Fertigation - Injecting soluble fertilizers into the irrigation system

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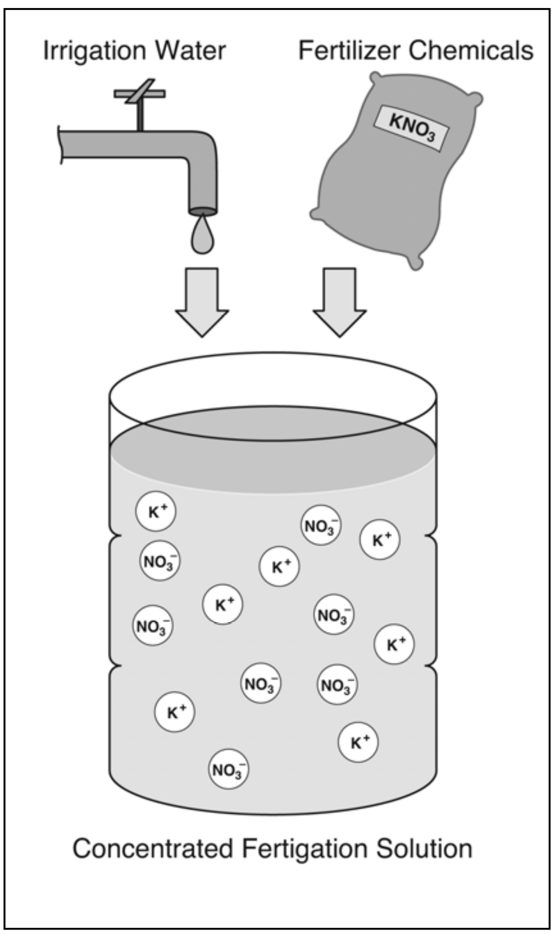
Introduction

Fertigation (fertilization + irrigation) is the newest way for nursery managers to apply fertilizer, and has become a standard practice in container nurseries. Because of the inherent inefficient water distribution patterns in field irrigation systems, fertigation has not been sidely used in bareroot nurseries. However, a bareroot nursery with a center-pivot irrigation system has successfully used fertigation (Triebwasser and Altsuler 1995), and other nurseries have applied soluble fertilizer through a tractor -drawn sprayer. Compared to traditional fertilization with dry, granular fertilizers, spray application of soluble fertilizer solutions was faster, more uniform and accurate, and easier to calibrate (Triebwasser 2004)

A Brief History - Fertigation can be traced back back to the mid-1800's when plants were grown in water or sand cultures as part of basic plant nutrition research. A variety of soluble fertilizer solutions were used in these experiments but the first commonly-used recipe was known as Hoagland's solution and was developed by plant scientists at the University of California at Berkeley back in the 1930's as part of nutriculture experiments. The composition of this solution was originally patterned after the solution extracted from soils of high productivity (Hoagland and Arnon 1950). Subsequent research has shown that plants are very selective in their nutrient uptake so a modified Hoagland solution can be used to produce a wide variety of container crops (Jones 1983). When the first container tree nurseries were started back in the early 1970's, a modified Hoagland’s solution was used to grow a wide variety of western conifers and some broadleaved woody plants (Tinus and McDonald 1979). A further modification was used for target nutrient levels in Volume Four of the Container Tree Nursery Manual produced the Target Nutrient Levels in



