2. Supplying Essential Nutrients

In this chapter, we describe the essential nutrients for plant growth, and fertilizer sources of these nutrients. We also describe how to interpret a fertilizer label so that you can select and use fertilizer successfully.

2.1 Essential Fertilizer Nutrients

Plants are mostly water. If we place 100 lb or kg of healthy living plant material into a drying oven to remove all the water, we will have only about 1/10 of the mass left. Most plants are about 90% water and 10% dry matter.

The 10% of dried plant material is made up of the "organic" components of carbon (C), hydrogen (H), oxygen (O), and a number of "inorganic" ions such as N (nitrogen), P (phosphorus), and K (potassium). Plants obtain most of their organic C, H, and O from water and air.

If we take the 10% of dry plant material and remove all the carbon, hydrogen, and oxygen, only about 1/10 remains as inorganic ash. Therefore, plant nutrition using inorganic fertilizers directly manages only about 1% of the plant by weight.

The plant ash is composed of plant nutrients that are essential for normal growth, metabolism and flowering. However, these nutrients are not all taken up at the same rate. Essential plant nutrients can be separated into two groups, termed macronutrients and micronutrients. Macronutrients are found at relatively high concentrations in the plant tissue and include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Micronutrients are found at much lower concentrations in the tissue than macronutrients and include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), and molybdenum (Mo) (Table 1). These twelve essential plant nutrients are commonly provided by various fertilizer sources applied during crop production.

Several other nutrients that are considered as essential or beneficial for normal growth including sodium (Na), chloride (Cl), Silicon (Si), Nickle (Ni), Cobalt (Co), and Aluminum. However, these latter plant nutrients are often found as contaminants in a number of different fertilizer sources, root substrate components, or irrigation water, and it is not normally necessary to apply extra of these nutrients.

Silicon is generally considered a beneficial rather than essential nutrient that protects plants from stress. Benefits of the nutrient become most evident in adverse situations such as exposure to pathogens (Figure 2.2). Silicon fertilizers can be applied as foliar or soil applications (typically as potassium (K_2SiO_4) or sodium (Na_2SiO_4) silicate or can be provided by the root substrate. Research by USDA-ARS found a relationship between increased Si uptake and disease resistance to powdery mildew in zinnia when plants were grown in root substrates containing rice hulls or miscanthus (which contain Si) compared to plant grown in with peat and pine-bark substrates without Si sources.

Phosphorus deficiency on Pansy.

Nitrogen deficiency on Vinca.

Iron/manganese toxicity on Marigolds

Figure 2.1 Nutritional problems found in container grown plants resulting from inadequate (deficient) or excess (toxic) amounts of nutrients.

Table 2.1: Essential fertilizer nutrients, chemical abbreviation, and typical concentrations found in dried plant material (percent of leaf dry weight)

Nutrients	Form Absorbed	Conc. In Tissue	Primary role in the plant	Mobility in the plant
Macronutrients				
Nitrogen (N)	NO_3^-, NH_4^+	4.0%	A component of chlorophyll, nucleic acids, proteins, and enzymes	High
Phosphorus (P)	$H_2PO_4^-$, HPO_4^{2-}	0.5%	Required to store and transport energy	High
Potassium (K)	K^+	4.0%	Acts as a osmotic regulator in water absorption and loss by the plant.	High
Calcium (Ca)	Ca^{2+}	1.0%	Cell structure, secondary plant hormone	Low
Magnesium (Mg)	Mg^{2+}	0.5%	Central ion in the chlorophyll molecule	High
Sulfur (S)	SO_4^{2-}	0.5%	A component of nucleic acids and proteins	Low to moderate
Micronutrients				
Iron (Fe)	Fe^{2+}	200 ppm	Required for chlorophyll synthesis and energy transferring pathways	Low
Manganese (Mn)	Mn^{2+}	200 ppm	Required for chlorophyll production and energy transferring pathways	Low
Zinc (Zn)	Zn^{2+}	30 ppm	Activates enzymes	Low
Copper (Cu)	Cu^{2+}	10 ppm	Involved in respiration and oxidation/reduction reactions	Low
Boron (B)	$H_2BO_3^-$	60 ppm	Essential for cell division and differentiation of young tissue	Low
Molybdenum (B)	MoO_4^-	1 ppm	Involved in nitrogen metabolism	Low
Others				
Sodium (Na)	Na^+	500 ppm	Osmotic regulator	High
Chloride (Cl)	Cl^-	0.1%	Required for photosynthesis	High
Silicon (Si)	H_4SiO_4	0.05-0.15%	Pathogen defense, drought and heat tolerance	
Cobalt (Co) and Nickel (Ni) are also listed as essential or beneficial nutrients, but little information exists about their absolute requirement in floricultural crops				

1% is equivalent to 10,000 ppm. Positively charged ions in the "Form absorbed" column are cations, and negatively charged ions are anions. Silicic acid (H_4SiO_4) is uncharged.

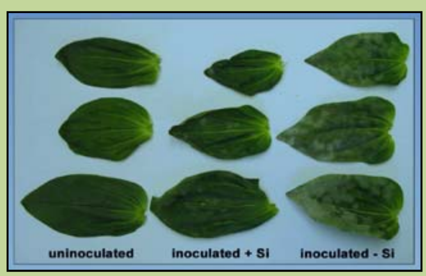


Figure 2.2 Zinnia plants that were not inoculated with powdery mildew spores or treated with Si were healthy (left). When plants were inoculated with powdery mildew spores, silicon fertilization (inoculated + Si) slowed infection (but did not eliminate it). Photo with permission from Dr. Jonathan Frantz, USDA-ARS.

Aluminum is not normally considered an essential nutrient, but has a unique role in floriculture where aluminum sulfate is added to the soil to induce blue coloration in hydrangea flowers.

In summary: There are 12 nutrients that need to be provided at moderate level by fertilizer. Several other nutrients such as sodium and chloride are usually available in water, air and the root substrate.
Deficiency symptoms are affected by the role of nutrients in plant growth, and whether the nutrient is mobile.

Plant response to low and high nutrient levels

Although the required concentration of essential nutrients varies between macro and micronutrients, all nutrients are needed in adequate supply for healthy growth. Liebig's "Law of the minimum" applies: whichever essential factor is in least supply (individual nutrients, water, light, or other factors) limits plant growth.

2.2 Response to Nutrient Level

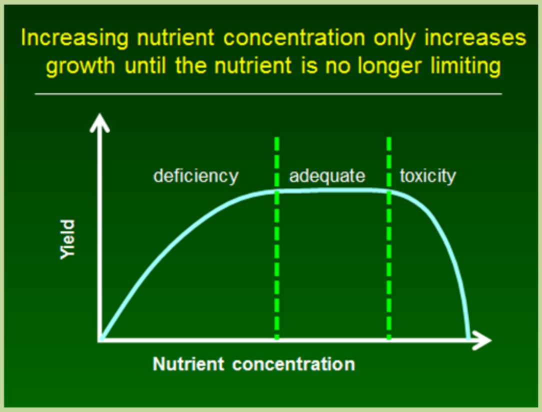


Figure 2.3 Generalized plant growth response to increasing nutrient level.

There is no one exact concentration that must be delivered, because plants can selectively take up most nutrients within an adequate range (Figure 2.3). Plant health problems and limited growth usually arises when nutrients are suppied in the deficient or toxic ranges. This helps us in growing crops - nutrient concentration in the soil solution does not have to exactly match the nutrient levels in the plant.

Liminting the application of N and P can be used to limit elongation of leaves and stems, and is commonly used in young plant production for growth control Low N also favors allocation of growth to roots over shoots, which improves transplant quality, and in some crops, flowering over vegetative growth. Increasing the concentration of nitrogen from ammonium rather than nitrate sources also tends to lead to increasing leaf expansion and soft growth.

