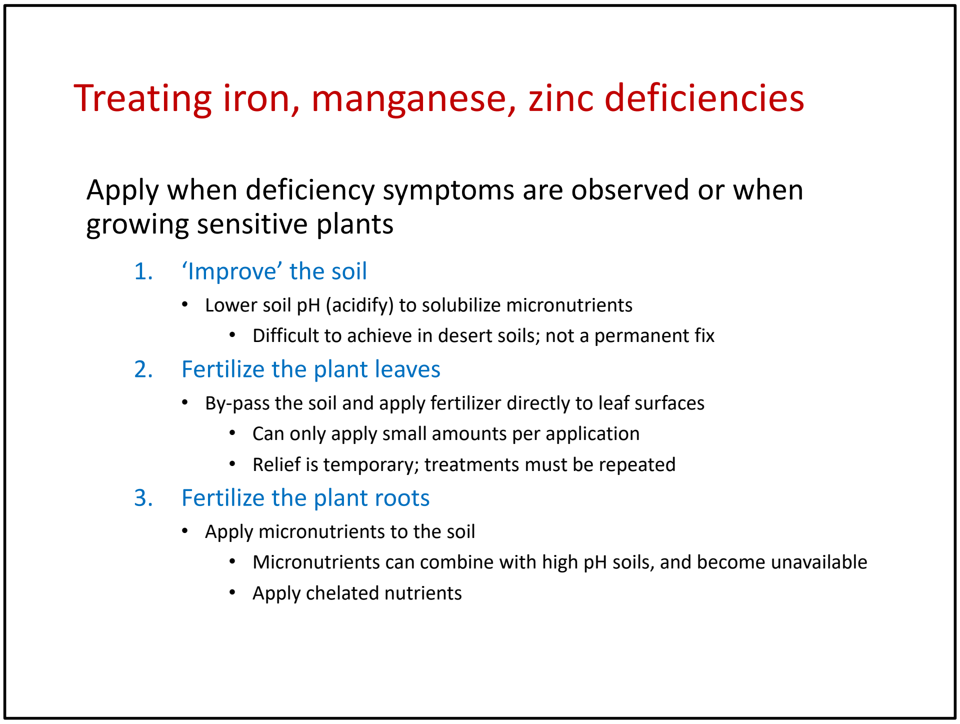
In zinc deficiency the distinction between veins and interveinal areas is still less distinct than manganese deficiency.

Once again, distinguishing between iron, manganese, and zinc deficiency is difficult. However, if you identify such symptoms as iron deficiency you'll likely be correct because iron deficiency is by far the more common malady.

Lilium michiganense

Neomarica

I could not find photos of iron deficiency in irises. On the left is a photo of a lily. On the right is a photo of my walking iris with what I believe is iron deficiency.



Treating iron, manganese, zinc deficiencies

Apply when deficiency symptoms are observed or when growing sensitive plants

1. 'Improve' the soil
   - Lower soil pH (acidify) to solubilize micronutrients
     - Difficult to achieve in desert soils; not a permanent fix
2. Fertilize the plant leaves
   - By-pass the soil and apply fertilizer directly to leaf surfaces
     - Can only apply small amounts per application
     - Relief is temporary; treatments must be repeated
3. Fertilize the plant roots
   - Apply micronutrients to the soil
     - Micronutrients can combine with high pH soils, and become unavailable
     - Apply chelated nutrients

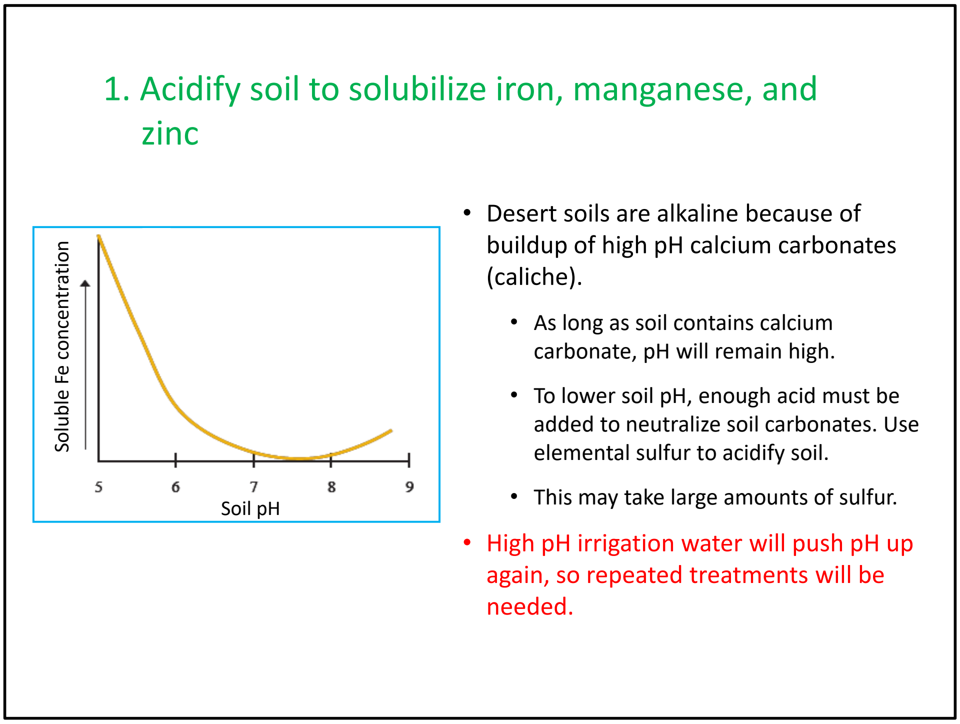
There are three methods of dealing with iron, manganese, and zinc deficiencies.

The first is to adjust soil pH, reducing soil alkalinity. This is accomplished by adding an acid or acid-forming material to soil. The safest and most practical material to add is elemental sulfur. Soil microbes convert this into sulfuric acid.

Second, we can fertilize the plant directly by applying nutrients directly to the plant's leaves. Here we are limited to applying small quantities to avoid damaging leaves. Because iron, manganese, and zinc are immobile within the plant, additional applications must be made as new foliage grows.

Lastly, we can fertilize the soil to increase availability to roots. Here the nutrient form is critical. Most forms of these nutrients are quickly tied up by soil constituents and rendered unavailable to plants. Therefore, we use 'chelated' nutrients when applying to alkaline soils.

The best way to avoid deficiencies is to grow desert-adapted plants that do not require supplemental iron, manganese, or zinc.



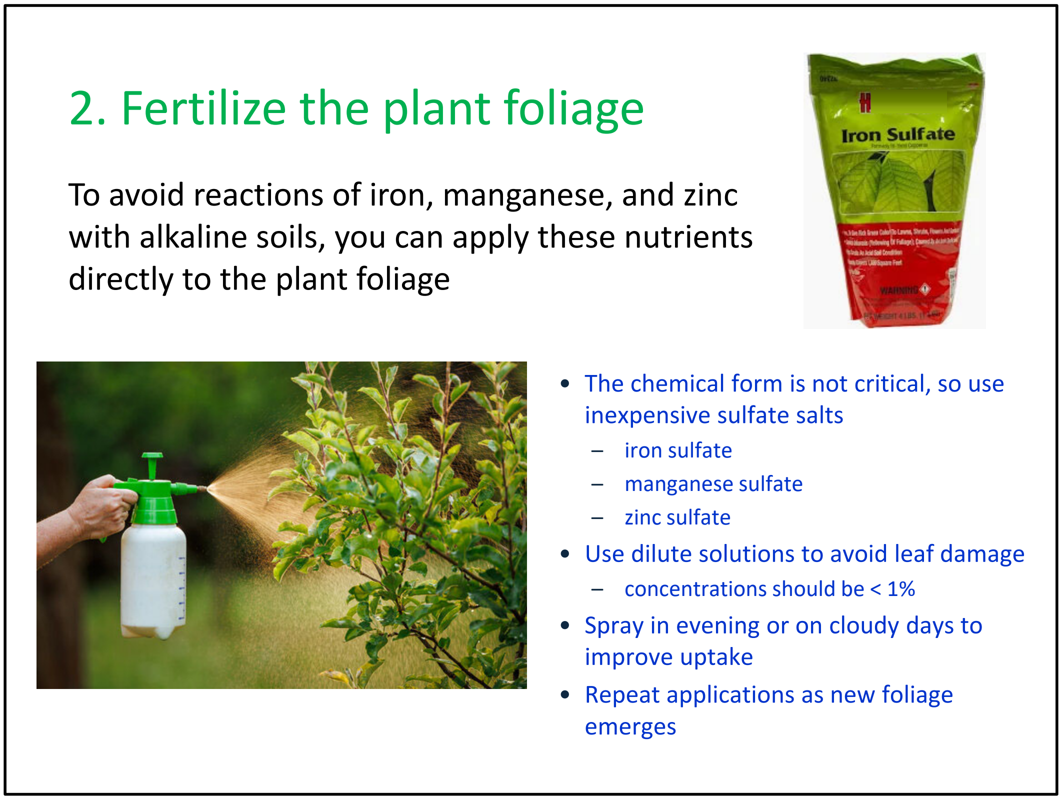
1. Acidify soil to solubilize iron, manganese, and zinc

- Desert soils are alkaline because of buildup of high pH calcium carbonates (caliche).
  - As long as soil contains calcium carbonate, pH will remain high.
  - To lower soil pH, enough acid must be added to neutralize soil carbonates. Use elemental sulfur to acidify soil.
  - This may take large amounts of sulfur.
- High pH irrigation water will push pH up again, so repeated treatments will be needed.

Lowering the pH of desert soils increases solubility and therefore availability of iron, manganese, and zinc. This can be challenging, however, because alkaline soil constituents (calcium carbonate) buffer the soil against acidification.

Elemental sulfur reacts over a period of weeks or months, so be patient. The amount of sulfur needed to lower pH is dependent on soil properties, including initial pH and the amount of calcium carbonate the soil contains. One way to determine this is through trial and error: add a specific amount of sulfur, wait a few weeks, and measure pH again. Apply more sulfur if necessary.

Over time, the soil pH will likely rise for two reasons. First, some unreacted calcium carbonate will likely remain in the soil after acidification, and this will slowly dissolve, raising pH. Second, if soils are watered with alkaline water (like that in most of southern Arizona), over time this will raise the pH again. To maintain a lower than natural soil pH, repeated treatments probably will be necessary.