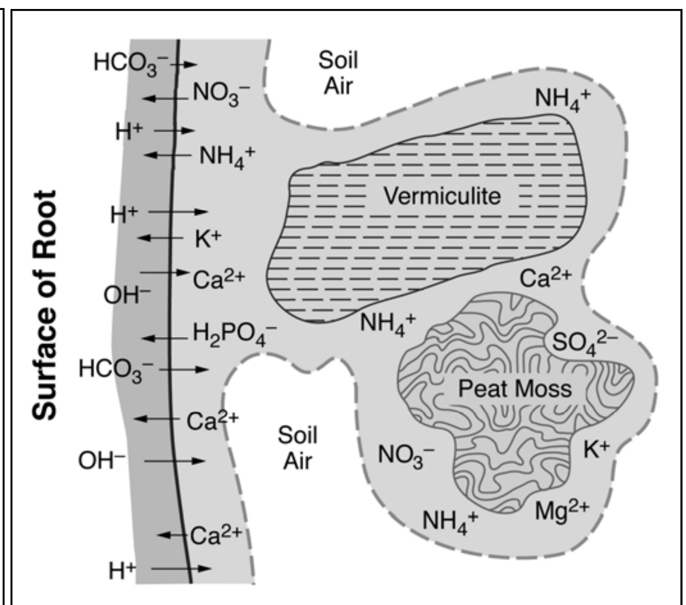


Figure 1 - The chemicals used to formulate fertigation solutions are technically salts; for example, potassium nitrate (KNO_3) dissolves into charged nutrient ions (K^+ and NO_3^-) (A). Because the nutrient ions supplied through fertigation have already dissolved into charged nutrient ions, they are easily taken-up by plant roots (B).

Mineral nutrient uptake - The chemicals used to make soluble fertilizers for fertigation are technically salts, which means that they readily dissolve in water into charged ions. For example, potassium nitrate (KNO_3) dissolves into two nutrient ions: the cation potassium (K^+) and the anion nitrate-nitrogen (NO_3^-) **(Figure 1A)**. One of the benefits of fertigation is that all the mineral nutrients are already in an ionic form when they are applied to the crop. With other granular or controlled release fertilizers, the nutrients must first dissolve in the ground water before they become available for plant uptake **(Figure 1B)**.

Lastly, before deciding to use fertigation, it would be wise to consider both the advantages and disadvantages (Landis and others 1989):

Advantages:

1. Fertigation allows precise control of both the concentration and balance of all 13 mineral nutrients.

2. Nutrient solutions can easily be customized or modified for any plant growth stage or species.

3. When properly formulated and applied, there is a very low chance of overfertilization and resultant salt injury.

4. Fertigation solutions are easily to monitor.

Disadvantages:

1. Nutrient injectors must be used for maximum effectiveness.

2. Frequent mixing and applying of liquid fertilizers increases labor costs.

3. A well-designed, automated irrigation system is essential to insure even fertilizer application.

Three Components of a Fertigation System

Fertigation should be thought of as a system with 3 major components **(Figure 2)**, which should be considered in reverse order of how they actually occur:

1. Applied Fertigation Solution. The pH and EC of the applied fertigation solution are a general check on how well the entire system is working, and should be checked at least weekly. The concentration of the 13 mineral nutrients in the applied solution should be close to the Target Nutrient Levels that you've selected for your crop. The ideal nutrient concentration will vary with the plant species that you are growing, and also with the phase of crop development.

Nitrogen (N) is one of the most important nutrients affecting plant growth and is the most frequently applied fertilizer element. Therefore, all fertigation programs are based around the N concentration, and the levels of all the other nutrients are established relative to N.

Each of the 3 growth phases for container nursery crops has its own N target concentration (Landis and others 1999):

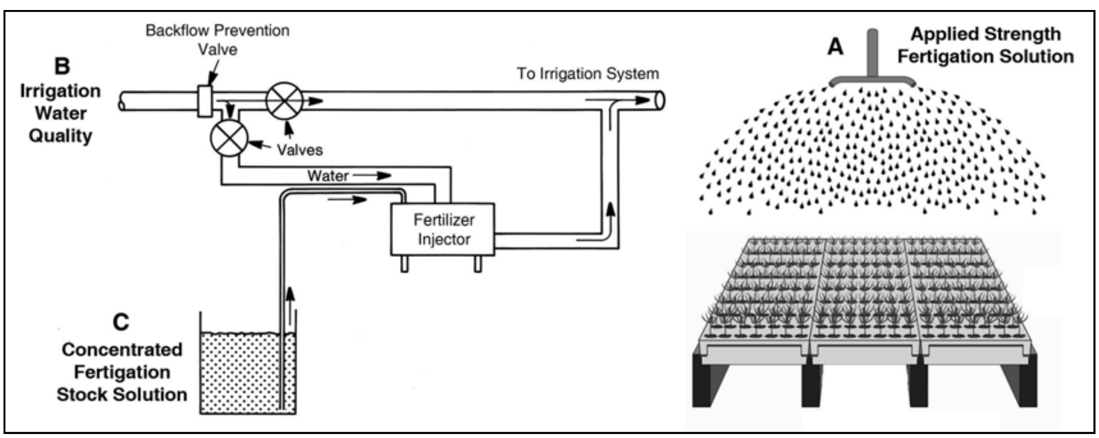


Figure 2 - The three major components of any fertigation system are: A) nutrient concentrations in the applied fertigation solution , B) base level of nutrients in the irrigation water, and C) composition of the fertigation stock solution. (modified from Nelson 1978).