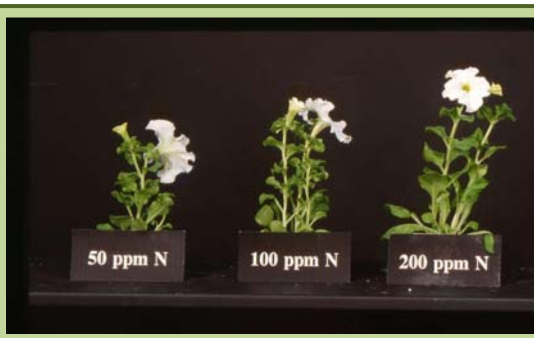


Figure 2.4 Effect of increasing fertilizer concentration on growth of petunias. The fertilizer source was 20-10-20 applied at 50, 100, or 200 ppm N with every irrigation. Picture was taken 5 weeks after transplanting from a 288 plug tray into a 1204 bedding flat.

Figure 2.5 Effect of simultaneously increasing concentration of phosphorus and the percent of nitrogen in the ammonium form (from left to right) on leaf expansion in geranium. Photo with permission from Dr. Harvey Lang, Syngenta.

If growth control is attempted by limiting nutrients other than N or P, however, plant stress or even tissue damage is likely. For example, limiting iron in the nemesias in Figure 2.6 and resulting interveinal chlorosis would require supplemental iron to produce a horticulturally acceptable plant.

Figure 2.6. Limiting supply of a nutrient such as iron in these nemesias, may reduce growth rate, but would also lead to an unsaleable plant. Note the greater chlorosis in younger leaves because iron is an immobile nutrient.

The role of nutrients in the plant, summarized in Table 2.1, affects visual deficiency symptoms. Deficiency of a mobile nutrient such as nitrogen that has many functions within the plant is likely to result in yellowing starting in the lower leaves that progresses to overall yellowing (Figure 2.7).

Figure 2.7 Nitrogen deficiency starts in the lower leaves and progresses to overall yellowing. Note the greater chlorosis in older leaves because N is a mobile nutrient.

Some nutrients are involved in the structural components and development of new organs in the plant such as calcium (in cell walls) and boron (formation of new branches and leaves). Deficiency in Ca or B therefore usually causes distorted new growth (Figure 2.8). Lack of Ca, as part of the protective "skeleton" of the plant, has been associated with susceptibility to plant pathogens such as botrytis in poinsettia.

Figure 2.8. A constant uptake of calcium is needed for normal cell wall development. Calcium deficiency in poinsettias can lead to leaf distortion during the vegetative phase of production, and distortion and bract edge burn at the end of the crop.

Magnesium and some of the micronutrients such as iron are involved in making chlorophyll, the pigment that drives photosynthesis and has a green color. A deficiency in one of these nutrients causes yellowing from lack of chlorophyll (Figure 2.6).

Nutrients can also be classified depending in their mobility within the plant (Table 1), which affects the location of deficiency symptoms on the plant. A mobile nutrient such as N, P, K, or Mg can be moved from "sources" such as old leaves into growing points (termed "sinks"). With mobile nutrients, deficiency symptoms are usually most severe in medium to older-aged leaves because plants can move the nutrients from the older leaves into new, actively growing tissue. For example, nitrogen deficiency shown in Figure 2.7.

In contrast, deficiency symptoms of immobile nutrients typically occur in growing points because the plant cannot move nutrients from other organs.

Examples are iron deficiency shown in Figure 2.6 or calcium deficiency shown in Figure 2.8.

Whether a plant nutrient is mobile or immobile within the plant affects it's application strategy. Mobile nutrients can be supplied in excess (often called luxury consumption), with the assumption that it will be redistributed in the plant if nutrient applications become limiting. For example, using nitrogen or phosphorus for growth control will only work if the tissue concentration is at or near levels that limit growth. So, the effectiveness on growth control of withholding nitrogen or phosphorus application will depend on their current concentration in the tissue that was influenced by previous fertilizer applications.

In comparison, immobile nutrients need to be supplied constantly to plants as new tissue develops. If the supply becomes limiting, the new growth is affected relatively quickly because the plant has no ability to move immobile nutrients from other parts.

Nutrient toxicities that gradually occur over time tend to occur in older leaves, because plants either move unwanted chemicals into those organs, or because the leaves have had longer time to accumulate excess levels (Figure 2.9).

Figure 2.9 Boron toxicity symptoms in this heliotrope are most severe in older leaves, which have more time to accumulate toxic levels of this nutrient.

In summary: Deficiency symptoms are affected by the role of nutrients in plant growth, and whether the nutrient is mobile. Nitrogen and Phosphorus are the only nutrients that should be used to limit plant growth in a controlled way.

2.3 Nutrient forms and plant uptake

Plant roots only take up nutrients that are dissolved in the soil solution. When fertilizer salts dissolve in water, they generally break apart into positively-charged “cations” or negatively-charged “anions”. For example, potassium nitrate (KNO_3) dissolves in water into a positive K^+ cation and a negative NO_3^- anion. The same chemical reaction occurs when fertilizers are mixed with water in a stock tank, or when they are applied as a dry granular fertilizer to the soil and are watered in. Table 2.1 lists the main cation or anion forms of essential nutrients taken up by plants.

For most nutrients, there is one primary form taken up by plants. Nitrogen is the exception, and its form has important implications on uptake, but also on the root environment.

There are three forms of nitrogen, ammoniacal nitrogen (NH_4^+-N), Nitrate nitrogen (NO_3^--N), and Urea ($CO(NH_2)_2$). Applications of ammoniacal nitrogen cause relatively strong acidic reactions in the substrate that can lead to the substrate-pH decreasing over time. Applications of nitrate nitrogen can cause relatively weak basic reactions in the substrate that can cause the substrate-pH to increase over time. Urea does not have a charge, but is normally converted in the substrate to NH_4^+-N (“urea hydrolysis”) before being taken up by plant roots. Urea hydrolysis has both basic and acidic reactions, but overall, the application of urea to a substrate is acidic, but less acidic than ammoniacal nitrogen.

The acidity or basicity of nitrogen and other nutrients is related to plant uptake. When any nutrient is taken up by plant roots, the charge of the nutrient affects substrate-pH. Plant roots cannot maintain an overall positive or negative charge like the electrodes in a battery, so they interact with and change the soil solution in order to balance the uptake of cations and anions. This “charge balance” is one way that plant roots can make the substrate-pH more acidic or basic.

When a cation (such as ammonium NH_4^+, potassium, K^+, calcium, Ca^{2+}, or magnesium,Mg^{2+}) is taken up by the plant, its charge can be balanced by extruding acid (the hydrogen H^+ ion). In that case, the pH drops in the soil solution (Figure 2.10).

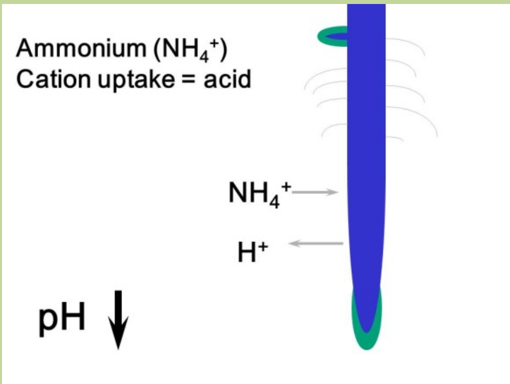


Figure 2.10 Cation uptake can have an acidic effect

The plant can also balance uptake of a cation by absorbing an anion (such as nitrate NO_3^-, phosphate, $H_2PO_4^{-1}$, or sulfate SO_4^{2-}). In that situation, pH of the soil solution does not change (Figure 2.11).

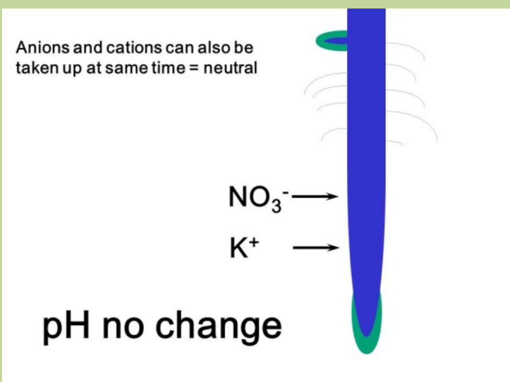


Figure 2.11 Co-absorption of cations and anions at the same rate does not lead to a change in pH.