2. Fertilize the plant foliage

To avoid reactions of iron, manganese, and zinc with alkaline soils, you can apply these nutrients directly to the plant foliage

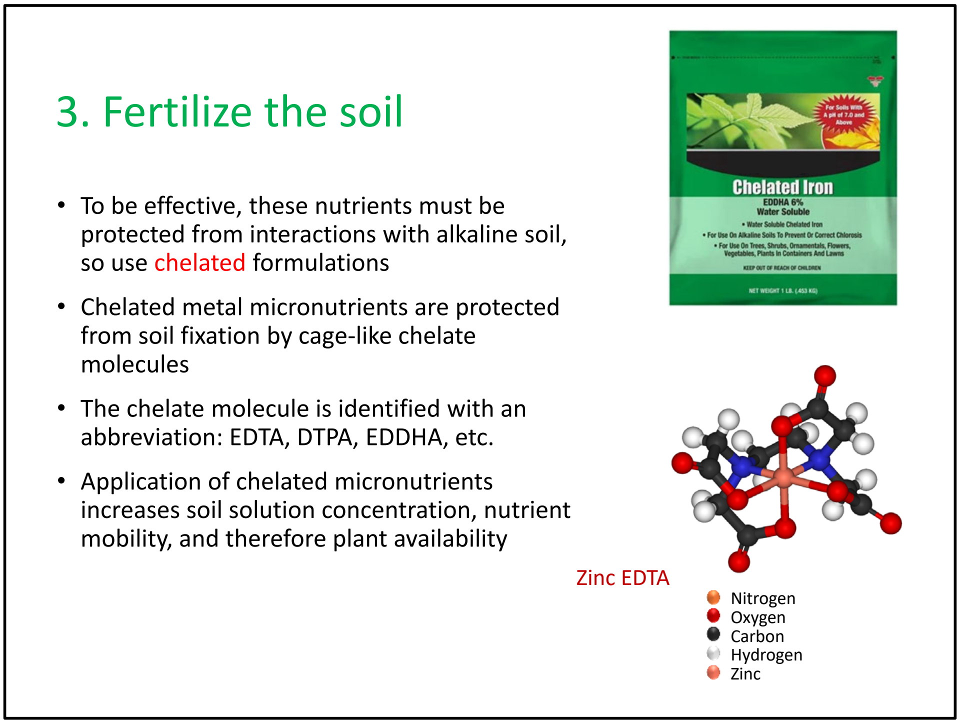
- The chemical form is not critical, so use inexpensive sulfate salts
  - iron sulfate
  - manganese sulfate
  - zinc sulfate
- Use dilute solutions to avoid leaf damage
  - concentrations should be < 1%
- Spray in evening or on cloudy days to improve uptake
- Repeat applications as new foliage emerges

Applying iron, manganese or zinc directly to plant foliage is an effective method for correcting deficiencies of these nutrients. Plants respond very quickly to foliar fertilization.

The particular form of fertilizer is not critical, as long as it can be dissolved in water. For foliar fertilization, we can use relatively inexpensive sulfate salts.

Plant leaves are tender and can be damaged easily, so spray solutions must be very dilute. A good rule of thumb is to keep fertilizer concentrations below 1% (by weight). Another good practice is to spray just a few leaves or treat a disposable plant to see if damage occurs before treating prized plants. Foliar sprays are absorbed while the spray remains in liquid form on the leaf, so spray in cool weather, in the evening, or on cloudy days to maximize nutrient absorption.

Because these nutrients are immobile within the plant, only leaves directly sprayed with foliar fertilizer will be fertilized. As new growth occurs, additional sprays will be need to treat the new leaves.



3. Fertilize the soil

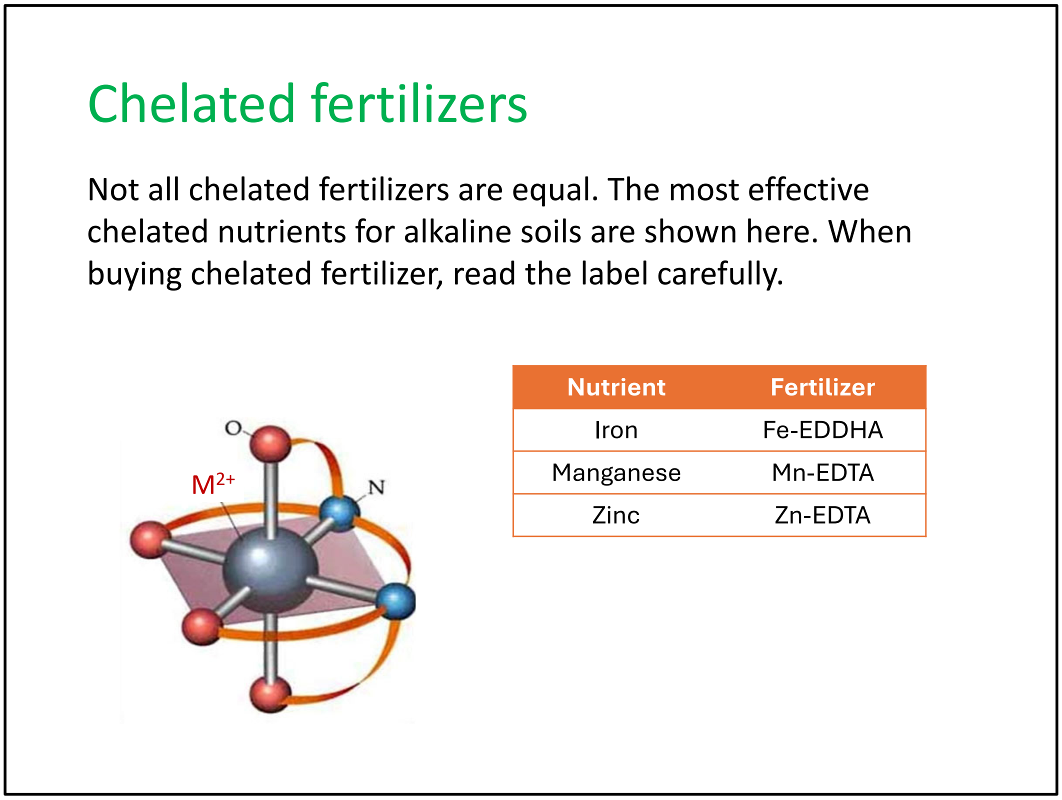
- To be effective, these nutrients must be protected from interactions with alkaline soil, so use chelated formulations
- Chelated metal micronutrients are protected from soil fixation by cage-like chelate molecules
- The chelate molecule is identified with an abbreviation: EDTA, DTPA, EDDHA, etc.
- Application of chelated micronutrients increases soil solution concentration, nutrient mobility, and therefore plant availability

Zinc EDTA

● Nitrogen
● Oxygen
● Carbon
● Hydrogen
● Zinc

Fertilizing alkaline soils with metal micronutrients is problematic, because the added micronutrients will quickly become insoluble. To avoid this problem we can apply ‘chelated’ nutrients. As shown in the molecular model here, a chelate molecule surrounds the micronutrient atom and protects it from soil reactions.

Chelates are broken down by soil microorganisms, so they have a limited lifespan. Soil-applied chelates can be effective for an entire growing season or more, but repeat applications will likely be needed in subsequent years.



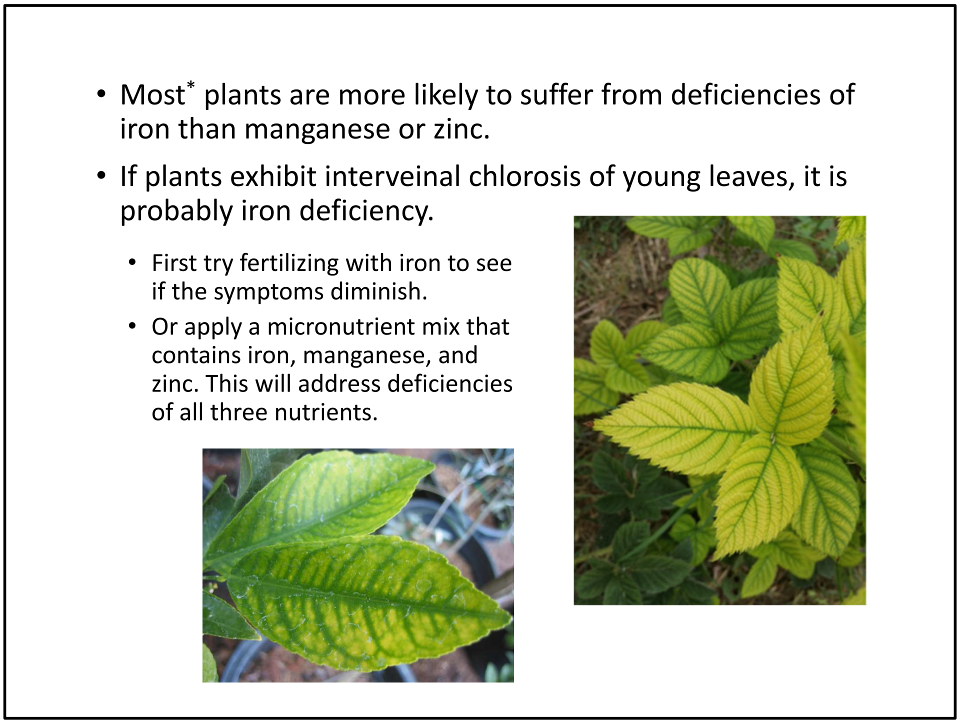
Chelated fertilizers

Not all chelated fertilizers are equal. The most effective chelated nutrients for alkaline soils are shown here. When buying chelated fertilizer, read the label carefully.

Nutrient	Fertilizer
Iron	Fe-EDDHA
Manganese	Mn-EDTA
Zinc	Zn-EDTA

Each nutrient:chelate combination has unique properties. It is critical to select appropriate chelated fertilizers for specific soil conditions. In alkaline soils the most effective are iron-EDDHA, manganese-EDTA, and zinc-EDTA.

It's not good enough that the label says, "chelated". For example, iron-EDTA is a common, inexpensive form, but it's not very effective in alkaline soils. Iron-EDDHA is more expensive, but also much more effective than iron-EDTA in alkaline soils, so it is well worth the extra cost. Read the fine print carefully to see which chelate is used.