Table 1 - Nutrient analysis of irrigation water from diverse forest and conservation nurseries compared to recommended mineral nutrient target concentrations (modifed from Landis 1997)				
Essential Mineral Nutrients	**Target * Nutrient Levels**	**Irrigation Water Analysis**		
		Hawaii Nursery	**Colo-rado Nursery**	**Califor-nia Nursery**
Macronutrients in parts per million				
Total Nitrogen (N)	200	NT*	3	7
Nitrate-nitrogen (NO_3)	150	NT*	3	5
Ammonium-nitrogen (NH_4)	50	NT*	0	0
Phosphorus (P)	60	0	0	0
Potassium (K)	160	0	2	2
Calcium (Ca)	60	1	82	66
Magnesium (Mg)	40	1	14	113
Sulfate-sulfur ($S0_4$)	60	Not Tested	43	315
Micronutrients in parts per million				
Iron (Fe)	4.00	0.20	0	0
Manganese (Mn)	0.50	0	0	0.01
Zinc (Zn)	0.05	0	0	0.05
Copper (Cu)	0.02	0	0	0
Chloride (Cl)	4.00	Not Tested	3.00	132.00
Molybdenum (Mo)	0.01	Not Tested	0	0
Boron (B)	0.50	0	0.06	1.00
Total Dissolved Salts in mcS/cm				
Electrical Conductivity	1200 to 1800	30	470	1610
*** = Target N levels will vary with plant species and nursery growth phase**				

Establishment Phase: 25 to 50 ppm N - All nutrient levels are kept low to allow the young seedlings to become established in the container without risk of salt injury. Phosphorus (P) is important because very little of this nutrient is stored in the seed and the new roots have limited absorption ability. Calcium (Ca) is also important for new root growth.

Rapid Growth Phase: 75 to 200 ppm N - This is the period of rapid shoot growth and the target N concentration will vary with crop characteristics, and how well shoot growth is occurring relative to the desired growth curves. Fast growing species, such as quaking aspen or sagebrush are given 50 ppm N to prevent excessive height growth. N levels of 75 to 150 ppm will be sufficient for the majority of native plant species. Some very slow growing plants such as whitebark pine may require 200 ppm N or more to force growth.

Hardening Phase: 50 to 75 ppm N - High N levels, and ammonium-N in particular, stimulate shoot growth at the expense of stem or root growth, and also are detrimental to cold hardiness development. Therefore, target N levels are kept at low concentrations during the hardening phase. The purported benefit of high potassium (K) during hardening has never been proven but higher Ca levels aid in the hardening process.

2. Irrigation Water Quality. Water quality has a major influence on any fertigation program. The most important considerations are the pH, total salt level as measured by electrical conductivity (EC), and the mineral nutrient concentration of the water that will be applied to your crop. The pH and EC readings are part of a water quality test **(Table 1)**, and should also be monitored regularly during the growing season.

Nutrients in the irrigation water - Most people don't consider water a source of nutrients and, if they are talking about animal nutrition, then that's correct. For plants, however, irrigation water can be a valuable source of secondary mineral nutrients. In fact, some irrigation waters can contain all or a substantial portion of the calcium (Ca), magnesium (Mg), and sulfur (S) needed for normal growth. The concentrations of soluble mineral nutrients in irrigation water vary considerably from nursery to nursery depending on the source of the water and the local geology. Because it has had less time to dissolve soluble minerals in the soil, irrigation water from surface sources such as streams and ponds will usually have lower soluble salt levels than well water.

