

Fertigation Nutrient Sources and Application Considerations for Citrus¹

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Introduction

Fertigation is the application of liquid fertilizer through an irrigation system. Microirrigation and fertigation offer the potential for precise control of nutrients and water, which are the main grower-controlled inputs to plant growth. A major benefit of fertigation is that it provides greater flexibility and control of applied nutrients than conventional broadcast applications. Fertilizers are applied when needed and in small doses, so water-soluble nutrients are less subject to leaching by excess rainfall or over-irrigation.

Care must be exercised to avoid emitter plugging problems resulting from reactions of the fertilizer with the irrigation water. The fertilizer source must be water-soluble. Chemical reactions between fertilizer materials can result in the formation of precipitates, which can plug the irrigation system. The uniformity of the fertilizer application depends on the uniformity of the water application. Therefore, high water application uniformity is very important for fertigation.

Nitrogen

Nitrogen (N) is the plant nutrient most often injected as fertilizer into microirrigation systems. One of the major benefits of small, frequent nitrogen applications is a potential reduction in leaching of nitrate into the groundwater. Only small amounts of N are applied at any one time,

therefore excess nitrate is not present to be leached in the event of heavy rainfall. Nitrogen can be applied using a number of different compounds, but urea and ammonium nitrate are the most desirable sources because they have a low plugging risk. Anhydrous or aqua ammonia are not recommended for use in micro irrigation systems because they will increase the pH of the irrigation water. Consequently, calcium, magnesium, and phosphorus may precipitate in the line and increase the plugging potential. Ammonium sulfate and calcium nitrate can be dissolved in water, but they may also cause plugging problems. If calcium or magnesium levels are high in the irrigation water, ammonium phosphate may cause precipitates to form, which can plug emitters. Nitrogen can contribute to microbial growth if it is applied continuously and remains in the irrigation line after the system has been shut off.

Nitrogen movement in the soil depends on the type of nitrogen fertilizer. The ammonium cation is less mobile in the soil than nitrate. The depth of movement depends on the cation exchange capacity (CEC) of the soil, and the rate of fertilizer application. Application of ammonium fertilizer to the soil surface may result in loss to the atmosphere by ammonium volatilization, especially if soil pH is greater than 7. Most ammonium will be transformed biologically to nitrate within 2 to 3 weeks at soil temperatures in the 75° to 90° F range. Nitrate will move with the irrigation water to the wetted front. Thus, with subsequent irrigations,

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nitrate may be leached beyond the root zone or may be pushed to the periphery of the wetted soil volume and only part of the root zone will have access to it. Urea is very soluble in irrigation water, and it is not adsorbed by soil. Thus, it will move deeper below the soil surface than ammonium, but will not leach as easily as nitrate. A balance between ammonium and nitrate in the nitrogen fertilizer is usually recommended.

Some water sources (such as recycled wastewater) may contain a significant amount of nitrate. This nitrogen should be taken into account when determining tree fertilizer requirements. The nitrogen added to the crop due to nitrate in the irrigation source water can be determined by:

$$N = C_n \times I_n \times D_i \text{ ----- Eq. 1}$$

Where:

N = nitrogen (lbs/ac),

C_n = a constant for unit conversion (0.226)

I_n = $\text{NO}_3\text{-N}$ concentration in the irrigation water (mg/L)

D_i = depth of irrigation water applied (inches).

Example

Determine the nitrogen supplied by the irrigation water if 14 inches of water are applied annually and the $\text{NO}_3\text{-N}$ concentration is 10 mg/L.

$$N = 0.226 \times 10 \times 14 = 32 \text{ lbs N/ac}$$

Nitrogen Cycle

Compounds containing nitrogen are of great importance in the life processes of all plants and animals. The chemistry of nitrogen is complex because of the numerous oxidation states that it can assume, and by the fact that changes in the oxidation state can be brought about by living organisms.

Because of environmental concerns, nitrate (NO_3^-) is of particular interest. It is very mobile and easily transported by water. In surface water systems, NO_3^- is a nutrient source and can contribute to the over-production of algae or other aquatic life, resulting in eutrophication of surface water bodies. Nitrate in ground water is of even greater concern since groundwater is the principal domestic water source in many areas. The EPA has established a drinking water maximum concentration level (MCL) of 10 mg/L as $\text{NO}_3\text{-N}$ or 45 mg/L NO_3^- .

Nitrogen is a very complex nutrient, and it exists in the environment in many forms. It is continually transformed because of biological and chemical influences. Nitrogen can be divided into two categories:

1. Organic N contains carbon in the compound and exists in plant residues, animal waste, sewage sludge, septic effluent, and food processing waste.
2. Inorganic N contains no carbon in the compound and exists as ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and nitrogen gas (N_2).

Understanding the behavior of N in the soil is essential for good fertilizer management. Many N sources are available for use in supplying N to crops. In addition to inorganic (commercial) fertilizer N, organic N from animal manures and waste products are also a significant source of N. Nitrogen fixation by legume crops can also supply significant amounts of N.

Sources of NO_3^- are both man-made and natural. The principal man-made sources of nitrate are commercial fertilizer and septic and sewage systems. The ultimate source of N used by plants is N_2 gas, which constitutes 78% of the earth's atmosphere. Nitrogen gas is converted to plant-available N by one of the following methods:

- Fixation by microorganisms that live symbiotically on the roots of legumes (also certain non-legumes).
- Fixation by free-living or non-symbiotic soil microorganisms.
- Fixation as oxides of N by atmospheric electrical discharges.
- Fixation by the manufacture of synthetic N fertilizer (Haber-Bosch process).