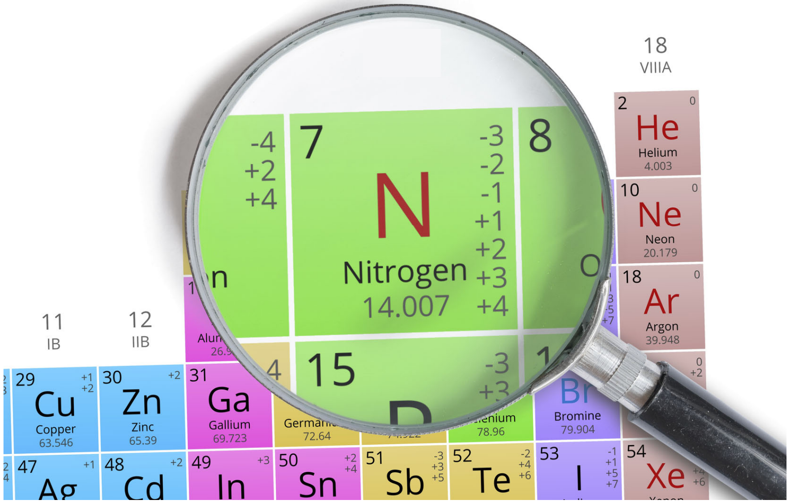
- Most* plants are more likely to suffer from deficiencies of iron than manganese or zinc.
- If plants exhibit interveinal chlorosis of young leaves, it is probably iron deficiency.
  - First try fertilizing with iron to see if the symptoms diminish.
  - Or apply a micronutrient mix that contains iron, manganese, and zinc. This will address deficiencies of all three nutrients.

The key symptom of iron, manganese, or zinc deficiency is interveinal chlorosis of young leaves. Interveinal chlorosis of young leaves nearly always indicates deficiency of one of these nutrients, but distinguishing between them can be very difficult, as we have seen. By far the most common of the micronutrient deficiencies in our area is iron deficiency, so this is a safe diagnosis in most circumstances.

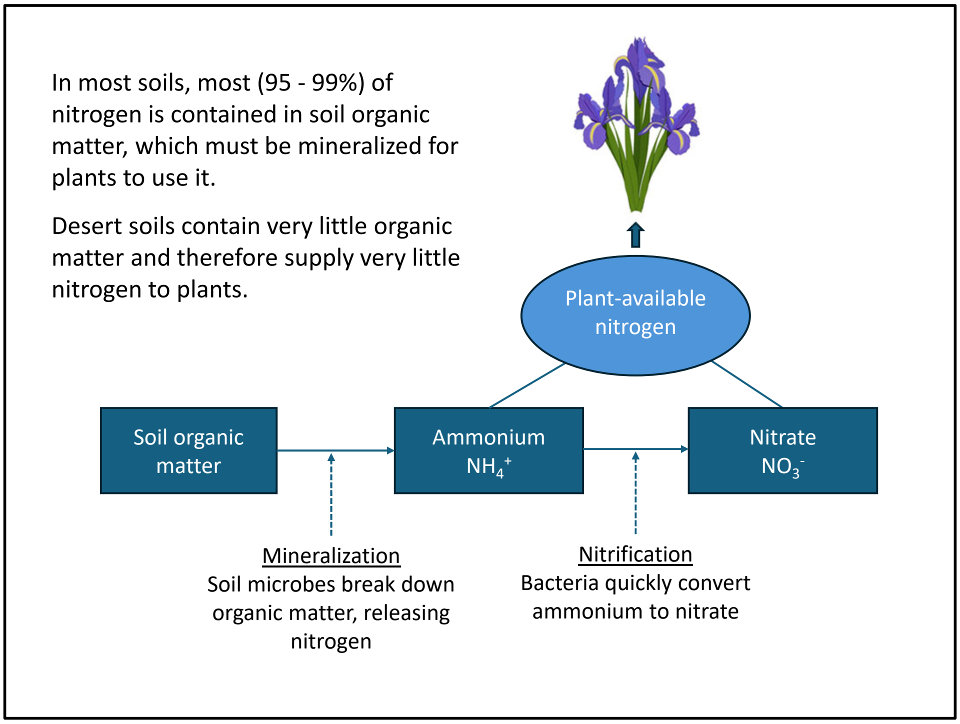
There are some plant species that are particularly sensitive to deficiencies of specific nutrients. Pecans, for example, have a strong tendency to develop zinc deficiency. Knowing that is helpful for making a correct diagnosis.

If you have identified a micronutrient deficiency but cannot identify a specific responsible nutrient, I suggest either of two treatment approaches. The first is to treat the plant with iron, usually as a foliar application. If this alleviates the problem, a diagnosis of iron deficiency was correct. A second approach is to treat with a cocktail containing a combination of micronutrients. This should alleviate deficiencies of any of the applied nutrients.

Nitrogen



Another nutrient often present in insufficient quantities is nitrogen. Nitrogen is the most managed nutrient in horticultural and agricultural production.



In most soils, most (95 - 99%) of nitrogen is contained in soil organic matter, which must be mineralized for plants to use it.

Desert soils contain very little organic matter and therefore supply very little nitrogen to plants.

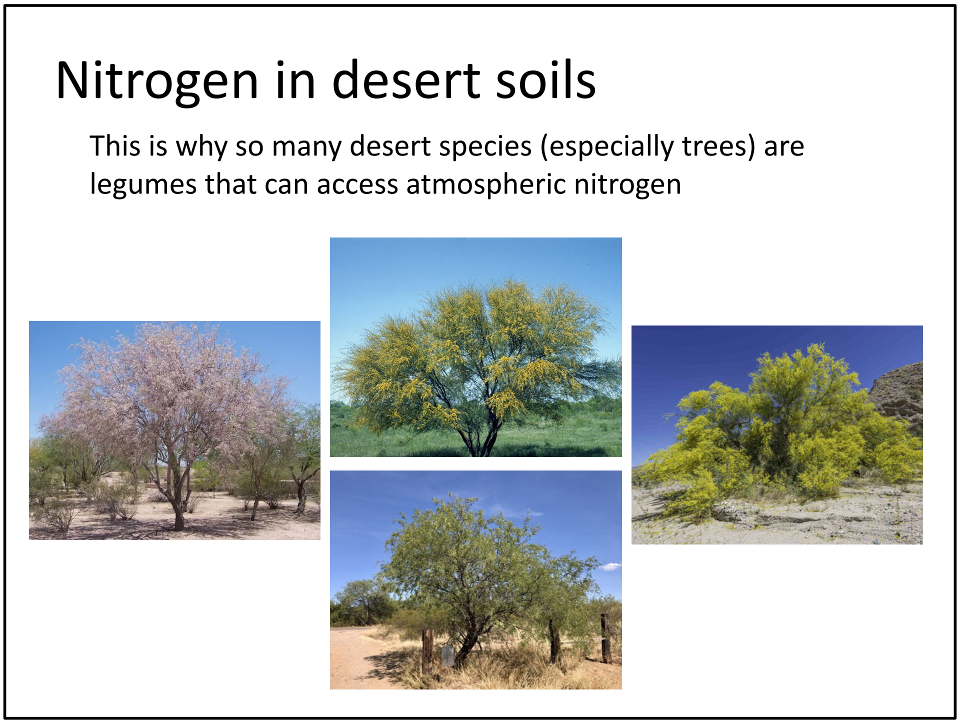
<u>Mineralization</u>
Soil microbes break down organic matter, releasing nitrogen

<u>Nitrification</u>
Bacteria quickly convert ammonium to nitrate

There are three dominant forms of nitrogen in soil. By far the most abundant is nitrogen contained in soil organic matter. This generally represents over 95% of soil nitrogen, but organic nitrogen is largely unavailable for plant uptake. As microbes decompose organic matter (mineralization), some of the nitrogen it contains is released into the soil in plant-available forms.

Inorganic nitrogen released by mineralization takes one of two forms in soil: ammonium (NH_4^+) or nitrate (NO_3^-). Plants can use either ammonium or nitrate, although a few plants have distinct preferences. Neither ammonium nor nitrate are stable in soils. Ammonium is quickly converted to nitrate in aerobic (not waterlogged) soils. This process, nitrification, releases acids that can slightly reduce soil pH while converting ammonium to nitrate. Nitrate can be lost from soil by leaching or converted by microbes to gaseous forms that are lost to the atmosphere. Neither inorganic form of nitrogen is long-lasting in soil.

Most soil nitrogen is contained in organic matter. Because desert soils have very little organic matter, they also contain less nitrogen than most other soils.



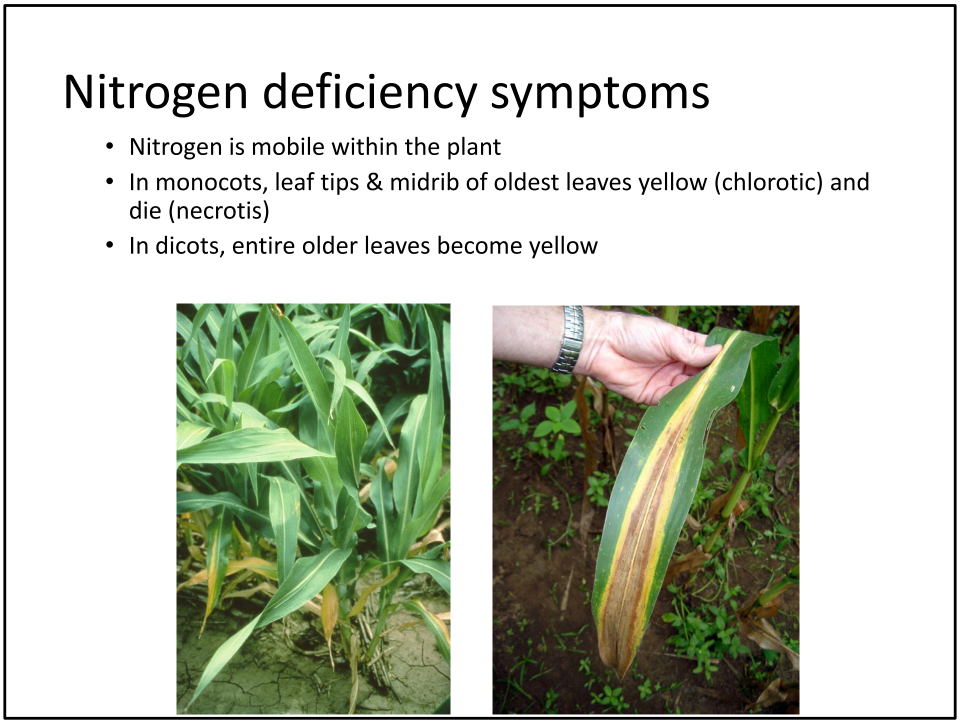
Nitrogen in desert soils

This is why so many desert species (especially trees) are legumes that can access atmospheric nitrogen

The lack of soil organic matter to supply nitrogen explains why so many desert plants are legumes which can access atmospheric nitrogen.