The mineral nutrient content of three very different water sources is presented in **Table 1.** In Hawaii, rain filters through young, pumice soils which do not contain many soluble minerals and so the irrigation water is very pure. Actually, irrigation water can be too pure for good plant growth because it quickly leaches out the soluble nutrients from the soil or growing medium - this same thing happens in open growing compounds during periods of heavy rainfall. The water at many places in the semi-arid Western US such as Colorado is called "hard" because it contains high levels of calcium and magnesium which cause scale to deposit on pipes and also leaves deposits on other surfaces. Nurseries with moderately hard water are fortunate because it often supplies all or most of the plant's calcium and magnesium requirement. Water from some irrigation wells can be too high in soluble salts as the analysis from the Sacramento Valley of California illustrates. Although these calcium, magnesium, and sulfur levels are above the recommended levels, the most serious factor is direct toxicity from high chloride levels.

Mineral nutrient analyses of irrigation water can be performed by most analytical testing laboratories, but growers should be sure to specify that they want a nutrient analysis, instead of a standard water quality test. It's a good idea to supply a list of the nutrients that you want tested from Table 1. A complete water analysis for both nutrients and quality should cost around $50 to $100, and many labs will E-mail results in around a week. The pH and electrical conductivity (EC) of the water should also be measured. The pH gives an indication of how much acid will be required to reach the desired 5.5 level, and the EC reflects the total dissolved salts.

Acidify irrigation water pH to target level - Once the base nutrient level of the water is known, its buffering capacity should be determined by acid titration. Titration is a process in which small increments of an acid are added to a known quantity of irrigation water (1 l) to determine the amount of acid that will be required to lower the pH to the desired level (pH 5.5). Titrations can be done by any water testing lab or by nursery personnel using a pH meter and a burette or pipette. Any acid can be used for titrating as long as its normality is known so that conversions between different acids can be made.

Several acids have been used for acid injection in container tree nurseries including nitric, sulfuric, and phosphoric but we prefer phosphoric acid (H_3PO_4) because it is relatively safe to handle. An added benefit is that the acidified water produces a constant source of soluble phosphorus, which is particularly valuable during germination and early growth. Sometimes, when irrigation water is very alkaline (high pH), some much phosphoric acid is required that the P level would exceed the target level of 60 ppm **(Table 1)**. In this situation, a stronger acid such as nitric acid can be used or even acetic acid which is safe and contributes no nutrient ions.

To keep the calculations simple and safe, we use a 1 % phosphoric acid solution for our titrations. Both 75 or 85% phosphoric acid are commercially available, and the calculations to make the 1% solution are proportional **(Table 2).** Once the amount of 1% H_3PO_4 needed to lower the pH of the water sample is known, the conversion to back to the 75 or 85% stock acid solution is made by dividing by either 75 or 85.

Titration curves for the irrigation water at Mt. Sopris Nursery which used to be in Carbondale, CO, and the Colorado State Forest Service Nursery in Ft. Collins, CO, are given in **Figure 3.** Note the difference between the two curves: the steeper the slope of the line, the lower the buffering capacity of the water. The water at the Colorado State Nursery has a very low buffering capacity and requires only 3 ml of H_3PO_4 to lower the pH of 1 liter of irrigation water to the desired level, whereas the Mt. Sopris Nursery water requires almost 16 ml of 1 % H_3PO_4 to reach the target pH.

Because the amount of acid may need to be adjusted for seasonal changes in water quality, regular pH monitoring is necessary. The pH will also change after the fertilizer chemicals have been added to the fertilizer solution, so other minor adjustments may be necessary.

3. Formulating fertilizer stock solutions. At this step, you have two options. The first is to use a commercial soluble fertilizer, and the second is to create a custom fertilizer from stock chemicals. We recommend using plastic containers to avoid corrosion, and most nurseries use 50 gallon or 200 liter stock tanks.

One inherent problem with formulating concentration stock solutions is solubility and the more concentration the solution, the great risk of precipitation. Calcium in particular causes problems because it forms precipitates when it is combined with high concentrations of phosphorus and sulfur. The best solution is to use two separate tanks and nutrient injector with 2 heads: the commercial fertilizer in the first, and the acid and any calcium and sulfate fertilizers in the second. Once the two solutions are mixed in the applied fertigation stream they have been diluted enough to prevent precipitation problems. For more information, see Figure 4.1.22 in Volume Four of the Container Tree Nursery Manual.