When an anion (nitrate) is taken up by the plant, its charge can be balanced by taking up a cation (potassium) as shown above, resulting in no pH change. Uptake of an anion can also be balanced by the roots exuding a basic hydroxide (OH^-) or bicarbonate (HCO_3^-) ion, which raises pH (Figure 2.12).

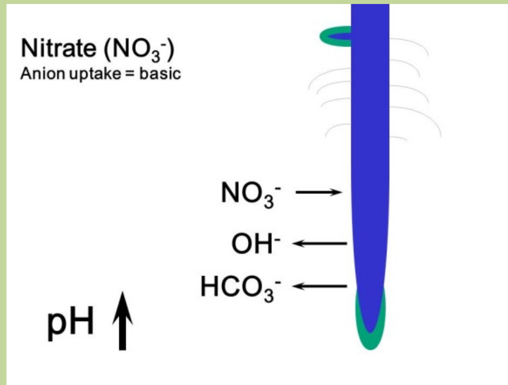


Figure 2.12 Anion uptake can have a basic effect

Finally, specifically for NH_4^+-N, there is an acidic process called nitrification that does not involve the plant but is driven by microbes contained in the substrate (Figure 2.13). Nitrification is favored by a substrate-pH above 6, warm and moderate moisture conditions, and a microbially active container substrate.

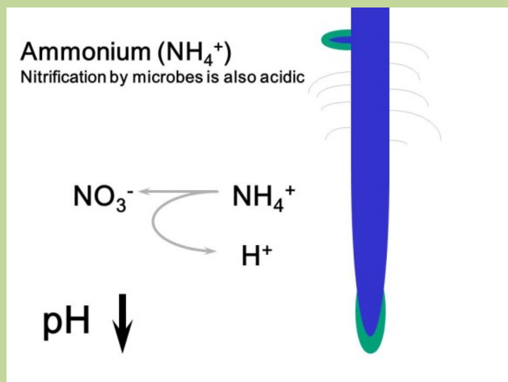


Figure 2.13 Acidity from nitrification

Plants use energy to selectively and actively take most nutrients up from the soil solution. If energy is limiting (such as under low light conditions), then nutrient uptake can be reduced. Therefore, providing plants with adequate light energy is important for having healthy nutrient uptake.

Plant roots need air to “burn energy” (respire) in active nutrient uptake. A waterlogged soil can reduce nutrient uptake by starving roots of air, and lead to root disease.

The exception to active nutrient uptake is with calcium and boron nutrition. The rate of uptake of calcium and boron depends on water moving into the plant at the root tip, which in turn depends on transpiration (evaporation of water from leaves to cool the plant). Any factor that limits water uptake, limits transpiration, or damages root tips will limit uptake of Ca and B.

In summary: Most nutrients are generally up as positively-charged cations or negatively-charged anions. Cation uptake tends to be acidic, and anion uptake tends to be basic, which affects the substrate-pH.

2.4 pH Affects Nutrient Solubility and Uptake

Substrate-pH affects the solubility of nutrients (Figure 2.14), and therefore availability for plant uptake. For example, iron (Fe) solubility (and uptake) generally decreases with increasing pH because iron precipitates out of the soil solution at higher pH levels, meaning that it converts to a solid form. Phosphorus (P) solubility also decreses with increasing pH. However, at around a pH of 7.8, the form of phosphorus changes from the $H_2PO_4^{-1}$ form to the HPO_4^{-2} form. The HPO_4^{-2} form has been shown to be much less available to the plant.

Nitrogen (N) uptake can be indirectly affected by substrate-pH. In general, the uptake of ammoniacal nitrogen is favored by plants over nitrate nitrogen. Urea nitrogen must first be converted to ammoniacal nitrogen for plant uptake. While both nitrification and urea hydrolysis occur rapidly at a substrate pH > 6.0, they are inhibited by a substrate pH < 5.5.

Since nitrification is affected by pH, it's efficiency will alter the ratio of NH_4-N:NO_3-N taken up by the plant given the same fertilizer. For example, plants grown with ammoniacal based fertilizers (for example, 20-10-20 with 40% of the N in the NH_4-N form) at a substrate pH < 5.5 will have higher tissue N concentrations than plants grown with the same fertilizer when the substrate pH is > 6.0. When the substrate pH is low, there is less nitrification, resulting in more of the applied NH_4-N available to be taken up by the plant. When the substrate pH is higher, nitrification is more efficient, resulting in of the applied NH_4-N to be available for plant uptake.

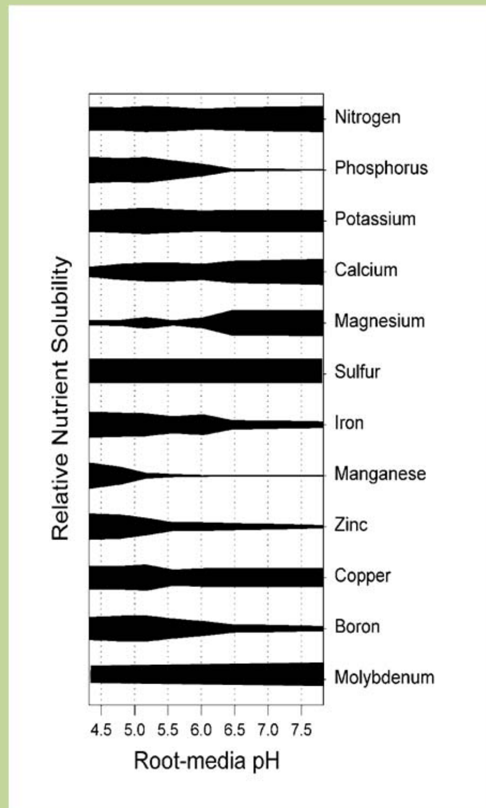


Figure 2-14 Relative solubility of nutrients at different pH levels in one peat-based root substrate (graph adapted from research by John Peterson).

Plant species differ in their ability to take up nutrients at a given pH level. For example geraniums and African marigolds are very efficient at taking up soluble iron (Fe) and manganese (Mn) from the soil solution. As described in Chapter 1, the most common nutritional problems for these "iron-efficient" or "geranium group" crops occurs when the substrate pH is low, which leads to an increase in the solubility of iron and manganese in the soil solution, which leads to high levels of iron and manganese being taken up into the plant, causing a toxicity.

In contrast, calibrachoa and petunias are very "iron-inefficient" or "petunia group" crops. When the substrate pH is high, iron solubility decreases, which leads to an inability of an iron-inefficient plant to take up enough iron into the plant, resulting in a deficiency.

Growers have learned to manipulate the acceptable pH range for these crops in order to optimize iron nutrition. For example, the acceptable pH range for growing iron-efficient geranium group crops (6.0 to 6.6) tends to be higher than the "intermediate group" crops (5.6 to 6.4) in order to limit iron and manganese solubility (lower solubility = less uptake). In contrast, the acceptable pH range for growing iron-inefficient petunia group crops is lower (5.4 to 6.2) in order to maximize iron solubility (more solubility, more uptake). This species difference provides an example of why it is helpful to understand different plant needs, rather than taking a "one-size-fits-all" approach to fertilizing all crop species.

In summary: Increasing substrate-pH reduces solubility of P, Fe, Mn, Zn, Cu, and B. Plant species differ in their ability to take up micronutrients, and therefore susceptibility to low or high pH related problems.

2.5 Nutrient Sources

In the broadest sense, a fertilizer is any material that supplies one or more essential nutrients to the plant (Figure 2.15).

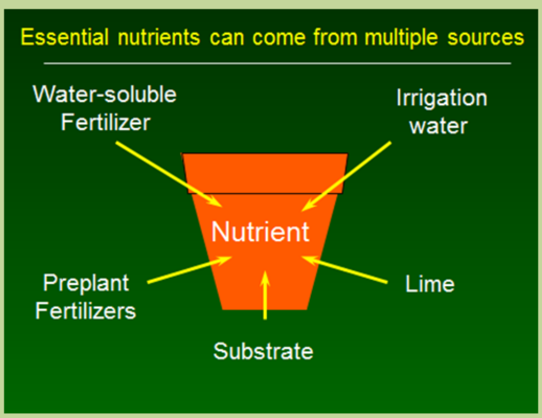


Figure 2.15 There are many potential sources of plant nutrients beyond what we normally think of as "fertilizers"

Nutrients differ in their release rate into the soil solutions and therefore availability to plants over time.