The atmosphere is 78% nitrogen, but it’s in a form that cannot be used by animals or by higher plants. Only a few microorganisms can capture and utilize atmospheric nitrogen. Legumes cultivate some of these microorganisms within their roots and consequently have access to the nitrogen captured by the microorganisms.

Nearly all non-riparian Sonoran desert tree species are legumes: palo verde, mesquite, acacia, ironwood, etc. Many other familiar desert species, such as calliandra, sophora, caesalpinia, senna, dalea, are also legumes.

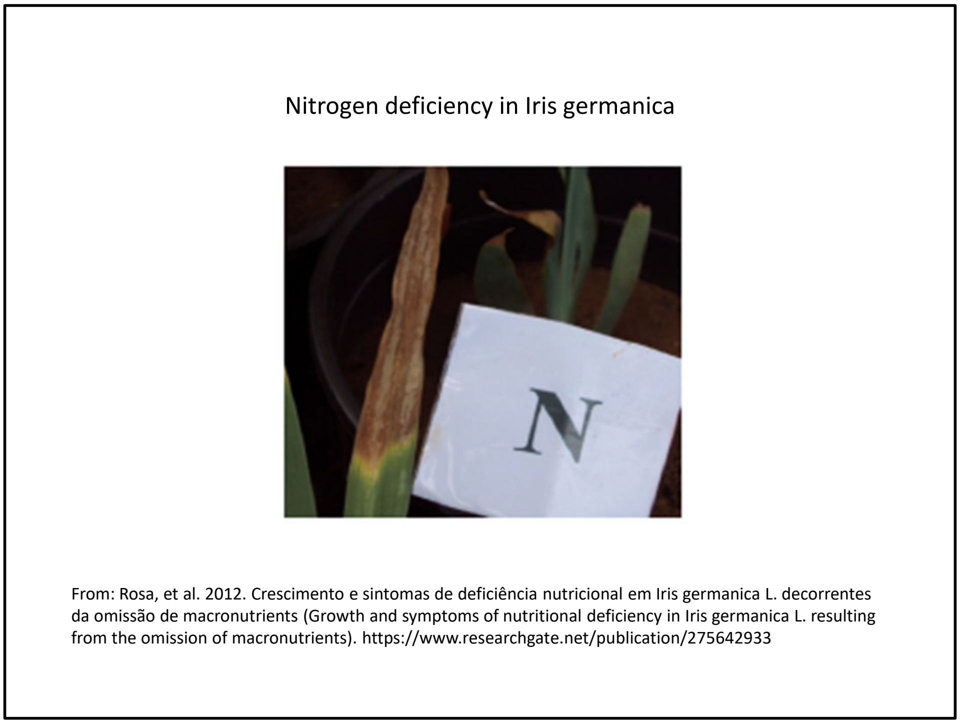


Nitrogen deficiency symptoms

- Nitrogen is mobile within the plant
- In monocots, leaf tips & midrib of oldest leaves yellow (chlorotic) and die (necrotis)
- In dicots, entire older leaves become yellow

Nitrogen deficiency begins in the oldest leaves of a plant because nitrogen is mobile within the plant. As a growing plant becomes short of nitrogen, it can move nitrogen from the least important old leaves and move it into critical growing areas, rendering older leaves nitrogen deficient.

The older leaves become yellow. In grasses, yellowing begins at the leaf tip and progresses back along the mid-rib, as in the photo at the right. In dicots the whole leaf may become yellow, but deficiency symptoms can vary considerable in different plant species.



Nitrogen deficiency in Iris germanica

From: Rosa, et al. 2012. Crescimento e sintomas de deficiência nutricional em Iris germanica L. decorrentes da omissão de macronutrients (Growth and symptoms of nutritional deficiency in Iris germanica L. resulting from the omission of macronutrients). https://www.researchgate.net/publication/275642933

I found just this one not-very-good photo of nitrogen deficiency in an iris. You can see that the symptoms started in the leaf tip and are working their way toward the leaf base. We cannot tell from this photo, but we are probably looking at an older leaf.

Severe nitrogen deficiency can affect the entire plant

Although nitrogen deficiency begins in the oldest leaves of a plant, when severe the entire plant becomes yellow, as can be seen in this photo of an orchid.

Plants may also be stunted.

Nitrogen Fertilizers

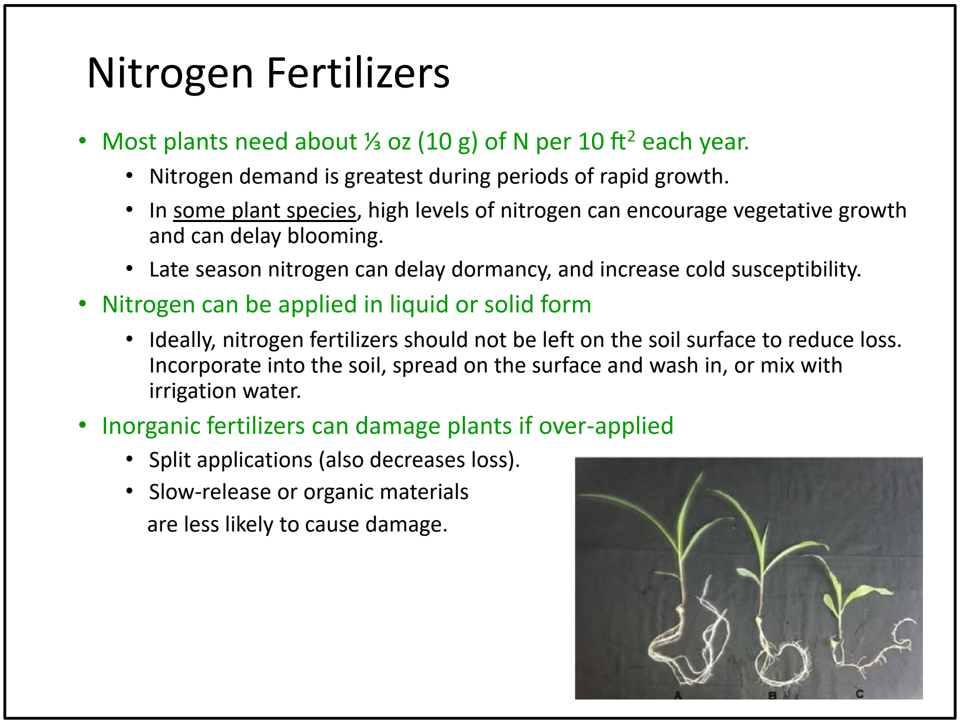
- Inorganic: ammonium nitrate, urea, ammonium sulfate, calcium nitrate
  - Most plants don't care too much whether nitrogen is supplied in ammonium or nitrate form. In soil, ammonium rapidly converts to nitrate.
  - These forms are immediately available. Excess can damage plants by raising soil salinity levels.
- Slow release: usually coated fertilizer pellets
  - Osmocote®, nutricote®, sulfur-coated urea, others.
- Organic: manure, compost, etc.
  - Must be microbially converted to inorganic forms before plants can use the nitrogen. Add repeatedly to build soil organic matter and supply nitrogen.

As indicated earlier, most plants are not particular about their form of nitrogen. Most want some ammonium and some nitrate, and this is not usually a major consideration when selecting fertilizers. A 2016 study (Zhao et al., Effects of Different NH_4:NO_3 Ratios on Growth and Nutrition Uptake in Iris germanica 'Immortality') indicated that *Iris germanica* growth and flowering were not affected by varying ammonium:nitrate ratio).

Keep in mind that these inorganic nitrogen fertilizers are water soluble and dissolve quickly in soil. They are salts and can damage plants if present in large quantities. Pay attention to application rates.

Because inorganic nitrogen fertilizers are very soluble they can be lost from soil easily. To avoid loss and to reduce the potential for damaging plants, nitrogen fertilizers can be treated so they dissolve slowly over time. These slow-release fertilizers are very effective, but more expensive that untreated fertilizers.

Lastly, adding nitrogen-containing organic matter (usually compost or animal manure) is a good way to provide nitrogen. As the organic material is digested by microbes, nitrogen is slowly released. In hot, irrigated desert soils, microbes decompose organic matter quickly, so repeat applications are recommended. Don't mix un-composted sawdust, shredded paper, or similar into the soils as they can temporarily reduce nitrogen availability.



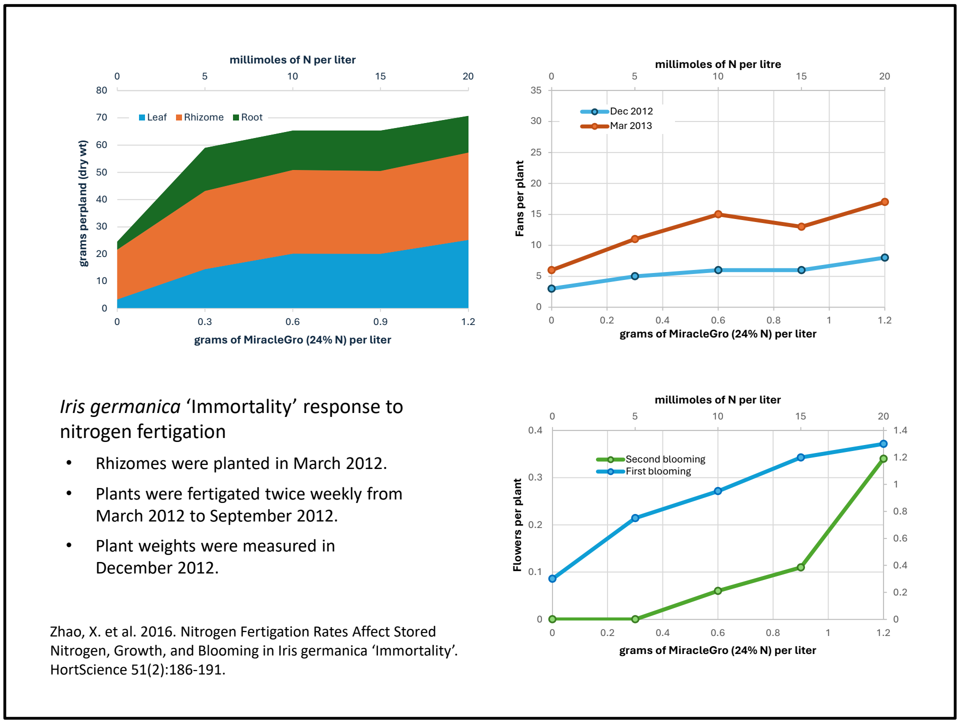
Nitrogen Fertilizers

- Most plants need about ⅓ oz (10 g) of N per 10 ft^2 each year.
  - Nitrogen demand is greatest during periods of rapid growth.
  - In some plant species, high levels of nitrogen can encourage vegetative growth and can delay blooming.
  - Late season nitrogen can delay dormancy, and increase cold susceptibility.
- Nitrogen can be applied in liquid or solid form
  - Ideally, nitrogen fertilizers should not be left on the soil surface to reduce loss. Incorporate into the soil, spread on the surface and wash in, or mix with irrigation water.
- Inorganic fertilizers can damage plants if over-applied
  - Split applications (also decreases loss).
  - Slow-release or organic materials are less likely to cause damage.