The virtually unlimited supply of nitrogen in the atmosphere is in dynamic equilibrium with the various fixed forms in the soil-plant-water system. The N cycle can be divided into N inputs and outputs (Fig. 1). Understanding this process can influence how nitrogen is managed to minimize its negative effects on the environment, while maximizing the beneficial value of N for plant growth.

Animals and higher plants are incapable of utilizing nitrogen directly from the atmosphere. The nitrogen cycle with inputs, outputs and cycling is complex. N in plant and animal residues and N derived from the atmosphere

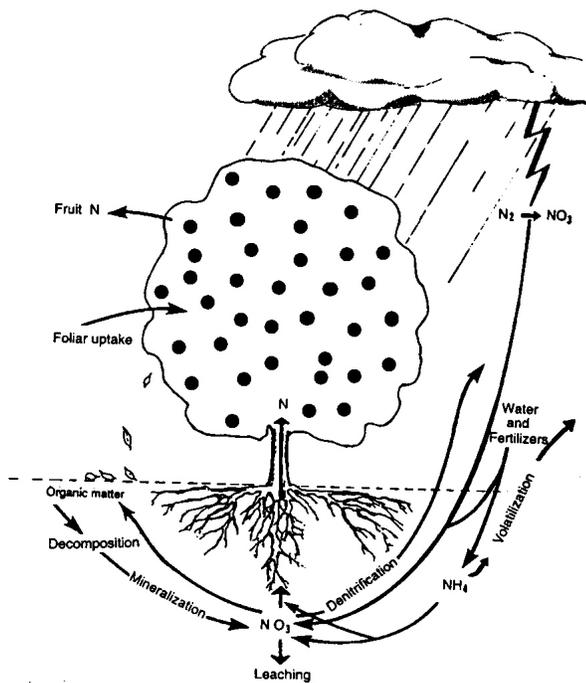


Figure 1. The citrus nitrogen cycle.

through electric, combustion, and industrial processes is added to the soil. N in these residues is mobilized as ammonium (NH_4^+) by soil organisms as an end product of decomposition. Plant roots absorb a portion of the NH_4^+ , but much of the NH_4^+ is converted to nitrate (NO_3^-) by nitrifying bacteria in a process called nitrification. The NO_3^- is taken up by plant roots and is used to produce the protein in crops that are eaten by humans and fed to livestock. NO_3^- is lost to groundwater or surface water as a result of downward movement of percolated water through the soil. NO_3^- is also converted by denitrifying bacteria into N_2 and nitrogen oxides that escape into the atmosphere. The major processes of the nitrogen cycle (Fig. 1) are N-mineralization, nitrification, NO_3^- mobility, de-nitrification, and volatilization.

N-mineralization

The conversion of organic N to NH_4^+ is called mineralization. Mineralization occurs through the activity of heterotrophic microorganisms, which are organisms that require organic carbon compounds (organic matter) for their energy source. The NH_4^+ produced by mineralization is subject to several fates:

- Converted to NO_2^- and then to NO_3^- by the process of nitrification.
- Absorbed directly by higher plants.

- Utilized by heterotrophic organisms to further decompose organic residues.
- Fixed in a biologically unavailable form in the lattices of certain clay minerals.
- Released to the atmosphere as N_2 .

The quantity of N mineralized during the growing season can be estimated. Soil organic matter contains about 5% N by weight; during a single growing season, 1 to 4% of the organic N is mineralized to inorganic N.

Example

If a soil contained 3% organic matter (OM) in the top 6 inches and 2% mineralization occurred, calculate the N made available (lbs/acre). (Assume an acre of soil 6 inches deep weighs 2 million lbs).

$$2,000,000 \text{ lb} \times 3\% \text{ OM} \times 2\% \text{ mineralization} \times 5\% \text{ N} = 60 \text{ lbs/acre of N mineralized}$$

N-immobilization

The conversion of inorganic N (NH_4^+ and NO_2^-) to organic N is termed immobilization, and is basically the reverse of N mineralization. If decomposing OM contains low N relative to C, the microorganisms will immobilize NH_4^+ or NO_3^- in the soil. Since soil organisms need N in a C:N ratio of about 8:1 or less, they will utilize inorganic N. They are very effective at competing with plants for available N. Thus, N fertilizer is often applied to compensate for N immobilization. After the decomposition of the low residuals, the N in the microorganisms is mineralized back to NH_4^+ .

Nitrification

The biological conversion of NH_4^+ to NO_3^- is called nitrification. This is a two-step process in which NH_4^+ first changes to NO_2^- , then to NO_3^- . This process is performed by autotrophic bacteria that obtain their energy from the oxidation of N, and their C from CO_2 . Nitrate leaching from field soil must be carefully controlled because of the serious impact that it can have on the environment. Since NO_3^- is very mobile and subject to leaching in the soil, understanding the factors that affect nitrification will provide insight into best management practices to minimize nitrate losses by leaching. Factors that affect nitrification in the soil are the following:

- Supply of NH_4^+ : If conditions do not favor mineralization of NH_4^+ from organic matter, nitrification does not occur. (If organic residue with a high C:N ratio is plowed into the soil before planting, microorganisms will tie up available N while trying to decompose the residue).
- Population of nitrifying organisms: Soils differ in their ability to nitrify NH_4^+ , even under similar conditions of temperature, moisture, and level of added NH_4^+ . One factor that may be responsible for this is the variation in the number of nitrifying organisms present.
- Soil pH: Nitrification takes place over a wide range of pH (4.5 to 10) conditions, but the optimum is thought to be about 8.5. The nitrifying bacteria also need an adequate supply of Ca. Thus, liming of low pH soil helps nitrification influence by both driving the soil pH closer to optimum, and also providing more available Ca for the activity of the nitrifying organisms
- Soil aeration: Aerobic nitrobacteria will not produce NO_3^- in the absence of O_2 .
- Soil moisture: Nitrobacteria activity is sensitive to soil moisture. Nitrification is greatest under moist (but not saturated) soil conditions.
- Temperature: Nitrification increases between 40° F and 95° F activity decreases at temperatures over 95° F.

NO_3^- mobility

The nitrate anion is very soluble in water, so leaching is a major cause of N loss from soils in humid climates or under irrigated conditions. Under irrigated conditions, the factors that most affect nitrate leaching from irrigation are as follows:

- Timing of irrigation
- Duration of irrigation
- Uniformity of irrigation
- The amount of NO_3^- available for leaching.

Denitrification

Crop removal and leaching constitute the major N losses from the soil; however, under certain conditions inorganic N ions can be converted to gases and lost to the atmosphere. When soil becomes waterlogged, O_2 is excluded and anaerobic decomposition takes place. Some anaerobic

organisms have the ability to obtain their O_2 from sulfate and nitrate, with the accompanying release of N, and N_2 . This is a common occurrence under Florida Flatwoods growing conditions.

Volatilization

Volatilization is the loss of N from the soil to the atmosphere. Ammonia volatilization can be significant, especially from calcareous (pH>7) soils under warm conditions.

Ammonium Process

The major source of nitrogen in synthetic fertilizers is ammonia, and it is produced by the Claude-Haber process. Purified nitrogen gas (N_2) reacts with hydrogen gas (H_2) at high temperature and pressure to form ammonia:



Ammonia is the starting point from which nearly all other nitrogen fertilizers are made (Table 1). It contains 82% nitrogen and is the cheapest source of nitrogen compared to other nitrogen materials. It is used extensively in many areas of the U.S., either as anhydrous ammonia or aqua ammonia, accounting for nearly half of the total nitrogen fertilizer consumed. Ammonia is used in the U.S. primarily as a direct-application material. A direct-application material is a fertilizer material that is purchased as the pure material, rather than as a blend with other fertilizer materials in mixed fertilizers.

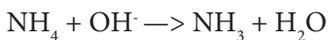
Losses of nitrogen from direct application of anhydrous ammonia to soils can be severe, particularly when applied to sandy soils. Application of anhydrous ammonia is not recommended for Florida citrus soils.

Urea and ammonium nitrate are mixed together with water and are often sold as a solution fertilizer containing up to 32% nitrogen. This material is quite stable and can be applied with relatively inexpensive, non-pressurized equipment. Nitrogen solutions are quite popular for direct applications to soil and are a major source of nitrogen for liquid fertilizer.

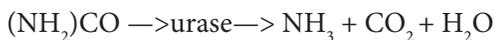
Nitrate-nitrogen (NO_3^- -N) is very mobile in soil and will move freely in irrigation and rain water. Since water percolates through sandy soils quite rapidly, application of large quantities of nitrate-nitrogen may increase nitrogen losses because of potential leaching.

Ammonium-nitrogen ($\text{NH}_4^+\text{-N}$) is adsorbed on cation exchange sites within the soil and is retained to some extent against leaching. However, it is rapidly converted to nitrate-nitrogen by soil microorganisms and, in this form, may be leached readily. Nitrate-nitrogen is also lost rapidly from flooded soils because, as soon as the oxygen in the soil is depleted, certain micro-organisms can immediately begin to utilize the oxygen present in nitrate-nitrogen. This process, called denitrification, converts nitrate-nitrogen back into nitrogen gas (N_2) which escapes to the atmosphere and is unavailable to plants. Recovery of fertilizer nitrogen by crops rarely exceeds 50% and often is less than 25%.

Other chemical processes can occur to cause nitrogen losses from soil. For example, ammonium sources of nitrogen should never be surface applied to soils recently limed or containing free calcium carbonate. In the alkaline pH environment surrounding the lime, ammonium will revert to ammonia gas and escape into the atmosphere:



The application of urea directly to the soil surface should also be avoided. Urea is quickly broken down into ammonia and carbon dioxide by the enzyme urease, which is normally abundant in cultivated soils:



It is always a good idea to mix urea thoroughly with the soil to minimize gaseous losses of nitrogen. All nitrogen fertilizers containing ammonium nitrogen leave an acid residue in soil as a result of the nitrification process:



The use of high rates of nitrogen on sandy soils low in calcium needs careful attention. These soils are poorly buffered against changes in pH caused by the acidity released during nitrification (Table 2). Florida has many soils in agricultural production that are sandy, low in organic matter (the principal component that aids in buffering) and containing less than 200 pounds of calcium per acre. These soils tend to be only mildly acid initially, but should be monitored carefully when large amounts of ammonium-nitrogen fertilizer are being applied.