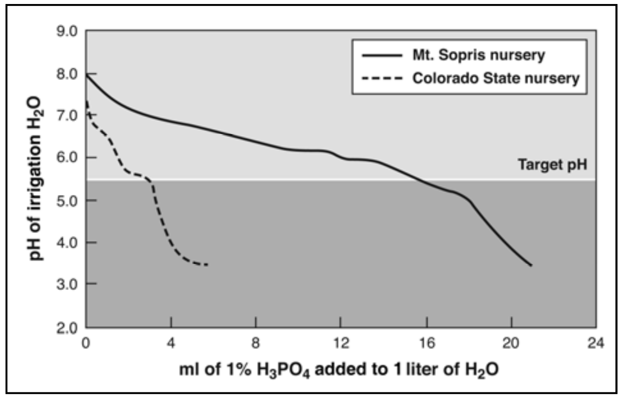


Figure 3 - Acid titration curves for two different nurseries in Colorado which were developed by adding successive 1 ml increments of 1 % phosphoric acid H_3PO_4 to 1 l of irrigation water (Landis and others 1979).

Using commercial soluble fertilizers - When we wrote Volume Four: Seedling Nutrition and Irrigation of the Container Tree Nursery Manual, 88% of the container nurseries in North America used commercial brand fertilizers, either alone or in combination with custom mixes. Some fertilizer brands contain both macronutrients and micronutrients whereas others contain only the major fertilizer elements, so be sure and check the label.

Table 2 - Calculations for making 1 liter of 1% phosphoric acid titrating solution from a 75% stock acid and distilled water

Concentration x Volume = Concentration x Volume

$$(0.01)(1{,}000\ \text{ml}) = (0.75)(X)$$

$$10 = 0.75X$$

$$X = 13.3\ \text{ml}$$

For safety reasons, always add acid to water: partially fill the flask with distilled water, slowly add the acid to it, and then add enough water to make 1 liter.

Table 3 - Elemental mineral nutrient concentration in an applied 100 ppm nitrogen solution of Peters Professional® Conifer Grower (modified from Scotts Company 2004)

Mineral Nutrient (Symbol)	ppm
Macronutrients	
Total Nitrogen (N)	100
Ammoniacal (NH_4 & NH_3)	(58)
Nitrate (NO_3)	(42)
Phosphorus (P)	15
Potassium (K)	79
Calcium (Ca)	0
Magnesium (Mg)	4
Sulfur	0
Micronutrients	
Iron (Fe)	2.00
Manganese (Mn)	0.30
Zinc (Zn)	0.30
Copper (Cu)	0.30
Molybdenum (Mo)	0.02
Boron (B)	0.12

Nutrients supplied by a typical fertilizer (Peters Professional® Conifer Grower) at a 100 ppm N rate are listed in **Table 3.** Note that neither calcium nor sulfur is supplied by the fertilizer due to solubility problems. If these nutrients are not sufficient in the irrigation water, then a second stock tank with calcium chloride and magnesium sulfate should be used.

Most commercial brands of soluble fertilizer will provide mixing instructions; the weight of Peters Professional® Conifer Grower (20-7-19) to add to 1 gallon of water are shown in Table 4. Note that all fertigation solutions are based on the parts per million of nitrogen. To calculate the concentrations of all the nutrients, use the following procedure which is based on the fact that parts per million (ppm) is the same as milligrams per liter (mg/l):

1. Set the target N level for the applied fertilizer solution (100 ppm, for example).

2. Determine how much bulk fertilizer must be used to produce the target concentration (100 ppm)- the fertilizer in our example is 20-7-19, or 20% N:

> 100 ppm = 100 mg/I but this fertilizer is only 20% N. So, we'll need to add 500 mg/I of bulk fertilizer

3. Adjust for the nutrient injection ratio (1:200, for example):

> 500 mg/I bulk fertilizer x 200 = 100,000 mg/I bulk fertilizer

4. Convert from milligrams per liter to grams per liter:

> 100,000 mg/I = 1,000 mg/g = 100 g/I bulk fertilizer

If using English units, convert grams per liter to ounces per gallon:

> 100 g/I x 0.1334 = 13.34 ounces of bulk fertilizer per gallon water (Note that this value agrees with the value in the mixing instructions in **Table 4** for 100 ppm N and a 1:200 injector).