Most plants need about 10 g of nitrogen per 10 ft^2 of area each year. Nitrogen does not persist in soil, so nitrogen is managed on a continuous basis, applied each year or even several times each year. You've probably read that applying too much nitrogen can cause lush growth and delay blooming. This is true of SOME, but not most plants. Too much late season nitrogen can, however, delay dormancy and leave perennial plants susceptible to frost damage.

Inorganic fertilizers can be applied as either liquids or solids, the choice one of convenience and cost. Mixing nitrogen with irrigation water is a particularly convenient method of application. Solid nitrogen fertilizers left on the soil surface may be lost to the atmosphere, depending on conditions. Incorporate into the soil to minimize loss. To avoid nitrogen loss and to prevent damage from over-fertilization, applications are often split into several small, often monthly, applications.

The nitrogen content of fertilizers is displayed on the label. Nitrogen is the first of the three nutrient numbers. A 10-20-20 fertilizer contains 10% plant-available nitrogen. Often, we fertilize to manage nitrogen, in which case we may be less concerned about the other label numbers (phosphorus and potassium).



Iris germanica ‘Immortality’ response to nitrogen fertigation

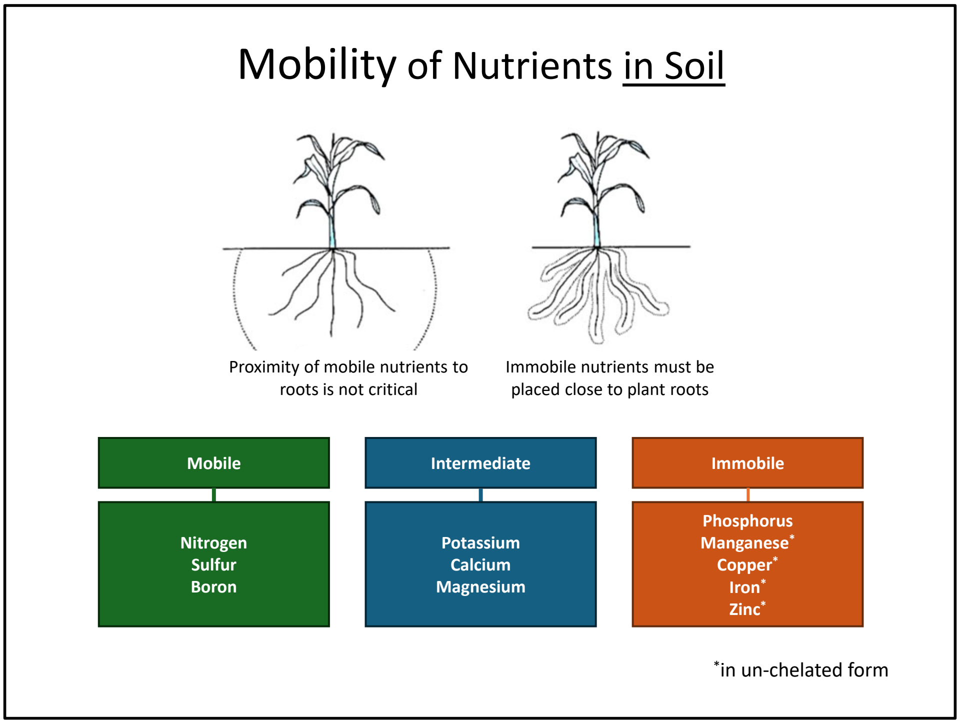
- Rhizomes were planted in March 2012.
- Plants were fertigated twice weekly from March 2012 to September 2012.
- Plant weights were measured in December 2012.

Zhao, X. et al. 2016. Nitrogen Fertigation Rates Affect Stored Nitrogen, Growth, and Blooming in Iris germanica ‘Immortality’. HortScience 51(2):186-191.

I found one good study of response of *Iris germanica* to varying concentrations of nitrogen applied in irrigation water. The research is reported in the PhD dissertation of Xiaojie Zhao (Nutrient management in reblooming iris ‘Immortality’) conducted at Mississippi State University as well as three articles published in HortScience.

They fertigated newly-planted rhizomes with nitrogen solutions (made from ammonium nitrate 34-0-0) ranging from 0 to 20 millimoles of nitrogen per liter)top axes). I’ve converted the nitrogen rate to equivalent concentrations of (MiracleGro 24% nitrogen) fertilizer (bottom axes).

I’ve reproduced their most relevant findings here. In the upper left can be seen the growth response over the year, divided into leaves, rhizomes, and roots. Growth of all three plant parts responded positively to increasing nitrogen concentrations, although the response diminished at hogher nitrogen concentrations. Similarly, the number of fans per plant increased as nitrogen concentrations were raised (upper right). The numbers of first bloom flowers increased steadily with increasing nitrogen and second bloom flowering was notably improved with the highest nitrogen concentration (bottom graph).



Mobility of Nutrients in Soil

Proximity of mobile nutrients to roots is not critical

Immobile nutrients must be placed close to plant roots

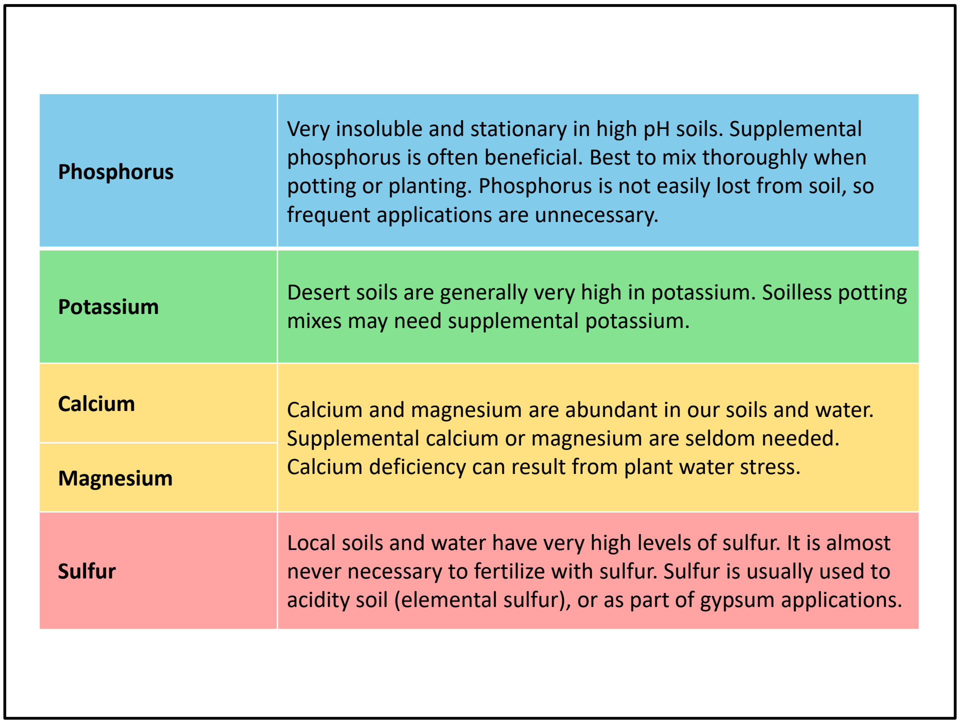
Mobile	Intermediate	Immobile
Nitrogen Sulfur Boron	Potassium Calcium Magnesium	Phosphorus Manganese* Copper* Iron* Zinc*

*in un-chelated form

A nutrient's mobility in soil dictates how we manage it. Plant-available (inorganic) nitrogen is highly mobile in soil. This means that fertilizer placement is not critical, as the nitrogen can move to plant roots. Also, we cannot build up soil inorganic nitrogen levels because they are dynamic. What we applied last year is no longer there. We manage nitrogen on a real-time basis: we supply nitrogen when the plant needs it.

At the other end of the spectrum is phosphorus. It is very insoluble and immobile in soil. Phosphorus has to be very close (a few millimeters) to a plant root to be available, so it is preferable to mix it into soil. And because phosphorus does not move or leach from soil, we can build up phosphorus levels. Phosphorus applications will be effective for several years.

Manganese, copper, iron, and zinc are denoted with asterisks because, whereas chelated forms added in fertilizer are mobile, un-chelated forms are extremely immobile. Similarly, some forms of calcium and magnesium are immobile, others more mobile. Potassium mobility is dependent upon soil mineralogy.