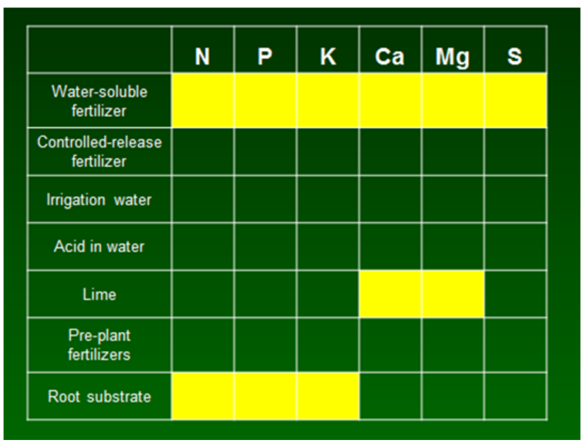
- Some nutrient sources can dissolve easily, such as materials used to make water-soluble fertilizer (for example, ammonium nitrate or calcium nitrate)
- Sources with limited solubility (such as gypsum ($CaSO_4$) or limestone ($CaCO_3$)) are typically added to the root substrate in a granular form prior to planting.
- Resin and other coated fertilizers are soluble fertilizers that are encapsulated to control or limit the release over time.
- Compost, compost extracts, and other animal and plant sources such as fish fertilizer provide a mix of immediately available nutrients in simple molecules, along with nutrients that are bound in more complex organic molecules that are released over time, as a result of microbial decomposition. Components and amendments of the root substrate can also supply nutrients to the plant. For example, bark or coir may contain potassium (K), calcium (Ca) and some phosphorus (P). Vermiculite can be a source of magnesium (Mg) and possibly potassium (K). Rockwool may contain sulfur (S). Peat can provide iron (Fe) at low pH. Limestone can be a source of calcium (Ca) and or magnesium (Mg) depending on the chemistry of the lime source.
- In general, irrigation water does not contain nitrogen (N), phosphorus (P) or potassium (K) at levels that are high enough to be considered a fertilizer source. However, irrigation water can be a significant source of calcium (Ca), magnesium (Mg), sulfur (S), boron (B), sodium (Na), and chloride (Cl). When alkaline irrigation water is acidified by the grower with a strong mineral acid (sulfuric, phosphoric, or nitric acid), the acid can be a significant source of N, P, or S, depending on the acid source.

For example, consider a scenario with the following bedding plant grower:

Bedding Plant Grower #1

- Water soluble fertilizer 13-2-13 at 125 ppm N
- No controlled-release fertilizer
- Pure irrigation water source (0.05 mS/cm)
- No acid needed for water source
- Dolomitic lime
- No pre-plant (starter) fertilizers
- Peat/perlite mix with 5% compost

In this case, most of the fertilizer will come from the water-soluble fertilizer, with some contribution from compost. Calcium and magnesium would slowly be released by the dolomitic limestone:

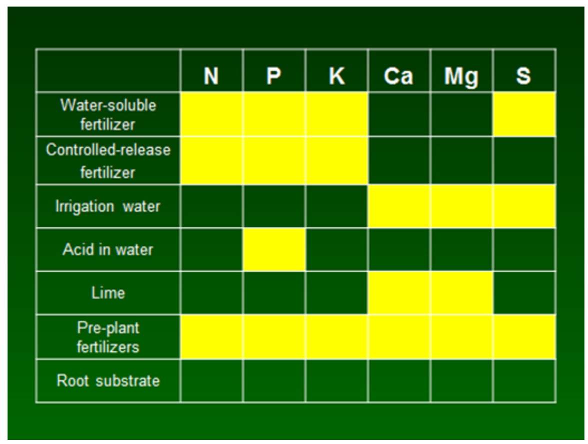


In a second case, the bedding plant grower has multiple fertilizer sources:

Bedding Plant Grower #2

- Water soluble 20-10-20 fertilizer at 125 ppm N
- Low rate of a 90-day 19-6-12 controlled-release fertilizer (2 lb/yd^3, 1.2 kg/m^3) added to the mix
- Irrigation water source with high alkalinity, calcium, magnesium, and sulfur (0.5 mS/cm)
- Uses phosphoric acid (85%) to control alkalinity in water
- Dolomitic lime
- Pre-plant (starter) granular fertilizer
- Peat/perlite mix

In this second case, there are multiple sources of all major nutrients.



For the second case, it is less critical that the grower provides all fertilizer from any one source, such as the water-soluble fertilizer or the controlled-release fertilizer.

However, if the second grower ends up with a nutritional issue such as high fertilizer salts, it may be harder to diagnose and correct the source of this problem.

In summary: In plant nutrition there are many ways to achieve the same end. It is generally a good practice to keeping the number of variables and management options simple.

2.6 Water-Soluble Macronutrient Fertilizers

Water-soluble fertilizers are purchased as either individual fertilizer salts or blended fertilizers. Fertilizer salts are individual chemicals such as potassium nitrate (KNO_3) that dissolves into separate potassium (K^+) ions and nitrate (NO_3^-) ions. Blended fertilizers are combinations of two or more fertilizer salts that supply several macronutrients. For example, 13-2-13 in Table 2.2 is a blend of calcium nitrate, magnesium nitrate, monoammonium phosphate, and potassium nitrate, and so supplies nitrogen, phosphorus, potassium, calcium, and magnesium.

When formulating blended fertilizers, there are eight water-soluble sources of nitrogen commonly used (Table 2.2), some of which only supply nitrogen like urea and ammonium nitrate. However, for most other nutrients, the choices are limited. For example, calcium nitrate is the only common form of water-soluble calcium.

Table 2.2 Formulation of selected commercially-available, blended water-soluble fertilizers

N-P_2O_5-K_2O Formula	Percent NH_4-N + Urea/ Total N	Concentration of other nutrients (in ppm) at a fertilizer concentration of 200 ppm N				Fertilizer salts[1]
		P	**K**	**Ca**	**Mg**	
21-7-7	100%	28	55	0	1	Potassium chloride, MAP, ammonium sulfate, urea, magnesium sulfate
25-10-10	89%	34	66	0	1	Potassium nitrate, MAP, urea, magnesium sulfate
9-45-15	100%	430	276	0	1	MAP, potassium chloride, magnesium sulfate
20-20-20	69%	86	166	0	1	MAP, potassium nitrate, urea, magnesium sulfate
20-10-20	40%	43	166	0	1	Ammonium nitrate, MAP, potassium nitrate, magnesium sulfate
15-15-15	52%	86	166	0	1	MAP, potassium nitrate, sodium nitrate, urea, magesium sulfate
20-0-20-6 Ca	25%	0	166	60	0	Ammonium nitrate, calcium nitrate, potassium nitrate
17-5-17-3 Ca-1 Mg	25%	25	166	35	11	Ammonium nitrate, calcium nitrate, magnesium nitrate, MAP, potassium nitrate
15-3-20-3 Ca-1 Mg	16%	17	221	40	13	Ammonium nitrate, calcium nitrate, magnesium nitrate, MAP, potassium nitrate
14-4-14-5 Ca-2 Mg	14%	24	166	71	28	Ammonium nitrate, calcium nitrate, magnesium nitrate, MAP, potassium nitrate
13-2-13-6 Ca-3 Mg	5%	13	166	92	46	Calcium nitrate, magnesium nitrate, MAP, potassium nitrate
14-0-14-6 Ca-3 Mg	8%	0	166	85	42	Calcium nitrate, magnesium nitrate, potassium nitrate
15-0-15-11 Ca	13%	0	166	146	0	Ammonium nitrate, calcium nitrate, potassium nitrate
34-0-0	50%					Ammonium nitrate
12-62-0	100%	444				Ammonium phosphate or MAP
15.5-0-0-19 Ca	10%			245		Calcium nitrate
11-0-0-9 Mg	0%				163	Magnesium nitrate
13-0-46	0%		587			Potassium nitrate
46-0-0	100%					Urea

1 Chemical formulas for the individual fertilizer salts are: Ammonium nitrate (NH_4HO_3), ammonium sulfate ($(NH4)_2SO_4$), greenhouse grade calcium nitrate ($5Ca(NO_3)_2 \cdot NH_4NO_3$ ($10H_2O$)), magnesium nitrate ($Mg(NO_3)_2$ ($6H_2O$)), magnesium sulfate ($MgSO_4$ ($7H_2O$)), monoammonium phosphate ($NH_4H_2PO_4$), potassium chloride (KCl), potassium nitrate (KNO_3), Sodium nitrate ($NaNO_3$), urea ($(NH_2)_2CO$).