5. Now that we have established the amount of 20-7-19 bulk fertilizer (step #2) needed to supply our N target (step #1), we need to calculate how much P will be contained in the applied fertilizer solution (note that the fertilizer contains 7% P_2O_5, NOT 7% P):

> 500 mg/I x 0.07 = 35 ppm

6. Now, we need to convert the oxide form (P_2O_5) to the elemental form:

> 35 ppm P_2O_5 x 0.4364 = 15 ppm P. Again, note that this agrees with the value in **Table 4**. Just to confirm, you can do similar calculations to compute the ppm of each of the mineral nutrients.

If this is all a bit intimidating, horticulture suppliers like Scotts® employ technical specialists who can help with the calculations, and have valuable information on their websites, *eg*. http://www.petersabc.com/ .

Table 4 - Ounces of Peters Professional® Conifer Grower (20-7-19) to add to 1 gallon of water to produce stock solutions with the following nitrogen concentrations (modified from Scotts Company 2004)

Nitrogen (ppm)	Nutrient Injector Ratios			EC (mcS/cm)
	1:15	1:100	1:200	
25	0.30	1.69	3.38	0.15
50	0.50	3.38	6.75	0.30
75	0.80	5.06	10.13	0.45
100	1.00	6.75	13.50	0.60
150	1.50	10.13	20.25	0.90
200	2.00	13.50	27.00	1.20
300	3.00	20.25	40.50	1.80

Developing a custom fertigation program - Custom fertilizer mixes utilize bulk chemicals to supply all the mineral nutrients necessary for plant growth. There are several grades of commercial chemicals that are classified according to use, but technical or purified grades are
best for custom fertilizer mixes in terms of purity and cost. Fertilizer grade chemicals are formulated for bareroot applications and are not recommended for soluble fertilizer mixes because they contain high percentages of impurities. A list of commonly-used chemicals can be found on pages 39-41 of Volume Four of the Container Tree Nursery Manual (Landis and others 1989). As mentioned in the first section, two stock solutions are typically used to prevent precipitation:

Stock solution 1 (SS#1). This solution contains the acid to lower the water pH and Ca and S if they are needed. The calculations for how much acid to add consist of expanding the ml per liter of water obtained in the titration **(Figure 2)** to the quantity of water in the stock tank. The accuracy of these computations should be checked by collecting some of the applied irrigation water and testing its pH. Due to changes in irrigation water quality over the season and the effect of other chemicals in the applied fertigation solution, the amount of acid added to the
stock solution may have to be adjusted occasionally. See Volume Four of the Container Tree Nursery Manual (Landis and others 1989) for more details.

(Rae – Table 5 is in the Final Graphics folder)

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Stock solution 2 (SS#2). Macronutrients except Ca and S. All the other mineral nutrients will be added to this solution. An example of the computations for this stock solution is provided in **Table 5.** The upper portion shows the target nutrient concentrations in parts per million, the amount of each nutrient in the irrigation water, and the amount needed to be added as fertilizer. The chemicals used to supply nutrients and their contribution in parts per million are shown in the left column. The final column on the right shows the total amount of the chemical
that would be present in the applied fertilizer solution.

The total parts per million of each nutrient must be converted to the weight of the chemical that needs to be added to each liter of water. This conversion is simple because 1 liter of water weighs 1 kg by definition. Therefore, on a weight per volume basis, 1 mg/I = 1 ppm. A list of mineral nutrients are supplied by each compound is given in Table 4.1.23 of Volume Four of the Container Tree Nursery Manual (Landis and others 1989). Using magnesium sulfate ($MgSO_4$) as an example, this chemical contains 10% Mg 13% S and the calculation in Table 4 shows that we need 38 ppm of Mg. So, how much $MgSO_4$ do we need?

$$\frac{38 \text{ mg/l Mg}}{0.10} = 380 \text{ mg/l}$$

To compute how much sulfur this would contribute:

380 mg/l x 0.13 = 49 ppm S

The recipe for all the ingredients is given in the "applied solution" column in **Table 5** -- this is the actual concen-

Table 5 - Sample calculations for a custom fertigation stock solution

	Nutrient concentration (ppm)								
	Total N	NO_3-N	NH_4- N	P	K	Ca	Mg	S	
Target	200	140	60	60	100	80	40	60	
- Water test	0	0	0	0	0	11	2	6	
= To add	200	140	60	60	100	69	38	54	
Fertilizer chemicals									**Applied solution**
85% H_3PO_4				17					
KH_2PO_4				43	52				
KNO_3	17	17			48				
NH_4NO_3	120	60	60						
Ca NO_3	63	63				71			
Mg SO_4							38	49	
Totals	200	140	60	60	100	71	38	49	