Ammonium sulfate is by far the most acid-forming source of nitrogen. This is because all the nitrogen is present as ammonium-nitrogen. Ammonium nitrate requires much less lime per pound of nitrogen since only half of the nitrogen is present as ammonium. If ammonium sulfate

is used instead of ammonium nitrate, more than twice as much lime is needed to neutralize the acidity produced. The initial reactions involving urea and anhydrous ammonia in soil are quite basic, which tends to neutralize, to some extent, the acidity produced during subsequent nitrification.

Fertilizer Solubility

Several dry fertilizer products (Table 3) used for making fertilizer solutions are marketed with or without a protective conditioner. Whenever possible, the “solution grade” form of these products should be purchased to avoid having to deal with the conditioners and the potential plugging problems they can cause. Most dry-solid fertilizers are manufactured by coating them (commonly clay, diatomaceous earth, or hydrated silica) to keep the moisture from being absorbed by the fertilizer pellets. To avoid having these materials create plugging problems, it is best to prepare a small amount of the mix to observe what happens to the coating. If the coating settles to the bottom of the container, the clear transparent liquid can be taken from the top portion without disturbing the bottom sediment. If a scum forms on the surface, conditioners may need to be added to facilitate the removal of the conditioner by skimming.

When urea, ammonium nitrate, calcium nitrate, and potassium nitrate are dissolved, heat is absorbed from the water and a very cold solution results. Consequently, it may not be possible to dissolve as much fertilizer as needed to achieve the desired concentration. It is often necessary to let the mixture stand for several hours and warm to a temperature that will allow all the mixture to dissolve.

Before injecting fertilizer solutions, a “jar test” should be conducted to determine clogging potential of the solution. Some of the fertilizer solution should be mixed with irrigation water in a jar to determine if any precipitate or milkiness occurs within one to two hours. If cloudiness does occur, there is a chance that injection of the chemical will cause line or emitter plugging. If different fertilizer solutions are to be injected simultaneously into the irrigation system, they all should be mixed in the jar. The jar test should be conducted at about the same dilution rate that is used in the irrigation system.

Nitrogen

Urea, ammonium nitrate, calcium nitrate, potassium nitrate, and ammonium sulfate are very soluble in water. These nitrogen fertilizer materials are readily available on

the market, and are used extensively in the preparation of single nutrient or multi-nutrient fertilizer solutions.

Phosphorus

Commercial fertilizers contain the guaranteed percentage of P_2O_5 on the label as water soluble and citrate soluble phosphate. Phosphorus is not very mobile in many soils and is much less likely to be lost when applied conventionally than nitrogen. Plants generally need phosphorus early in their life cycle, so it is important that this element, if deficient in the soil, be applied at or before planting. If the plant shows phosphorus deficiency symptoms during the growing season, injection of phosphorus into the irrigation water allows for later stage correction.

Phosphorus fertilizer injection may cause emitter plugging. Solid precipitation in the line occurs most often due to interaction between the fertilizer and the irrigation water. Most dry phosphorus fertilizers (including ammonium phosphate and superphosphates) cannot be injected into irrigation water because they have low solubility. Monoammonium phosphate (MAP), diammonium phosphate (DAP), monobasic potassium phosphate, phosphoric acid, urea phosphate, liquid ammonium polyphosphate, and long chain linear polyphosphates are water soluble. However, they can still have precipitation problems when injected into water with high calcium concentration. Problems occur when the polyphosphate injection rates are too low to offset the buffering effects of the calcium and magnesium concentrations in the irrigation water.

The application of ammonium polyphosphate fertilizers to water that is high in calcium will almost always result in the formation of precipitants, which can plug the emitters. These precipitants are very stable and not easily dissolved. Phosphorus and calcium, when in solution together, may form di- and tri-calcium phosphates, which are relatively insoluble compounds. Similarly, phosphorus and magnesium can form magnesium phosphates, which are also insoluble and plug emitters. Of considerable concern in south Florida is the formation of iron phosphates, which are very stable. Given the high levels of calcium, iron, and bicarbonate in Florida irrigation water, phosphorus should not be injected unless significant precautions are taken.

Phosphoric acid is sometimes injected into micro irrigation systems. It not only provides phosphorus, but also lowers the pH of the water, which can prevent the precipitation problems previously mentioned. This practice will be effective as long as the pH of the fertilizer-irrigation water mixture remains low. As the pH rises due to dilution,

phosphates precipitate. One approach that is sometimes successful is to supplement the phosphoric acid injections with sulfuric or urea sulfuric acid to assure that the irrigation water pH will remain low ($pH < 4.0$). Continuous use of phosphoric acid at levels in excess of 25 mg/L, however, can produce zinc deficiencies in some crops. Phosphoric acid injection should be used only when the combined Ca and Mg concentration of the water is below 50 ppm and the bicarbonate level is less than 150 ppm.

Potassium

Potassium fertilizers are all water soluble, and injection of K through micro irrigation systems has been very successful. The problem most often associated with potassium injection is solid precipitants that form in the mixing tank when potassium is mixed with other fertilizers. The potassium sources most often used in micro irrigation systems are potassium chloride (KCl) and potassium nitrate (KNO_3). Potassium phosphates should not be injected into micro irrigation systems. Potassium sulfate is not very soluble and may not dissolve in the irrigation water. Potassium thiosulfate (KTS) is compatible with urea and ammonium polyphosphate solutions; however, it should not be mixed with acids or acidified fertilizers. When KTS is blended with urea ammonium nitrate solutions, a jar test is recommended before mixing large quantities. Under certain mixing proportions, particularly when an insufficient amount of water is used in the mix, potassium in KTS can combine with nitrates in the mix to form potassium nitrate crystals. If this happens, adding more water and/or heating the solution should bring the crystals back into solution.