The usual source of potassium is potassium nitrate, and monoammonium phosphate (MAP) is the most common source of phosphorus. Monopotassium phosphate (28.2% K and 22.7% P) is sometimes also used as a source of P and K alone, along with potassium sulfate (43% K and 18% S).

Magnesium is supplied by either magnesium sulfate (9.5% Mg and 14% S) or magnesium nitrate. Sulfur is supplied mainly by ammonium sulfate or magnesium sulfate, along with salts of potassium and the micronutrients Fe, Mn, Zn, and Cu.

Compatibility of different fertilizer salts (Table 2.3) in a single stock tank directly affects the formulation of blended fertilizers.

Table 2.3 Incompatible fertilizer combinations to avoid in a single stock tank

Combination	Problem
Calcium with sulfate	Forms insoluble gypsum ($CaSO_4$)
Calcium (and to some extent magnesium) with phosphate	Forms Ca or Mg phosphate
Calcium with potassium bicarbonate	Forms lime ($CaCO_3$)
Ammonium with potassium bicarbonate or liquid lime ($CaCO_3$ slurry)	Ammonium gas (NH_3)
Iron-EDDHA chelate with copper	Forms Copper-EDDHA, and the iron is no longer chelated

Salts are also less likely to dissolve when concentrations are near their solubility limits, or water is cold.

In practice, stock tank reactions and limited salts have the following practical implications:

- Growers will sometimes separate fertilizers into two or more tanks to avoid reactions occurring (Figure 2.16).
- Blended fertilizers that are high in phosphorus also tend to be high in ammonium nitrogen, because phosphorus is usually supplied as monoammonium phosphate.

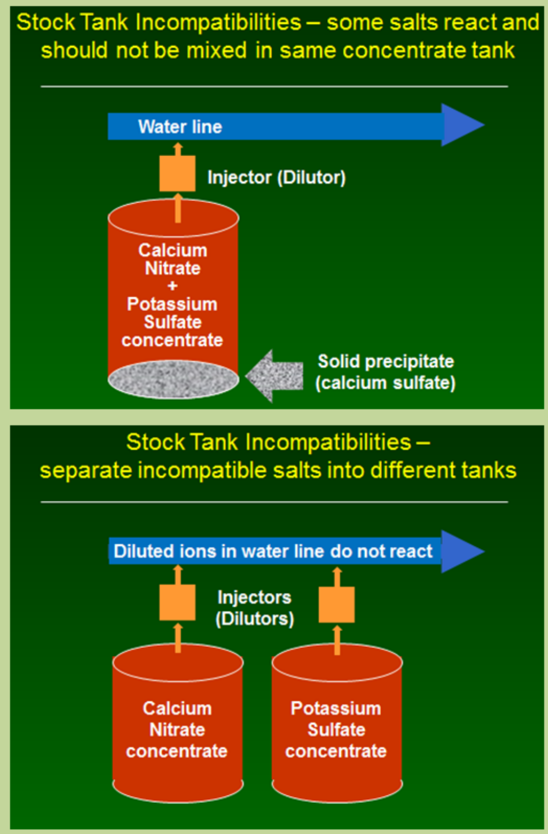


Figure 2.165 At high concentration, certain ions such as calcium and sulfate need to be separated into different stock tanks.

- Fertilizers that contain calcium are also high in nitrate, because calcium nitrate is the main water-soluble source of calcium. In fact, all commercially available blended fertilizers that contain calcium also have ammonium nitrogen levels of 25% or less of the total nitrogen. Fertilizer-grade calcium nitrate salt almost always includes a small percentage of ammonium nitrogen, so N is not 100% in the nitrate form (Table 2.2).
- Calcium nitrate and monoammonium phosphate or monopotassium phosphate cannot be mixed in the same concentrated stock solution at high concentrations because insoluble calcium phosphate will form. However, the amount of calcium and phosphorus that can be mixed in the same stock tank can be increased by lowering the pH of the stock tank solution. Commercially

available fertilizers that contain calcium and phosphorus tend to have low levels of phosphorus (i.e. 13-2-13-6 Ca-3 Mg) and will also contain a weak acid to lower the pH of the concentrated stock solution.

- Because calcium nitrate and magnesium sulfate are incompatible in the same stock tank, a single tank fertilizer that contains calcium will use magnesium nitrate as the magnesium source. A fertilizer that contains magnesium without calcium tends to use magnesium sulfate as the magnesium source.

In summary: There is a limited range in common fertilizer sources. Ensure that salts blended in a single tank are compatible.

2.7 Micronutrient sources

Micronutrient (iron, manganese, zinc, copper, boron, and molybdenum) nutrition is different from managing macronutrients such as nitrogen in three fundamental ways.

1. The solubility and plant availability of micronutrients is affected by substrate-pH to a much greater extent than is macronutrient solubility.
2. The difference between acceptable concentrations of micronutrients and concentrations that are either too low (deficiencies) or too high (toxicities) is small compared with a broader acceptable range for macronutrients.
3. Whereas most macronutrients are mobile within the plant, most micronutrients are immobile. As a result, a constant supply is needed for the duration of the crop or growth and plant appearance may be affected.

In this section, we will focus on micronutrient sources, and how they are applied to a crop.

Pre-plant sources of micronutrients

In soilless media, preplant sources of micronutrients are often added at mixing. In general, the sources in starter fertilizers can include both soluble forms (usually sulfates) and

Table 2.4 Common sources of micronutrients used for incorporation into root substrate at mixing.

		Percent of each nutrient						
Common Name	**Formula**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**	**S**
Iron sulfate heptahydrate, Ferrous sulfate heptahydrate	$FeSO_4{\cdot}7H_2O$	20.5						11
Iron sulfate monohydrate, Ferrous sulfate monohydrate	$FeSO_4{\cdot}H_2O$	31.0						17
Iron Oxide, Ferric Oxide	Fe_2O_3	62.0						
Manganese sulfate	$MnSO_4{\cdot}H_2O$		24.6					12
Manganese oxide	MnO		77.4					
Zinc sulfate	$ZnSO_4{\cdot}7H_2O$			36.4				15
Zinc oxide	ZnO			80.3				
Copper sulfate	$CuSO_4{\cdot}5H_2O$				25.0			14
Copper oxide	CuO				79.8			
Boric acid	H_3BO_3					17.5		
Borax	$Na_2B_4O_7{\cdot}10H_2O$					11.3		
Solubor	$Na_2B_8O_{13}{\cdot}4H_2O$					20.5		
Sodium molybdate	$Na_2MoO_4{\cdot}2H_2O$						39.7	
Ammonium molybdate	$(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$						54.3	
FTE 555 (Frit Industries)		14.0	5.0	5.0	1.5	0.80	0.070	0
MicroMax (Scotts)	sulfates	12.0	2.5	1.0	0.5	0.10	0.050	15

NOTE: Several fertilizer companies also sell starter fertilizer blends that contain both macronutrients and micronutrients.

insoluble forms (oxides or fritted trace elements) (Table 2.4). Sometimes, water-soluble fertilizers or micronutrient sources are sprayed onto the root substrate at mixing (Table 2). In general, micronutrients are incorporated in a root substrate at low rates and therefore only represent a relatively small percentage of the total amount applied to a crop.

The one exception is iron. Iron sulfate is acidic, and is sometimes added at rates up to 4 pounds per cubic yard (2.4 kg/m^3) in a starter fertilizer to supply iron and to help keep the substrate-pH low when using alkaline irrigation water. Depending on the rate used, the effect will probably not last for more than 3 to 4 weeks and may need to be reapplied.