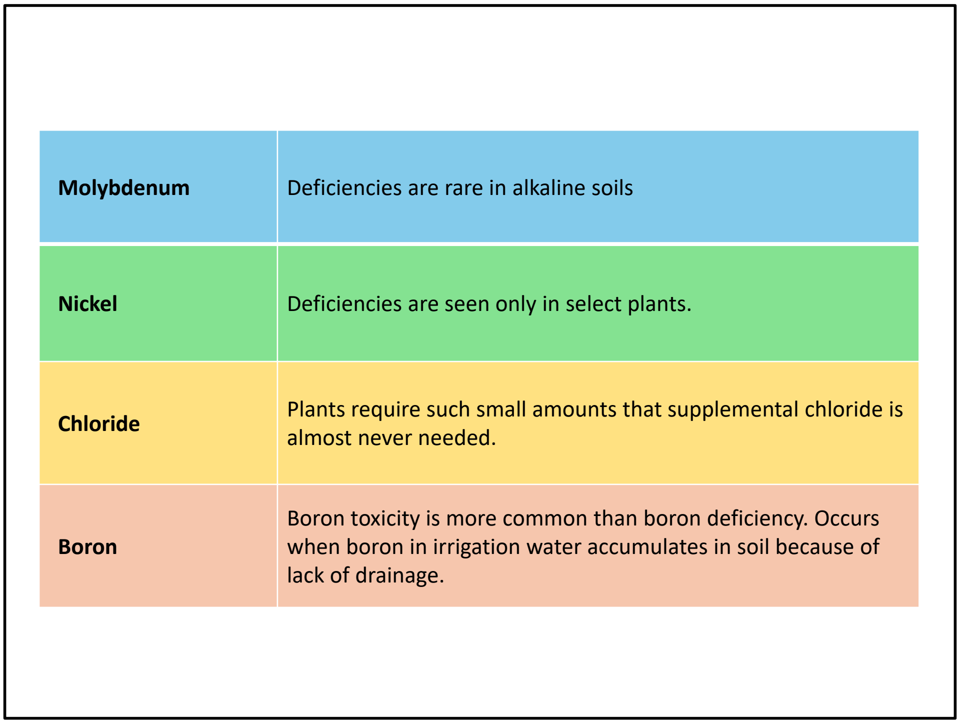
Phosphorus	Very insoluble and stationary in high pH soils. Supplemental phosphorus is often beneficial. Best to mix thoroughly when potting or planting. Phosphorus is not easily lost from soil, so frequent applications are unnecessary.
Potassium	Desert soils are generally very high in potassium. Soilless potting mixes may need supplemental potassium.
Calcium	Calcium and magnesium are abundant in our soils and water. Supplemental calcium or magnesium are seldom needed. Calcium deficiency can result from plant water stress.
Magnesium	
Sulfur	Local soils and water have very high levels of sulfur. It is almost never necessary to fertilize with sulfur. Sulfur is usually used to acidity soil (elemental sulfur), or as part of gypsum applications.

Here is a quick rundown on nutrients we haven't discussed. A few comments regarding phosphorus are warranted. Plants growing in desert soils often respond positively to supplemental phosphorus.

Phosphate is the second number on a fertilizer label. Ideally, phosphorus fertilizer should be incorporated into soil, which is difficult with established perennial plants. When planting long-lived perennials, I recommend mixing the fertilizer throughout the planting hole before planting. An exception is the phosphorus in water-soluble fertilizers (Miracle-Gro, etc.). These fertilizers typically contain a form of water-soluble phosphorus that is mobile in soil for a few days.

Removing calcium sulfate from ordinary or single superphosphate (0-20-0) produces triple superphosphate (0-45-0) which is more concentrated (2.25 X more concentrated) and has greater solubility than ordinary superphosphate. Rock phosphate is insoluble and therefore ineffective in our alkaline soils.

Sulfur is abundant in desert soils. Supplemental sulfur is seldom needed. We often apply sulfur, however, either as elemental sulfur to acidify soil, or as gypsum (calcium sulfate) to improve soil physical properties.

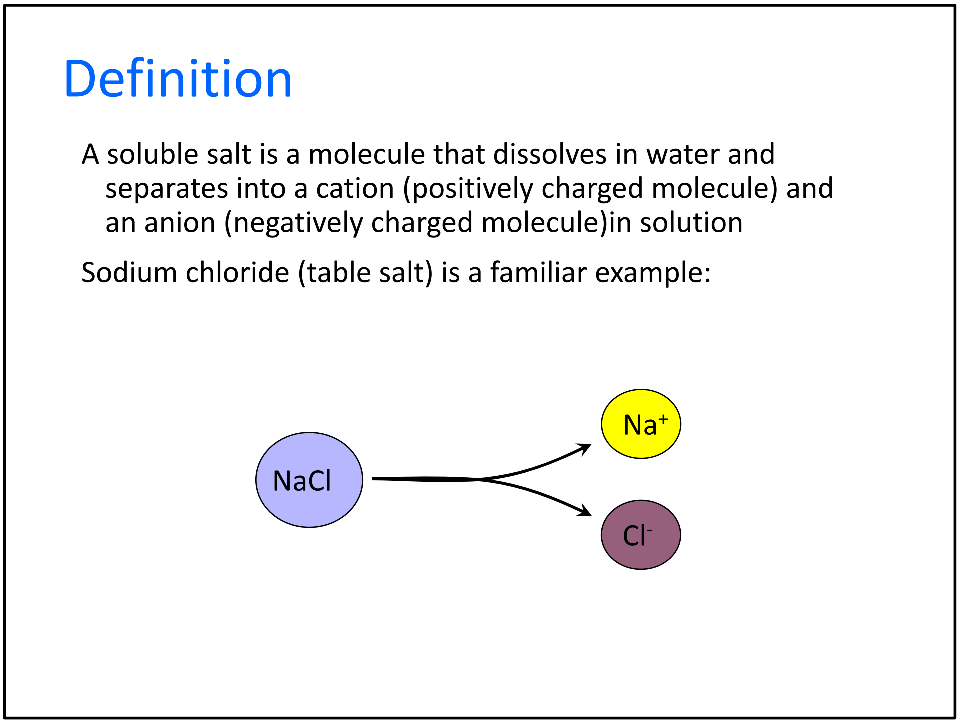


Molybdenum	Deficiencies are rare in alkaline soils
Nickel	Deficiencies are seen only in select plants.
Chloride	Plants require such small amounts that supplemental chloride is almost never needed.
Boron	Boron toxicity is more common than boron deficiency. Occurs when boron in irrigation water accumulates in soil because of lack of drainage.

Boron is very soluble and mobile in soil. Boron toxicity is more common in our area than boron deficiency. Some groundwater contains significant levels of boron. If irrigating with boron-containing water, boron can accumulate unless soils are adequately leached, sometimes building up to toxic levels. This condition is easily remedied by periodic leaching.

SALT

Managing soil salts is as important as managing nutrients in irrigated horticulture.



Definition

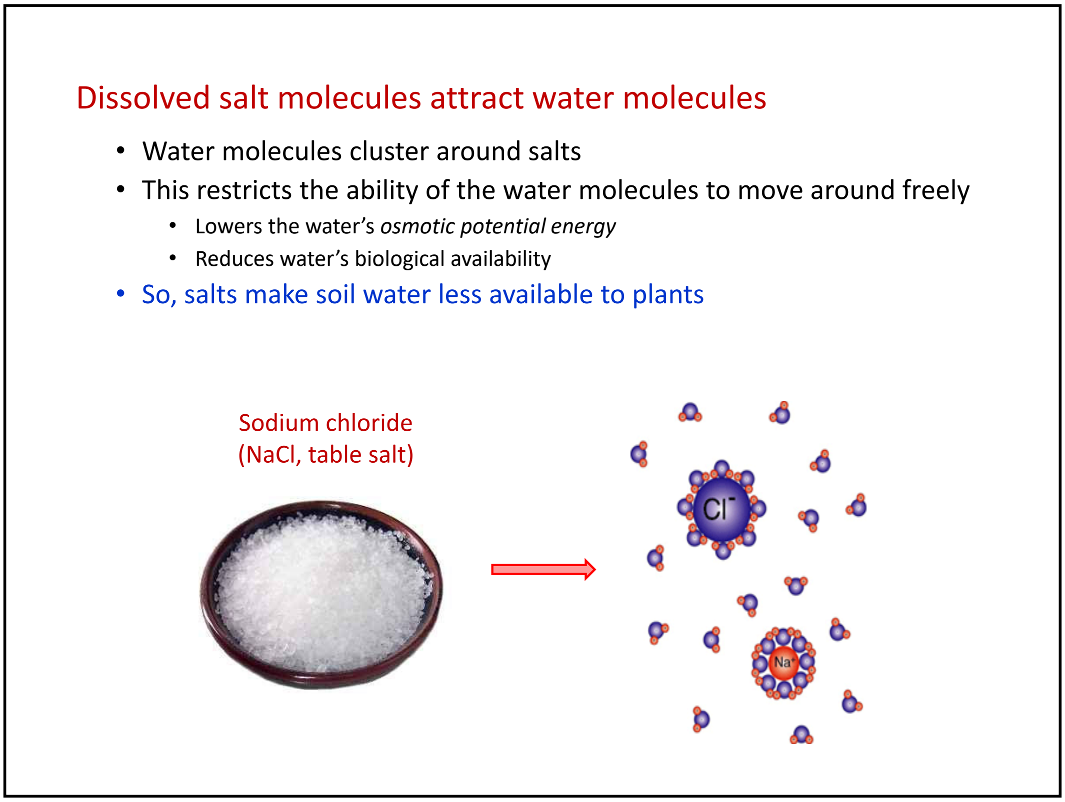
A soluble salt is a molecule that dissolves in water and separates into a cation (positively charged molecule) and an anion (negatively charged molecule)in solution

Sodium chloride (table salt) is a familiar example:

First, let's define what we mean when we use the word salt. For our purposes a salt is a material composed of a cation (a molecule with a positive electrical charge) and an anion (negatively charged molecule). Salt compounds form solid crystals when dry. Soluble salts dissolve in water, and once dissolved, the anion and cation separate and become individual ions.

The most familiar example is sodium chloride – table salt, but there are many kinds of soil salts. A sodium chloride crystal separates into its component ions (sodium cation and chloride anion) when it dissolved in water.

Soil salts are composed of any of several anions (carbonate, bicarbonate, sulfate, nitrate, phosphate, chloride) and cations (sodium, magnesium, potassium, calcium, ammonium) which can pair in various combinations.