Calcium

Fertilizers containing calcium should be flushed from all tanks, pumps, filters, and tubing prior to injecting any phosphorus, urea-ammonium nitrate, or urea sulfuric fertilizer. The irrigation lines must be flushed to remove all incompatible fertilizer products before a calcium containing fertilizer solution is injected. Calcium should not be injected with any sulfate form of fertilizer. It combines to create insoluble gypsum.

Micronutrients

Several metal micronutrient forms are relatively insoluble and therefore, not used for fertigation purposes. These include the carbonate, oxide, or hydroxide forms of zinc, manganese, copper, and iron. These relatively inexpensive materials can be broadcast and incorporated into the soil. However, they constitute a long term source of

micronutrients and will supply only a low level of nutrients for many years.

The sulfate form of copper, iron, manganese, and zinc is the most common and usually the least expensive source of micronutrients. These metal sulfates are water soluble and are easily injected. However, using these materials for fertigation is not very successful in alleviating a micronutrient deficiency, since the metal ion has a strong electrical charge (2+) and becomes attracted to the cation exchange sites of clay and organic matter particles, where it tends to sit near the soil surface. Consequently, the micronutrient usually does not reach the major plant root zone. If the soil pH is high, manganese, iron, and copper are changed into unavailable forms, and little or no benefit will be obtained from their use. If the metal sulfate solutions are acidified, however, the availability of the micronutrient can be prolonged in the soil.

Common Fertigation Materials

Ammonium Nitrate Solution (20-0-0)

$\text{NH}_4\text{NO}_3 \cdot \text{H}_2\text{O}$ is ammonium nitrate fertilizer dissolved in water with a density of 10.5 pounds per gallon. It is the most widely used nitrogen source used for Florida citrus.

Urea-ammonium Nitrate Solution (32-0-0)

$(\text{NH}_2)_2\text{CO} \cdot \text{NH}_4\text{NO}_3$: Urea-ammonium nitrate solution is manufactured by combining urea (46% N) and ammonium nitrate (35% N) on an equal nitrogen content basis. The combination of urea and ammonium nitrate contains the highest concentration of nitrogen of all the nitrogen solution products. When urea-ammonium nitrate solutions are combined with calcium nitrate, a thick, milky-white insoluble precipitate forms, presenting a serious potential plugging problem.

Calcium Nitrate (15.5-0-0-19 Ca)

$5\text{Ca}(\text{NO}_3)_2 \cdot \text{NH}_4\text{NO}_3 \cdot 10\text{H}_2\text{O}$: This fertilizer is high in nitrate-nitrogen (14.5%) with 1% ammonium-nitrogen, and supplies calcium. The product can be combined with ammonium nitrate, magnesium nitrate, potassium nitrate, and muriate of potash. It should not be combined with any products containing phosphates, sulfates or thiosulfates.

Ammonium Thiosulfate (12-0-0-26)

$(\text{NH}_4)_2\text{S}_2\text{O}_3$ is used as both a fertilizer and as an acidulating agent. When applied to the soil, *Thiobacillus* bacteria oxidize the free sulfur to sulfuric acid. The acid then dissolves

lime in the soil and forms gypsum. The gypsum helps to maintain a good, well granulated, aerated, and porous soil structure. Ammonium thiosulfate is ideal for treatment of calcareous (high lime) soils. It is compatible with neutral or alkaline phosphate liquid fertilizers and nitrogen fertilizers. Ammonium thiosulfate can be applied in liquid mixes or by itself.

Ammonium thiosulfate should not be mixed with acidic compounds because it will decompose into elemental sulfur and ammonium sulfate at $\text{pH} < 6$. Application to neutral and acidic soils (without free lime) may result in a pronounced drop in soil pH over several weeks. The extent of the pH drop in these types of soils depends upon the total amount of this fertilizer applied, the cation exchange capacity of the soil, and the buffering capacity of the soil. The higher the clay content and the higher the lime content of the soil (i.e., the larger the buffering capacity), the slower the pH will drop with the same fertilizer application.

Phosphoric Acid (0-54-0)

H_3PO_4 has a density of approximately 14.1 pounds per gallon. The acid is a syrupy liquid that requires storage in stainless steel (No. 316) tanks. Phosphoric acid can be used in many formulations of nitrogen, phosphorus, and potassium mixes. Phosphoric acid should never be mixed with any calcium fertilizer. It will form insoluble calcium phosphate, which can plug irrigation lines.

Potassium Chloride (0-0-62)

Potassium chloride (KCl) is generally the least expensive source of potassium and is the most popular K fertilizer applied through fertigation. It may not be desirable for use on citrus if irrigation water contains high salinity levels.

Potassium Nitrate (13-0-46)

Potassium nitrate is expensive, but the consumer benefits from both the nitrogen and the potassium in the product. It is an excellent choice of potassium fertilizer for areas where irrigation water salinity problems are present. It is less soluble than potassium chloride, but more soluble than potassium sulfate.

Potassium Sulfate (0-0-52)

K_2SO_4 can be an alternative to KCl in high salinity areas and provides a source of sulfur. It is fairly popular for fertigation. It is less soluble than potassium chloride and potassium nitrate.