There are several considerations for using iron sulfate for iron nutrition and acidification in a starter fertilizer. Iron sulfate oxidizes easily and so it can be difficult to obtain consistent results. Never mix iron sulfate with limestone before incorporation, because the high pH of the lime can cause the iron sulfate to oxidize and become ineffective. Finally, if you are using both iron sulfate and lime in a root substrate, you may get better, more uniform pH control by leaving the iron sulfate out completely and reducing the lime incorporation rate.

In soilless media culture, most micronutrients are applied to a crop after planting. The sources can include individual micronutrient sources blended together, commercially prepared micronutrient blends, or the micronutrient package contained in a commercially prepared water-soluble fertilizer (Table 2.5).

Table 2.5. Common water-soluble sources of micronutrients

		Percent of each nutrient						
Common Name	**Formula**	**Fe**	**Mn**	**Zn**	**Cu**	**B**	**Mo**	**S**
Iron sulfate, Ferrous sulfate	$FeSO_4 \cdot 7H_2O$	20.1						14
Sequestrene Fe, Dissolvine E-FE-13	FeEDTA	13.0						
Sequestrene 330, Sprint 330, Dissolvine D-FE-11	FeDTPA	10.0						
Sequestrene 138, Sprint 138, Dissolvine Q-FE-6	FeEDDHA	6.0						
Manganese sulfate	$MnSO_4 \cdot H_2O$		24.6					12
Manganese chelate	MnEDTA		13.0					
Zinc sulfate	$ZnSO_4 \cdot 7H_2O$			36.4				15
Zinc chelate	ZnEDTA			15.0				
Copper sulfate	$CuSO_4 \cdot 5H_2O$				25.0			14
Copper chelate	CuEDTA				14.0			
Boric acid	H_3BO_3					17.5		
Borax	$Na_2B_4O_7 \cdot 10H_2O$					11.3		
Solubor	$Na_2B_8O_{13} \cdot 4H_2O$					20.5		
Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$						39.7	
Ammonium molybdate	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$						54.3	
Blended Micronutrient formulas								
Chelated Micronutrient Mix (Plant Products)	EDTA Chelates	7.0	2.0	0.4	0.1	1.3	0.06	0
Chelated Trace Element Mix (Jack's Professional)	EDTA Chelates	1.5	0.7	0.07	0.1	0.2	0.02	0
Chelated Water-soluble micros (GreenCare)	EDTA Chelates	5.0	2.5	2.5	1.2	1.2	0.50	0
Chemec (Plant Marvel)	EDTA Chelates	1.2	0.6	0.6	0.6	0.2	0.01	0
Compound 111 (Scotts)	EDTA Chelates	1.5	0.1	0.1	0.1	0.2	0.02	0
Formula 222 (Masterblend)	EDTA Chelates	3.0	0.2	0.1	0.2	0.4	0.04	0
Mix of Soluble Traces (Jack's Professional)	Sulfates	9.0	9.0	4.4	2.3	1.4	0.04	15
Sol-Trace (Plant Marvel)	Sulfates	7.5	8.0	4.5	3.2	1.4	0.04	14
Stem (Scotts)	Sulfates	7.5	8.0	4.5	3.2	1.3	0.04	14
Water-soluble Micros (GreenCare)	Sulfates	7.0	3.5	3.5	1.7	1.7	0.70	14
Water-soluble Micros (Masterblend)	Sulfates	7.5	8.0	4.5	3.2	1.5	0.05	14

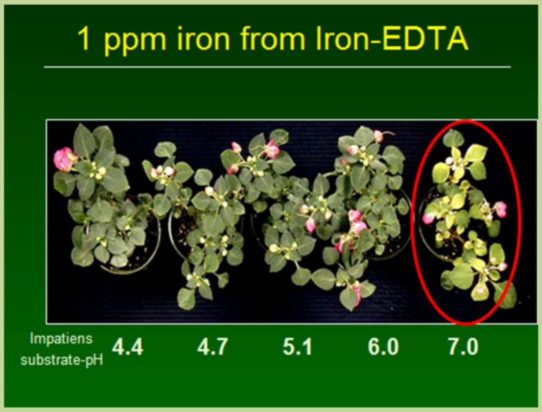


Figure 2.17 Iron from FeEDTA has low solubility, resulting in iron deficiency symptoms in these impatiens grown in a peat-perlite substrate with a range in pH levels achieved with different lime rates. Plants received 1 ppm Fe with each irrigation.

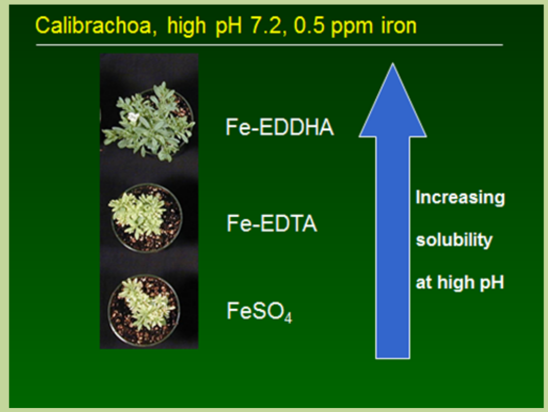


Figure 2.18 Plants grown at high pH (7.2), with 0.5 ppm Fe in each irrigation, showed different total size and leaf greenness depending on the iron form.

Water-soluble sources of micronutrients

The sources of water-soluble micronutrients come in two forms, either as inorganic salts (all micronutrients) or chelates (only iron, manganese, zinc, and copper). Inorganic salts are materials that dissolve in water to form ions that are available to the plant. For example, iron sulfate will dissolve into separate iron (Fe^{2+}) and sulfate (SO_4^{2-}) ions.

In contrast with inorganic micronutrients, chelates are organic molecules that envelop the nutrient ion and protect it from interacting with other ions in the soil solution. The micronutrient ion is held by the chelate until either the ion is taken up by the plant or, if pH is excessively high, the ion decouples from the chelate and precipitates from solution

There are many chelating molecules available, but only three that are in common use in horticulture, EDTA, DTPA, and EDDHA. These abbreviations refer to the chemical structure of the organic molecule. In general, manganese, zinc, and copper chelates are only found in the EDTA form. In contrast, there are three forms of iron chelate, FeEDTA, FeDTPA, and FeEDDHA, although the most common form is FeEDTA. Each iron form has a maximum pH above which the iron is not sufficiently soluble to meet plant needs. For example, Figure 2.17 shows iron deficiency with FeDTA chelate at substrate-pH 7 – a pH that is too high for this chelate to be effective.

Upper limits to pH at usual Fe concentrations are:

- Inorganic iron (such as $FeSO_4$) below pH 6
- FeEDTA below pH 6.5
- FeDTPA below pH 7
- FeEDDHA no upper pH limit in normal substrate ranges

Micronutrient sulfates are often used in formulas that contain calcium and magnesium (example is 13-2-13 or 15-5-15) in order to provide a low concentration of S. Because the amount of sulfate supplied by the inorganic micronutrient salts is very low compared with calcium, there is no problem with precipitation between the sulfate and the calcium. Manganese, zinc, and copper are supplied in the EDTA form for most N-P-K fertilizers (example are 20-10-20, 20-20-20, 21-7-7). In all formulas, boron and molybdenum are supplied as inorganic salts.

Iron Nutrition

At a given iron concentration, therefore, the choice of iron form is very important (Figure 2.18). Commercially prepared water-soluble fertilizers usually include micronutrients, with iron most commonly supplied as iron-EDTA.

Between a media-pH of 4.0 to 5.5, any form of iron will be sufficiently soluble (including iron sulfate and also iron contained in substrate components such as peat) to supply iron to the

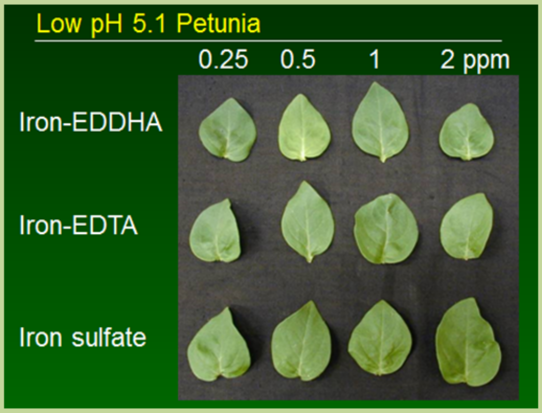


Figure 2.19 Petunia grown at a low pH 5.1 showing little response to different continuous Fe concentrations and forms.

plant (Figure 2.19). However, as the media-pH increases above 7.0 only the iron from Iron-EDDHA has high solubility (Figure 2.20).