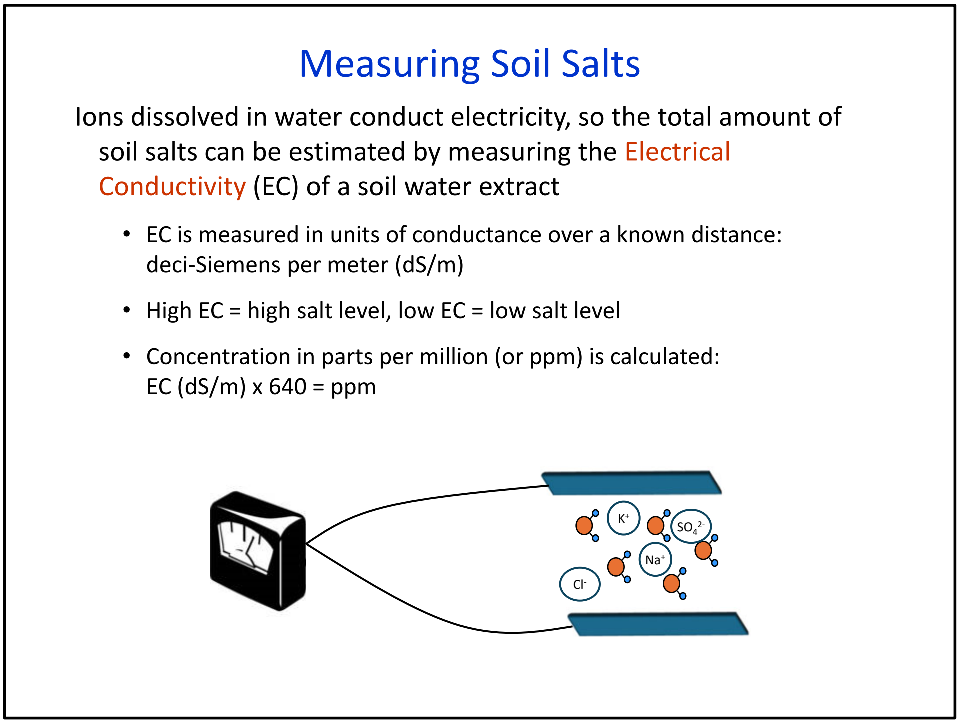


Dissolved salt molecules attract water molecules

- Water molecules cluster around salts
- This restricts the ability of the water molecules to move around freely
  - Lowers the water's *osmotic potential energy*
  - Reduces water's biological availability
- So, salts make soil water less available to plants

Sodium chloride
(NaCl, table salt)

As this cartoon shows, when salts dissolve in water, the two halves (anion and cation) separate. Each half attracts and attaches to water molecules. Water molecules attached to salts are difficult to separate and utilize. Consequently, salty water is less plant-available than clean water.



Measuring Soil Salts

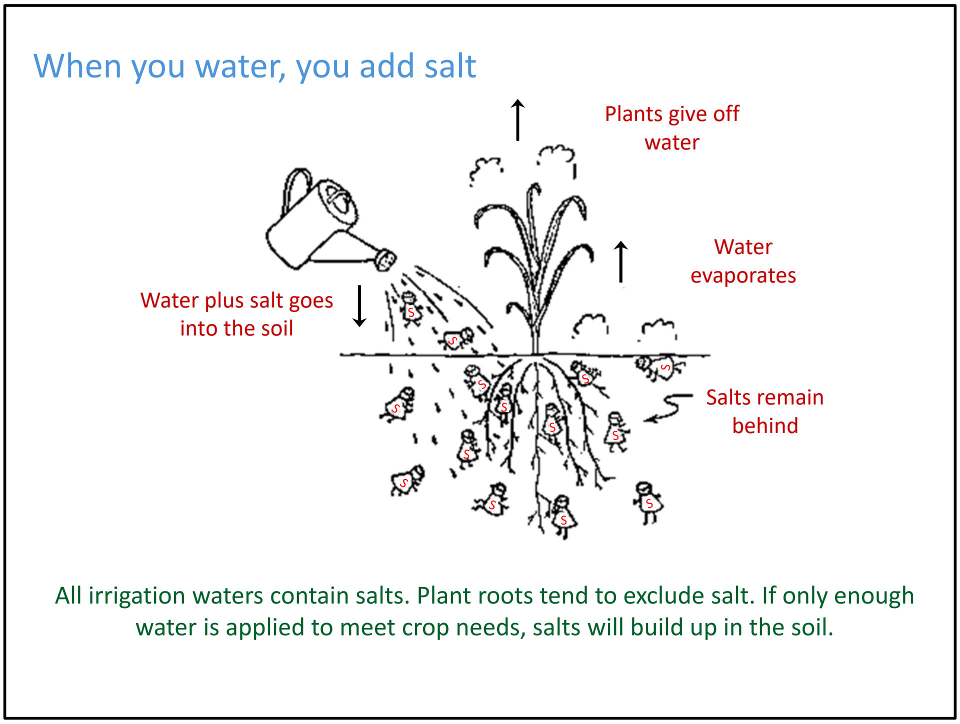
Ions dissolved in water conduct electricity, so the total amount of soil salts can be estimated by measuring the Electrical Conductivity (EC) of a soil water extract

- EC is measured in units of conductance over a known distance: deci-Siemens per meter (dS/m)
- High EC = high salt level, low EC = low salt level
- Concentration in parts per million (or ppm) is calculated: EC (dS/m) x 640 = ppm

Salts, when dissolved in water, cause the water to become a better electrical conductor. Therefore, we can estimate the amount of salt in water by measuring the electrical conductivity, or EC. The higher the EC, the greater the salt concentration. To measure soil EC, we make mud, extract the water, and measure the EC of the extract.

The units of EC are deci-siemens per meter (dS/m). Water salinity is often reported in ppm. EC measurements can be converted into parts per million (ppm) of salt by multiplying EC x 640.

Reliable, inexpensive EC meters are excellent tools for measuring salinity.



When you water, you add salt

Plants give off water

Water evaporates

Water plus salt goes into the soil

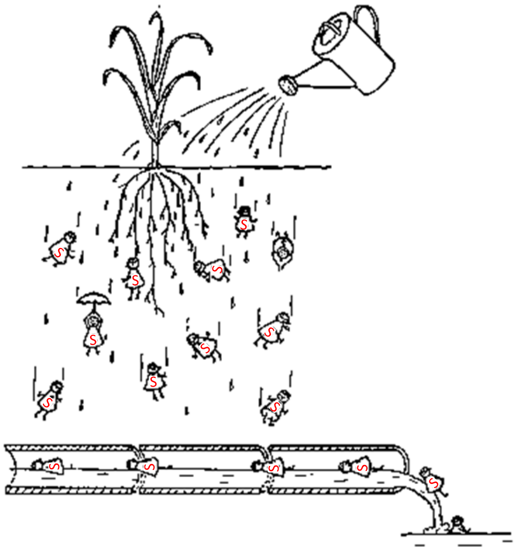
Salts remain behind

All irrigation waters contain salts. Plant roots tend to exclude salt. If only enough water is applied to meet crop needs, salts will build up in the soil.

All naturally-occurring water contains salt. Rainwater has only a little salt (less than 20 ppm). Tucson water contains about 300 to 400 ppm of salt, depending on where it’s delivered. CAP water has about 650 ppm.

Salt added in irrigation water can accumulate, and soil salinity can reach levels toxic to many plants. High levels of soil salts can also inhibit some soil microbes. Water lost by evaporation, either from soil or from plant leaves, is relatively pure. Salts remain in the soil unless leached from the soil.

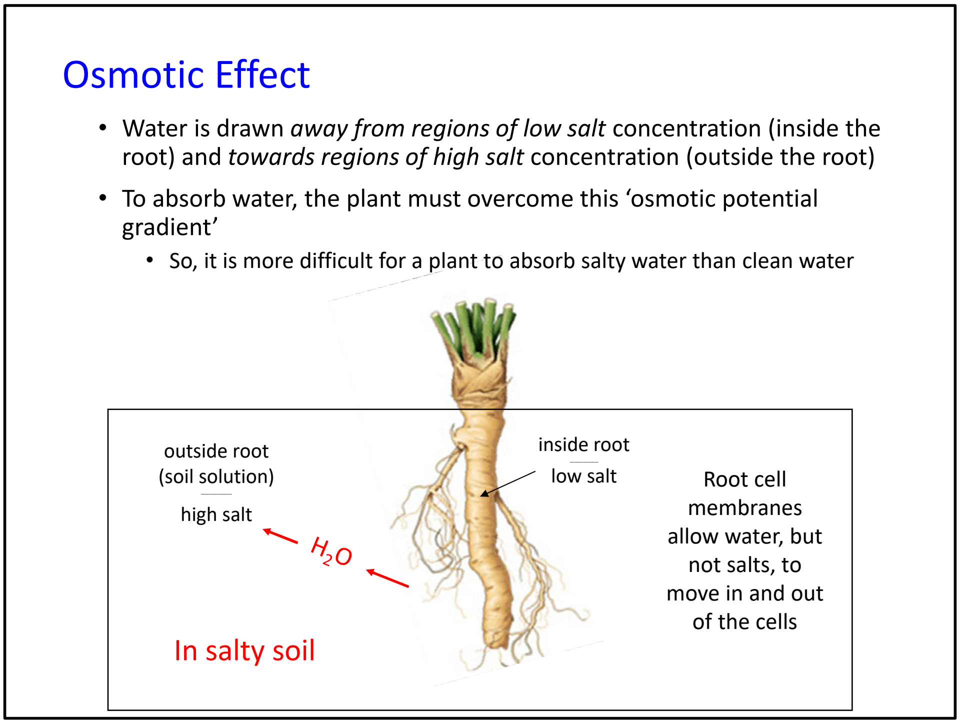
Here is a potted plant with soil that has accumulated salt to the extent that we can see the salt crystallized on the soil surface.



Application of excess water will leach salts from the root zone.

If we apply excess water, soluble salts will leach out of the soil with the drainage water. Irrigated soils must be leached or salts will eventually accumulate. The amount of leaching needed depends on both irrigation water salinity and plant salinity tolerance.

A key to leaching is to ensure that soils are well-drained. Unless water can drain freely from the root zone, salts are likely to accumulate. Before putting a plant in the ground, make sure the hole will drain rapidly when filled with water.