Potassium Thiosulfate (0-0-25-17 and 0-0-22-23)

$K_2S_2O_3$ (KTS) is marketed in two grades and is a neutral to basic, chloride-free, clear liquid solution. This product can be blended with other fertilizers, but KTS blends should not be acidified below pH 6.0. The proper mixing sequence for KTS is water, pesticide, KTS, and/or other fertilizer. Always perform a jar test before injecting blends. Potassium thiosulfate provides not only potassium, but the thiosulfate is oxidized by *Thiobacillus* bacteria to produce sulfuric acid. This acid reacts with calcium carbonate in the soil, which releases additional calcium for the plant. Thus, potassium thiosulfate use on calcareous soils not only supplies potassium and sulfur, but aids in increasing the availability of calcium to plants.

Sulfuric Acid

H_2SO_4 is not a fertilizer, and thus has a grade of 0-0-0. It has a density of approximately 15.3 pounds per gallon when concentrated. Sulfuric acid is a clear liquid when pure; however, much of the agricultural material may have a brown to black color. It has no odor and pours as an oily liquid. It is injected into high bicarbonate water to control the pH by reducing it to about pH 6.5 to 7.0. It is sometimes injected directly into calcareous soils (high lime) where the reaction produces gypsum. Sulfuric acid should not be injected with calcium fertilizers since calcium sulfate (gypsum) will form and create a creamy suspension very much like cottage cheese, which can easily plug the lines. O.S.H.A. requirements for safe handling preclude fertilizer dealers from storing sulfuric acid on the premises; therefore, it is difficult to find a source of sulfuric acid. Sulfuric acid is extremely corrosive and must be handled with proper equipment and clothing. Never combine urea and sulfuric acid in the field.

Urea Solid (46-0-0) and Urea Solution (23-0-0)

Urea is sold as 46-0-0 dry fertilizer or as a liquid 23-0-0 urea solution. Commercial urea contains about 2.25% biuret, a byproduct that forms only during the manufacturing process. It can inhibit plant growth or damage plants. Urea with less than 0.25% biuret content should be used for foliar applications. Urea should never be mixed with sulfuric acid.

Urea Sulfuric Acid

Urea sulfuric acid ($CO(NH_2)_2 \cdot H_2SO_4$) is an acidic fertilizer that combines urea and sulfuric acid. By combining the two materials into one product, many disadvantages of

using these materials individually are eliminated. The sulfuric acid decreases the potential ammonia volatilization losses from the soil surface and ammonia damage in the root zone that can occur with the use of urea alone. Urea sulfuric acid is safer to use than sulfuric acid alone. Urea sulfuric acid is well suited for fertigation and can be used for other purposes such as to acidify the irrigation water (reducing plugging potential from carbonates and bicarbonates); maintenance injections to keep lines and emitters clear of calcium carbonate deposits; to clean irrigation lines once they have been plugged; and to acidify the soil.

Corrosion

Fertilizers and other injected chemicals can be corrosive to irrigation equipment. Table 4 lists the relative corrosion of six metals immersed in eight different fertilizer solutions for four days. Higher ratings mean greater damage to the material. Note that severe damage resulted to galvanized iron from ammonium nitrate and phosphoric acid solutions. A general materials acid compatibility chart for materials commonly used in irrigation systems is presented in Table 5.

Injection Time

To determine the time required to fertigate and flush the system, the time for water to travel from the injection point to the farthest emitter must be known. The travel time for a chemical that is water soluble can be estimated by the average velocity of the irrigation water. The travel time from the injection point to the last emitter can be calculated by summing the travel times for each pipe segment. For a pipe segment, travel time can be determined as follows:

$$T = D/V \text{ ----- Eq. 3}$$

Where:

T = time of travel (minutes)

D = distance or length of pipe (ft)

V = velocity (ft/min)

Example: Determine the travel time from the injection point to the manifold based on average velocity, given a 6-inch (0.5 ft) ID 1,000 ft pipe with a flow rate (Q) of 500 gpm.

$$X/C \text{ area} = 3.14 \times d^2/4 = 3.14 \times 0.5^2/4 = 0.2 \text{ ft}^2$$

$$500 \text{ gal/min} / 7.48 \text{ gal/ft}^3 = 66.8 \text{ ft}^3/\text{min}$$

$$V = Q/A = 66.8 \text{ ft}^3/\text{min} / 0.2 \text{ ft}^2 = 334 \text{ ft}/\text{min}$$

$$T = D/V = (1000 \text{ ft} / 334 \text{ ft}/\text{min}) = 2.9 \text{ min.}$$

The travel time for a lateral of uniform diameter with evenly spaced emitters that have equal discharge rates can be estimated as follows:

$$T = t (0.577 + \ln(N)) \text{ ----- Eq. 4}$$

Where:

T = travel time for entire lateral (minutes)

t = travel time between the last two emitters (minutes)

N = total number of emitters on the lateral

Ln = natural logarithm

The value of t is determined by:

$$t = A \times S/q \text{ ----- Eq. 5}$$

Where:

A = cross-sectional area of the pipe (ft²)

S = emitter spacing (ft)

q = emitter discharge (ft³/min)

Example:

Determine the travel time based on average velocity for: emitter flow = 0.21 gph, lateral diameter = 0.632 inches, emitter spacing = 1 foot, and lateral length = 250 ft.

$$A = 0.00218 \text{ ft}^2$$

$$S = 1 \text{ ft}$$

$$q = 0.000468 \text{ ft}^3/\text{min}$$

$$t = AS/q = 0.00218 \text{ ft}^2 \times 1 \text{ ft} / 0.000468 \text{ ft}^3/\text{min}$$

$$= 4.66 \text{ minutes}$$

$$T = 4.66 [0.577 + \ln(250)] = 28 \text{ minutes}$$

The above procedure can be applied to the submain if it has equally-spaced lateral outlets. However, the manifold is often tapered (non-uniform diameter) and in that case a step-by-step analysis must be performed. Total travel time

is the sum of the all the segment travel times for the entire pipe system from the injection point to the last emitter, which would typically include the mainline, submain, manifold, and lateral line.