To some extent, reduced solubility can be compensated for at high pH by increasing Fe concentration (Figure 2.21). However, managing substrate-pH in an acceptable range (around 6) is less likely to result in deficiencies in iron and other micronutrients. For example, if Fe is no longer limiting at high pH, deficiencies in other nutrients such as B, Mn, or P are likely as Liebig's "Law of the Minimum" cascades down to the next limiting micronutrient.

Figure2.21 Calibrachoa olants grown at high pH (7.2), with 0.5 to 4 ppm Fe with each irrigation. Plant size and leaf greennees increased with more soluble Fe forms, and with increasing applied Fe concentration.

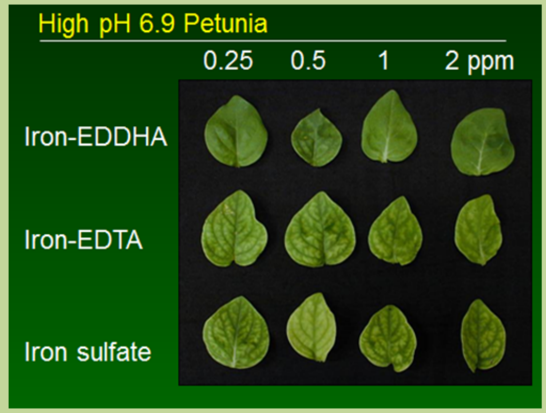


Figure 2.20 Petunia grown at a high pH 6.9 showing a strong response to different continuous Fe concentrations and forms.

Iron cost per ppm increases in the order from $FeSO_4$ < FeEDTA < FeDTPA < FeEDDHA. Some growers will add a low concentration (0.5 to 1 ppm) of iron from FeEDDHA with each irrigation as an "insurance" to make plants more resilient to a possible rise in substrate-pH. This may be in addition to the standard application of 0.5 to 1 ppm of iron from the lower-cost FeEDTA that is usually included in blended fertilizers.

In summary: The micronutrient form, particularly for iron (Fe), has a major effect on whether the nutrient is soluble and available for plants at high pH. Solubility at high pH increases in the order of inorganic Fe < FeEDTA < FeDTPA < FeEDDHA.

2.8 Nutrient Ratios, and Reading a Water-Soluble Fertilizer Label

Fertilizers sometimes include a descriptive name such as “20-20-20 Complete Fertilizer”. Another example is 13-2-13 “Plug Care Special” indicating that the fertilizer is suited to growing seedling plugs. In the 13-2-13 example, the name is based on the features that (a) most of the nitrogen is in the nitrate form (which leads to compact growth and will not cause ammonium toxicity in dark winter conditions) and (b) because the fertilizer is low in phosphorus relative to nitrogen (N) and potassium (K), which also reduces stem elongation.

However, fertilizer marketing names such as “Complete Fertilizer”, “Kalanchoe Special” or similar are largely historical – they might have been originally formulated for one particular grower in one situation. So read on to understand how to see past the marketing and promotion and interpret technical details on the label.

By tradition, fertilizers in North America are described as the percent by weight of N-P_2O_5-K_2O (nitrogen-phosphate-potash) rather than elemental NPK. Therefore, to convert a label such as 20-20-20 (or other fertilizers in Table 2.2) to NPK:

- For N no conversion is required (20% N)
- For P_2O_5 to P, multiply by 0.43 (20% P_2O_5 equals 8.8% P)
- For K_2O to K, multiply by 0.83 (20% K2O equals 16.6% K)
- Overall, 20-20-20 N-P_2O_5-K_2O is actually 20-8.8-16.6 N-P-K.

The percentage of nutrients in plant tissue (i.e., what plants actually take up through roots and require for healthy growth) is typically in the ratio about of 4-0.5-4 (equivalent to 20-2.5-20 N-P-K). Therefore 20-8.8-16.6 includes much more P than the plant requires.

What is the best macronutrient ratio? Forty years ago, fertilizer with N-P_2O_5-K_2O ratios of 1:1:1 (20-20-20 or 15-15-15 General Purpose fertilizers) were the norm. 20-10-20 with N-P_2O_5-K_2O ratio of 1:0.5:1 with 40% it's nitrogen in the ammonical form was considered a high nitrate, low P formula.

Modern fertilizer formulas tend to be lower in phosphorus than older formulas. Plants are efficient at taking up P from the soil solution, so the high P concentrations found in older formulas are not really necessary. In addition, applying lower P concentrations with the fertilizer reduces the risk of P runoff into the environment. Current "Best Managment Practices" recommend using lower P concentrations in the fertilizer. With modern fertilizer formulas, 20-10-20 is considered a fertilizer with a high level of ammoniacal nitrogen. Formulas with moderate to low levels of ammoniacal nitrogen and lower levels of P are much more common. For example, formulas like 17-5-17 and 15-5-15 have 20-25% NH4-N and a N-P_2O_5-K_2O ratio of about 1:0.3:1 are typical for finished plants and low ammonical, low P formulas are common for plug and liner production. For example, 13-2-13 has 5% ammonical N and a N-P_2O_5-K_2O ratio of 1:0.15:1

GUARANTEED ANALYSIS

For Continuous Liquid Feed Programs

Total Nitrogen (N)	20%
3.89% Ammoniacal Nitrogen	
6.11% Nitrate Nitrogen	
10.00% Urea Nitrogen	
Available Phosphate (P_2O_5)	20%
Soluble Potash (K_2O)	20%
Magnesium (Mg) (Total)	0.05%
0.05% Water Soluble Magnesium (Mg)	
Boron (B)	0.0068%
Copper (Cu)	0.0036%
0.0036% Chelated Copper (Cu)	
Iron (Fe)	0.05%
0.05% Chelated Iron (Fe)	
Manganese (Mn)	0.025%
0.025% Chelated Manganese (Mn)	
Molybdenum (Mo)	0.0009%
Zinc (Zn)	0.0025%
0.0025% Chelated Zinc (Zn)	

Derived from: Ammonium Phosphate, Potassium Nitrate, Urea, Magnesium Sulfate, Boric Acid, Copper EDTA, Iron EDTA, Manganese EDTA, Sodium Molybdate, Zinc EDTA.

Potential Acidity: 558 lb. Calcium Carbonate equivalent per ton.

Figure 2.22 Fertilizer formulation for 20-20-20 General Purpose blended fertilizer.

The ratio of N:K_2O is typically 1:1, which can be used for any ornamental crop. However, the proportion of K_2O is sometimes increased in order to provide more compact growth. Since High K fertilizers use more KNO3 than traditional formulas, so they tend to have lower calcium and magnesium than standard formulas. For example, 14-4-14 has 14% of the nitrogen in the ammoniacal form, and 5% calcium and 2% magnesium. 15-3-20 has 16% of the nitrogen in the ammonical form, but only 3% calcium and 1% magnesium.

Typical N (with the same K_2O concentration using a 1 N:1 K_2O fertilizer) on a continuous basis are:

- 50-75 ppm N plugs and liners in propagation
- 100-150 ppm N bedding plant flats and finished liners
- 200-300 ppm N larger containers

This recommendation of the concentration used for different crops needs to be modified based on substrate and tissue tests, irrigation practices, how much nutrient solution is leached out during irrigation, and plant performance.

These are average fertilizer concentrations and many growers do not fertilize with each irrigation, for example if they have a portable fertilizer injector (dilutor) that is moved from one greenhouse to another. If fertilizers are irrigated with clear water, or are drenched with a pesticide solution, then average out the applied N concentration for the week. For example, 1 fertilizer applied at 300 ppm on Monday, followed by clear water applications on Wednesday and Friday, would equal 300 ppm N/3 irrigations = average 100 ppm N. Similarly, if you drench your crop with 100 ppm Ca on Monday, followed by applications of a fertilizer with no calcium on

Wednesday and Friday, would equal 100 ppm Ca/3 irrigations = average 30 ppm Ca.