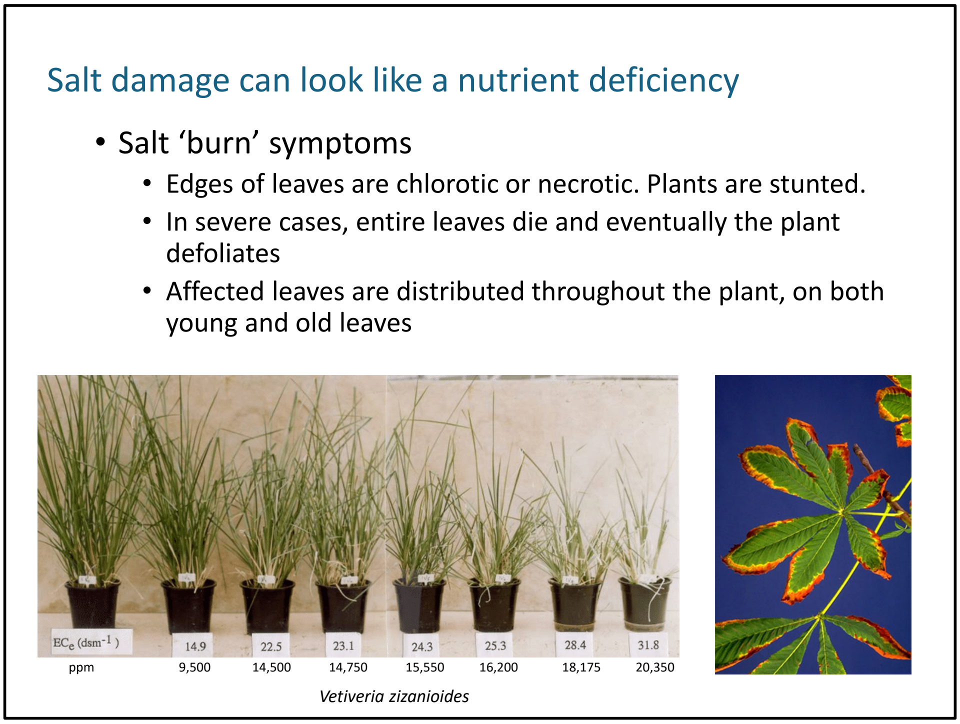
Osmotic Effect

- Water is drawn *away from regions of low salt* concentration (inside the root) and *towards regions of high salt* concentration (outside the root)
- To absorb water, the plant must overcome this ‘osmotic potential gradient’
  - So, it is more difficult for a plant to absorb salty water than clean water

Root cell membranes allow water, but not salts, to move in and out of the cells

Soil salts and the plants compete for water molecules. Water moves into living cells only if the water potential inside the cell is lower than the water potential outside the cell.

If the soil solution is salty, then the plant must “pull harder” to get water from the soil. If the soil solution is too salty, it can actually draw water out of living cells. Ultimately, salty water is less available to plants than clean water.



Salt damage can look like a nutrient deficiency

- Salt 'burn' symptoms
  - Edges of leaves are chlorotic or necrotic. Plants are stunted.
  - In severe cases, entire leaves die and eventually the plant defoliates
  - Affected leaves are distributed throughout the plant, on both young and old leaves

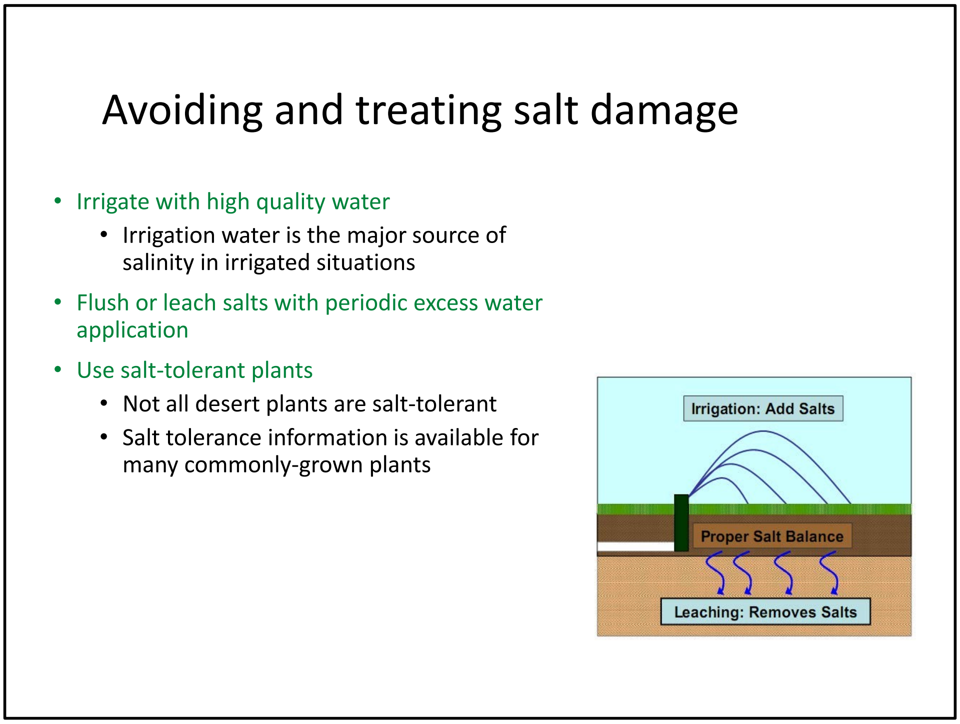
EC_e (dsm^{-1})	14.9	22.5	23.1	24.3	25.3	28.4	31.8
ppm	9,500	14,500	14,750	15,550	16,200	18,175	20,350

Vetiveria zizanioides

Salt damage appears as chlorotic or necrotic tissues along leaf edges. Plants become stunted and eventually die.

There's a tremendous range of salt tolerance among plants. Very tolerant plants can live in ocean water, whereas sensitive plants are inhibited by much lower salt levels.

One clue to symptoms of salt damage is that, unlike most nutrient deficiency symptoms, salt damage occurs throughout the plant and is not focused on older or younger leaves.



Avoiding and treating salt damage

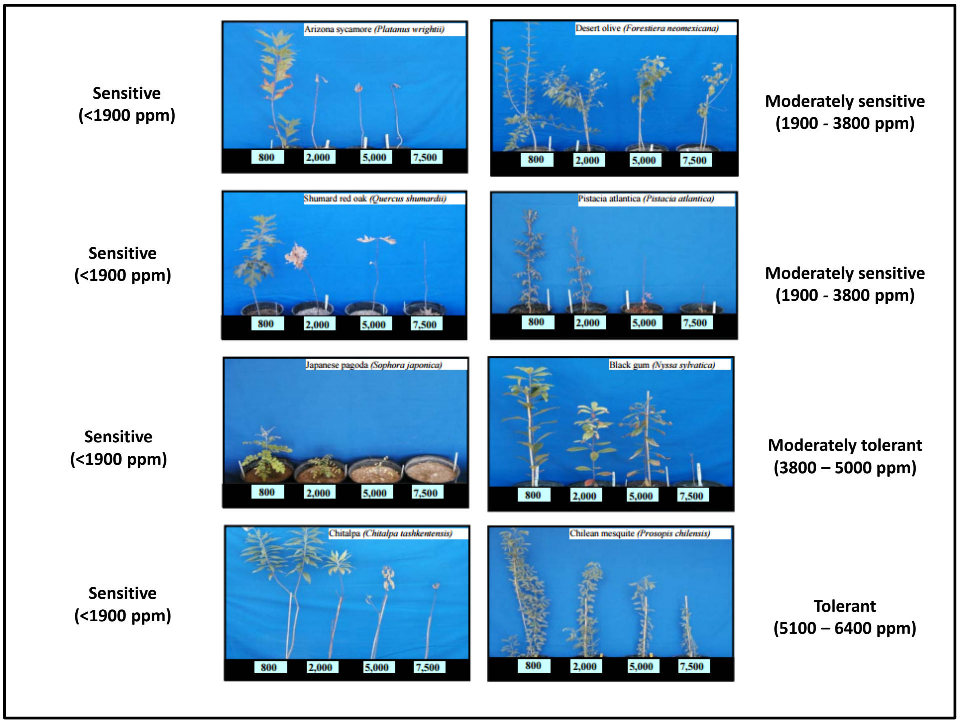
- Irrigate with high quality water
  - Irrigation water is the major source of salinity in irrigated situations
- Flush or leach salts with periodic excess water application
- Use salt-tolerant plants
  - Not all desert plants are salt-tolerant
  - Salt tolerance information is available for many commonly-grown plants

Problems associated with salt accumulation can be addressed in a couple of ways.

Watering with all but the cleanest water necessitates periodic leaching. This may occur naturally if monsoon rains are abundant. Otherwise, occasional over-watering is needed to leach salts. Farmers will sometimes irrigate during monsoon rains to increase leaching.

Salt-tolerant plants can withstand greater salt levels, and therefore require less leaching than salt-sensitive plants. More leaching is required when watering with salt-laden water. If irrigating entirely with clean rainwater, salt accumulation will be very slow and leaching less critical. More extensive leaching is required when watering with salty water.

The ideal way to minimize salt issues is to use salt-tolerant plants. In general, arid-region plants exhibit greater salt tolerance than tropical or temperate plants. Unfortunately, salinity tolerance data are available only for widely-grown plants. Information on ornamentals may be difficult to find.



Sensitive
(<1900 ppm)

Moderately sensitive
(1900 - 3800 ppm)

Sensitive
(<1900 ppm)

Moderately sensitive
(1900 - 3800 ppm)

Sensitive
(<1900 ppm)

Moderately tolerant
(3800 – 5000 ppm)

Sensitive
(<1900 ppm)

Tolerant
(5100 – 6400 ppm)

The photos shown here are from the publication “Salt Tolerance of Landscape Plants Common to the Southwest” 2008 by S. Miyamoto. They show impact of salinity of some salt sensitive, moderately sensitive, moderately tolerant, and tolerant plants. Here it is easy to see the magnitude of difference in salt tolerance in a few plants.

I could find very little information about iris salt tolerance, and it probably varies quite a lot between genera and species. A rough rule of thumb is that tropical species from high rainfall areas have less salt tolerance than plants from drier regions. Irises seem to fall into the moderately sensitive category.

This photo shows Pioneer Peak, in Palmer Alaska, in the background. The Palmer Hay Flats, an estuary of the Knik River in the Upper Cook Inlet consists of many acres of coastal and freshwater wetlands, in spring much of it covered by blooming irises. The route from Palmer to Anchorage crosses the hay flats, passing through miles of wetland covered with irises and other flowers in the spring.

Resources

- **Foliar Fertilization – Scientific Principles and Field Practices**. 2013. V. Fernandes, T. Sotiropoulos, P. Brown. International Fertilizer Industry Assn. https://www.fertilizer.org/resource/foliar-fertilization-scientific-principles-and-field-practices/.
- **Nature and Properties of Soils**, 15th Edition. 2017. R. Weil, N.C. Brady. Pearson Education, Inc.
- **Nitrogen Fertigation Rates Affect Stored Nitrogen, Growth, and Blooming in Iris germanica 'Immortality'**. 2016. Zhao, X., G. Bi, R. Harkess, J. Varco, T. Li. HortScience 51(2):186-191.
- **Western Fertilizer Handbook**, 10th Edition. 2023. Western Plant Health Association.
- **Soil Fertility and Fertilizers: An Introduction to Nutrient Management**, 8th Edition. 2016. L. Havlin, S. Tisdale, W. Nelson, J. Beaton. Pearson.