Travel time calculations are based on average velocity of water in the pipeline. Actually, velocity is higher at the center of the pipe than near the pipe wall. So to insure complete flushing, the flush time should be twice the calculated travel time.

For an existing irrigation system, chemical travel time can be easily measured in the field by injecting a dye, acid, or fertilizer salt. If a fertilizer is used, a simple electrical conductivity (EC) meter can detect when the fertilizer has arrived at the farthest outlet of the irrigation system. Sampling should be continuous until the chemical arrives, which will be indicated by an increase in the EC of the water. Similarly, a pH meter (or pH strips) may be used if the injected material is an acid.

Calibration of Fertilizer Injectors

Only water-soluble fertilizers or fertilizer suspensions that are compatible with the irrigation and crop production systems should be injected. Because they are potentially corrosive, fertilizers should be flushed from the irrigation system after each application. Fertilizer solutions should always be injected before (upstream of) the filters in microirrigation systems. The compatibility of fertilizer solutions with the irrigation water and with any other chemicals being injected should be tested to avoid the formation of chemical precipitates in the irrigation system.

Care must be taken to ensure that injected materials do not react with dissolved solids in the irrigation water in such a way as to form precipitates or deposits in the irrigation system. The chemicals must be soluble and remain in solution throughout the operating conditions of the irrigation system. The fertilizers selected to be injected into the irrigation water need to be entirely soluble in water, and should not react with salts or chemicals in the water. Most nitrogen sources cause few clogging problems. The exceptions are anhydrous ammonia, aqua ammonia, and ammonium phosphate, which increase the pH of the water and cause precipitates with calcium and magnesium to form. Application of most forms of phosphorous through the system can result in extensive clogging. However, phosphoric acid can be safely injected in most waters since it acidifies the solution to a point where precipitation is prevented. All of the common potassium fertilizers are readily soluble and present no clogging problems.

Fertilizers can be highly corrosive, and are a potential health hazard to skin and eyes. Therefore, all system components including pumps, injection devices, lines, filters, and tanks should be inspected prior to use. There should be a routine monitoring program of the fertigation process with particular emphasis on the start-up and shut-down periods. Injection rates and times should be calibrated and re-checked frequently to ensure proper operation of the system. Leaks, runoff, excess applications, and application to areas with open water should be prevented. All system components should be flushed with clean water following each use.

When injecting fertilizers, the salinity of the irrigation water with the fertilizer in it should be checked. Heavy dosages of fertilizers can cause leaf burn, even if relatively low salinity water is used. It is generally preferable to inject small dosages of fertilizer frequently rather than make fewer applications at a high rate.

It is essential that proper and legal backflow prevention devices be used in the irrigation system to prevent fertilizers from being back-siphoned into the water supply. The injection device itself should have a screen and check valve. It is recommended that injection take place upstream of filters, so that any contaminants or precipitates can be filtered out.

Fertigation rates and times should be calibrated for each area that is fertigated. Flushing time needs to be at least as long as the travel time in the system from the injection point to the farthest emitter. In many microirrigation systems, this time is often 20-30 minutes. Fertilizer injections need to be at least this amount of time, and flush times need to exceed this travel time so that nutrients will not remain in the lateral tubing and promote algal growth.

Table 1. Synthetic nitrogen fertilizer materials that are derived from ammonia.

Reaction	Material	Commercial Grade N-P ₂ O ₅ -K ₂ O
$\text{NH}_3 + 2\text{O}_2 \rightarrow \text{HNO}_3 + \text{H}_2\text{O}$	nitric acid	-----
$\text{NH}_3 + \text{HNO}_3 \rightarrow \text{NH}_4\text{NO}_3$	ammonium nitrate	33.5-0-0
$2\text{NH}_3 + \text{H}_2\text{SO}_4 \rightarrow (\text{NH}_4)_2\text{SO}_4$	ammonium sulfate	20.5-0-0
$\text{NH}_3 + \text{H}_3\text{PO}_4 \rightarrow \text{NH}_4\text{H}_2\text{PO}_4$	monoammonium phosphate	11-48-0
$\text{NH}_3 + \text{H}_3\text{PO}_4 \rightarrow (\text{NH}_4)_2\text{HPO}_4$	diammonium phosphate	18-46-0
$2\text{NH}_3 + \text{CO}_2 \rightarrow (\text{NH}_2)_2\text{CO} + \text{H}_2\text{O}$	urea	45-0-0

Table 2. Pounds of lime required to neutralize the acidity produced by one pound of nitrogen when applied as a particular fertilizer.

Material	N (%)	Lb of lime per lb N
Ammonium sulfate	20.5	5.35
Urea	45	1.8
Ammonium nitrate	33.5	1.8
Anhydrous ammonia	82	1.8
Nitrogen solutions	21-32	1.08

Table 3. Solubility rates for various fertilizer materials used to prepare fertigation solutions.