Notice at the bottom of Figure 2.21 the statement "Potential acidity: 558 lb. Calcium carbonate equivalent per ton". (1 lb/ton = 0.5 kg/metric ton). This potential acidity means that applying 1 ton of fertilizer would supposedly require the equivalent of 558 lb of calcium carbonate (limestone) to neutralize this acidity. Basic fertilizers often list a "potential basicity" meaning that applying a ton of the fertilizer would be equivalent to applying a certain equivalent weight of limestone.

These acidity or basicity values found on the bag of fertilizer should be viewed as relative indicators only of potential to produce an acidity or basicity reaction. The potential acidity or basicity can also not be predicted by measuring the pH of the applied solution. These reactions only occur once the fertilizer is applied to the crop. For example, a fertilizer labeled as having 200 lb. of potential acidity is less acidic than a fertilizer with 1000 lb. of potential acidity. However, it is impossible to exactly how much more acidic one is from another simply by looking at the potential acidity value on the bag.

Instead, a better way to compare the acidic or basic nature of a fertilizer is to know the amount of the total nitrogen that is in the ammoniacal nitrogen form. As discussed in Section 2.3, ammonium is strongly acidic, nitrate is weakly basic, and urea is moderately acidic. In the case of 20-20-20, all three nitrogen forms are present. Fertilizers that have more than 25% of the total nitrogen in an acidic forms or ammonium or urea tend to have an overall acid reaction and tend to lower substrate-pH over time when used with pure or near pure irrigation water.

To calculate the percentage of nitrogen contained in the 20-10-20 formula from Figure 2.22:

$$\frac{\textbf{(3.89\% Ammonium-N + 10\% urea-N)}}{\textbf{20\% Total-N}}$$

Equals 69% of nitrogen in an acidic form. Because this proportion is more than 25%, the fertilizer is likely to have an overall acidic effect.

In general, fertilizers very high in ammoniacal N or urea (> 40% of the nitrogen in the NH_4-N form) will have high acidity values; fertilizers that are very low in ammoniacal N (< 20% of the nitrogen in the NH_4-N form) will have neutral or basic effect.

The acidity of a fertilizer can be matched with water alkalinity to provide a stable pH effect of the nutrient solution over time (see Chapter 5). High alkalinity water can either be acidified with a mineral acid such as sulfuric, nitric, or phosphoric acid (see Section 2.9), or high alkalinity can be matched with a high-ammonium fertilizer (Table 2.6).

Table 2.6 Matching fertilizers with different acidity or basicity and nitrogen forms to water alkalinity. 1 lb/ton = 0.5 kg/metric ton

Example fertilizer	(NH_4-N + Urea-N)/ Total N	Potential reaction (A=acid, B=base) in lb/ton	Match to this ppm $CaCO_3$ of water alkalinity
21-7-7	100%	A 1560	300 ppm
20-10-20	40%	A 406	200 ppm
17-5-17	20%	B 0	100 ppm
15-0-15	13%	B 420	50 ppm

Using fertilizers that contain a high percentage of their nitrogen in the ammonical N form can lead to excess accumulation and ammonium toxicity symptoms, especially in cool wet conditions when there is less microbial activity and conversion of ammonium to nitrate in the substrate through the nitrification process. Therefore fertilizers that have less than 15% of nitrogen in the ammonium form are more suitable for winter conditions (hence the name "Dark Weather Feed" for 15-0-15, which is 13% ammonium-N, Table 2.2).

Nitrate-N also tends to lead to more compact growth and higher Ca levels because of formulation with calcium nitrate. High nitrate/low ammonium fertilizers are therefore commonly used with transplants and also production of unrooted cuttings on stock plants.

100 ppm N Solution Contains the Following Elemental ppm		
Ammonium-N	(NH_4 – N)	19.5
Nitrate-N	(NO_3 – N)	30.50
Urea-N	(Urea-N)	50.0
Phosphorus	(P)	43.7
Potassium	(K)	83.3
Calcium	(Ca)	0
Magnesium	(Mg)	0.25
Boron	(B)	0.034
Copper	(Cu)	0.018
Iron	(Fe)	0.250
Manganese	(Mn)	0.125
Molybdenum	(Mo)	0.005
Zinc	(Zn)	0.0125

Figure 2.23 Fertilizer concentrations at 100 ppm N from 20-20-20 General Purpose blended fertilizer.

Fertilizers that are high in ammoniacal or urea nitrogen, like 20-20-20, do not include calcium, and contains only a very low level of magnesium (Figures 2.22 and 2.23). These nutrients are not included, in order to avoid precipitation with phosphate in a single stock tank. However irrigation water and dolomitic limestone are often important contributors of these nutrients.

Sulfur is also very low in 20-20-20. Although not listed in Figure 2.23, at 100 ppm N there would only be 0.4 ppm S. Sulfur deficiency is rare, but can occur. Irrigation water contaminants, acidification of alkaline water with sulfuric acid, or pre-plant gypsum ($CaSO_4$) are common S sources in addition to water-soluble fertilizer.

Commercially prepared water-soluble fertilizers that contain micronutrients usually have one of two levels of micronutrients (Table 2.7). "General Purpose" formulas such as the 20-20-20 label in Figure 2.23 were designed when field soil was a primary component in container media. Since field soil often contained micronutrients, the levels contained in these fertilizer formulas were relatively low. "Peat-Lite" formulas were designed for soilless media culture, and therefore have a higher micronutrient levels (Table 2.7).

To calculate the concentration of micronutrients supplied by a blended fertilizer, you need to know the concentration of nitrogen in the fertilizer solution and the ratio of nitrogen to that micronutrient that is listed under the "Guaranteed analysis" on any fertilizer bag.

For example, to calculate the concentration of iron supplied by 20-20-20 General Purpose formula (0.05% Fe) at 200 ppm N, you divide the % Fe by the %N, then multiply by the nitrogen concentration of the fertilizer solution.

$$\frac{0.05\ (\%\text{Fe})}{20\ (\%\ \text{N})} \times\ 200\ (\text{ppm N}) = 0.5\text{ppm Fe}$$

So at 200 ppm N, you are also supplying about 0.5 ppm Fe with this fertilizer.

For growers that are adding micronutrients to the fertilizer, a "safe" concentration would be similar to that supplied by a "Peat-Lite" water soluble fertilizer at a concentration 100 and 200 ppm N. Using iron as an example, that would correspond to a concentration of 0.5 to 1.0 ppm Fe from one of the water-soluble sources found in Table 2.2 If you are adding supplemental micronutrients to the base rate provided by a blended water-soluble fertilizer, remember to take the micronutrients supplied by the water-soluble fertilizer into your calculation.

The concentration of micronutrients other than Fe is usually in a fairly standard ratio and total concentration. Mn level is usually half the Fe level (around 0.25 to 0.5 ppm on a continuous basis). Uptake of Fe and Mn are antagonistic, in a similar way to Ca and Mg.

Concentration of Zn, Cu, and B is usually below that of Mn (0.2 to 0.4 ppm on a continuous basis). Certain crops such as petunia and pansy are susceptible to B deficiency, and B is sometimes

Table 2.7 Approximate concentration of micronutrients supplied by either "General Purpose" formulas or "Peat-Lite" formulas at a nitrogen concentration of 200 ppm N. Micronutrient concentration given in ppm or mg/L.

	Fe	Mn	Zn	Cu	B	Mo
General Purpose	0.5	0.25	0.1	0.05	0.05	0.03
Peat-Lite	1.0	0.5	0.4	0.3	0.2	0.08

supplemented to around 0.5 ppm on a continuous basis.

Mo is around 0.1 ppm for fertilizers formulated for poinsettia (plants in the genus *Euphorbia* are susceptible to Mo deficiency), but may be as low as 0.01 ppm in other blended fertilizers. Mo toxicity is not an issue at 0.1 ppm for any floricultural crops, and many growers use that as a standard concentration.

In summary: Be an informed consumer. Understand the effects of nutrient types and ratios on a fertilizer label rather than selecting fertilizer based on the marketing name alone.