Fertilizer chemicals		Applied solution	Injector concentrate	Stock solution
Common name	**Formula**		(1 : 200)	(200 l)
85% Phosphoric Acid	H_3PO_4	0.0375 ml/l	7.52 ml/l	1.5 l
Monopotassium phosphate	KH_2PO_4	187 mg/l	37.4 g/l	7.5 kg
Potassium nitrate	KNO_3	130 mg/l	26.0 g/l	5.2 kg
Ammonium nitrate	NH_4NO_3	353 mg/l	70.6 g/l	14.1 kg
Calcium nitrate	Ca NO_3	420 mg/l	84.0 g/l	16.8 kg
Magnesium sulfate	Mg SO_4	380 mg/l	76.0 g/l	15.2 kg

tration of fertilizer that is applied to the seedlings. These values are carried down to the "Applied solution" column at the bottom of the table, where the conversions are made for the nutrient injector and the stock solution. The adjustment for the nutrient injector (1:200) consists of multiplying the applied solution values by 200 and then converting milligrams to grams. Continuing with our example for $MgSO_4$:

380 mg/I x 200 = 76,000 mg/I = 76 g/I

To compute how much bulk chemical is needed for the 200-liter stock solution tank, multiply by 200 and convert to kilograms:

76 g/I x 200 = 15,200 g = 15.2 kg

The true test of the fertigation calculations is to collect a sample of the Applied Fertigation Solution and have it chemically analyzed. **Table 6** shows the total fertigation program for the Mt. Sopris Nursery for pH, EC and all the mineral nutrients. The values in the Applied Solution reflect the base levels in the irrigation water plus what was added in the fertigation stock solutions. Comparing these values with the Targets shows that our calculations were reasonably close. The Applied values are the final check on the fertigation programs and should be retested each season to make certain that everything is working properly.

Types of Injectors (Do we need to keep this and the following sections for a Part 2 in the next issue?)

The fertigation method varies depending on the type of irrigation and the size
and sophistication of the nursery. The simplest method is to combine soluble fertilizers (figure 11.9A) in a watering container or use a hose injector (figure 11.9B), and water plants by hand. This method can be tedious and time consuming, however, when fertigating a large quantity of plants. On the other hand, this method may be best when growing many different
species with different fertilizer needs in small areas. For larger nurseries growing large numbers of plants with the same fertilizer requirements, injectors are used to mix the fertilizer concentrate into the irrigation system. The simplest siphon injectors are attached to the water faucet and use the venturi effect to suck the fertilizer solution up through a piece of rubber tubing at a fixed 1:16 ratio. Although simple and inexpensive, the injection ratio varies with water pressure. The Hozon™ requires a water pressure of at least 30 pounds per square inch (psi) to work properly, whereas the EZ-FLO® functions at water pressures as low as 5 psi.

When to Fertigate

Continuous

Periodic

Monitoring Fertigation

EC

Chemical Analysis

Summary

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Table 6 - Custom fertigation program used at Mt. Sopris Nursery, Carbondale, CO				
	Units	**Irrigation Water**	**Applied Fertigation Solution**	**Target**
Water Quality Indices				
pH	**log units**	6.9	6.0	5.5
Electrical conductivity	**mcS/cm**	470	1,680	1,200 to 1,800
Macronutrients				
Nitrate Nitrogen	ppm	3	170	156
Ammonium Nitrogen	ppm	0	11	66
Total Nitrogen	ppm	3	181	222
Phosphorus	ppm	0	54	60
Potassium	ppm	2	140	155
Calcium	ppm	82	80	60
Magnesium	ppm	14	48	40
Sulfate Sulfur	ppm	43	135	63
Micronutrients				
Iron	ppm	0.02	2.60	4.00
Manganese	ppm	0.01	1.1	0.50
Copper	ppm	0.01	0.07	0.02
Zinc	ppm	0.01	0.07	0.05
Molybdenum	ppm	0.10	0.10	0.01
Boron	ppm	0.06	0.14	0.50
Chlorine	ppm	3.00	4.00	4.00

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