Material	Grade	Form	Temp (°F)	Solubility (gm/100mL)	Solubility (Lbs./gal)
Nitrogen Fertilizers					
Ammonium Nitrate	34-0-0	NH ₄ NO ₃	32	18.3	9.87
Ammonium Polysulfide	20-0-0	NH ₄ S _x		high	high
Ammonium Sulfate	21-0-0	(NH ₄) ₂ SO ₄	32	70.6	5.89
Ammonium Thiosulfate	12-0-0	(NH ₄) ₂ S ₂ O ₃		v. high	v. high
Calcium Nitrate	15.5-0-0	Ca(NO ₃) ₂	62	121.2	10.11
Urea	46-0-0	CO(NH ₂) ₂		100	8.34
Urea Sulfuric Acid	28-0-0	CO(NH ₂) ₂ • 9H ₂ SO ₄		high	high
Urea Ammonium Nitrate	32-0-0	CO(NH ₂) ₂ • NH ₄ NO ₃		high	high
Phosphate Fertilizers					
Ammonium Phosphate	8-24-00	NH ₄ H ₂ PO ₄		moderate	moderate
Ammonium Polyphosphate	10-34-0	(NH ₄) ₅ P ₃ O ₁₀ & others		high	high
Ammonium Polyphosphate	16-37-0	(NH ₄) ₇ P ₅ O ₁₆ & others		high	high
Phosphoric Acid, green	0-52-0	H ₃ PO ₄		45.7	high
Phosphoric Acid, white	0-54-0	H ₃ PO ₄		45.7	high
Potash Fertilizers					
Potassium Chloride	0-0-60	KCl	68	34.7	2.89
Potassium Nitrate	13-0-44	KNO ₃	32	13.3	1.1
Potassium Sulfate	0-0-50	K ₂ SO ₄	77	12	1
Potassium Thiosulfate	0-0-25-17S	K ₂ S ₂ O ₃		150	12.5
Monopotassium Sulfate	0-52-34	KH ₂ PO ₄		33	2.75
Micronutrients					
Borax	11 % B	N ₂ B ₄ O ₇	32	2.1	0.17
Boric Acid	17.5% B	H ₃ BO ₃	86	6.35	0.53
Solubor	20% B	Na ₂ B ₈ O ₁₃	86	22	1.84
Copper Sulfate (acidified)	25% Cu	CuSO ₄	32	31.6	2.63
Cupric Chloride (acidified)		CuCl ₂	32	71	1;(0)1
Gypsum	23% Ca	CaSO ₄		0.241	6..65
Iron Sulfate (acidified)	20% Fe	FeSO ₄		15.65	1.31
Magnesium Sulfate	9.67% Mg	MgSO ₄ • 7H ₂ O	68	71	C) I
Manganese Sulfate (acidified)	27% Mn	MnSO ₄ • 4H ₂ O	32	105.3	8.79
Ammonium Molybdate	54% Mo	(NH ₄) ₆ Mo ₇ O ₂₄ • 4H ₂ O		43	3.59
Sodium Molybdate	39% Mo	Na ₂ MoO ₄	44.3		3.7
Zinc Sulfate	36% Zn	ZnSO ₄ • 7H ₂ O	68	96.5	8.05
Zinc Chelate	5 - 14% Zn	DTPA & EDTA		v. Sol.	v. Sol.
Manganese Chelate	5 - 12% Mn	DTPA & EDTA		v. Sol.	v. Sol.
Iron Chelate	4 - 14% Fe	DTPA & EDDHA	v. Sol.	v. Sol.	
Copper Chelate	5 - 14% Cu	DTPA & EDTA		v. Sol.	v. Sol.
Sulfuric Acid	95%	H ₂ SO ₄		V. high	v. high

Table 4. Relative corrosion of various metals (adapted from Martin, 1953). Solutions made by dissolving 100 lbs. of material in 100 gallons of water - metals immersed for 4 days. Ratings: 0=none, 1=slight, 2=moderate, 3=considerable, 4=severe.

Kind of Metal	Calcium Nitrate	Sodium Nitrate	Ammonium Nitrate - 20	Ammonium Sulfate	Urea	Phosphoric Acid	Diammonium Phosphate	17-0-17 mix (NH ₄) ₂ SO ₄ + DAP + K ₂ SO ₄
Galvanized Iron	2	1	4	3	1	4	1	2
Sheet Aluminum	0	2	1	1	0	2	2	1
Stainless Steel	0	0	0	0	0	1	0	0
Phospho-Bronze	1	0	3	3	0	2	4	4
Yellow Brass	1	0	3	2	0	2	4	4
Solution pH	5.6	8.6	5.9	5.0	7.6	0.4	8.0	7.3

Observations:

Ammonium nitrate, phosphoric acid, and ammonium sulfate very corrosive. Brass and bronze are corroded by phosphate, especially if ammonium is present. Copper is very corrosive to aluminum even in small doses. 316 grade stainless is corrosion resistant, other grades of stainless may be corrode.

Table 5. General acid compatibility of component materials.

Material	Occasional	Continual
Buna-N	No	No
Ceramic/Graphite	Yes	Yes
EPDM	Yes	Yes
Hypalon	Yes	No
Leather	No	No
Neopreme	Yes	Yes
Teflon	Yes	Yes
Viton	Yes	Yes
Aluminum	Yes	No
PVC	Yes	Yes
Brass	Yes	No
Polypropylene	Yes	Yes
303 stainless	Yes	No
316 stainless	Yes	Yes
Galvanized	No	No