ARGUS®
CONTROLS

Argus Nutrient Dosing Handbook

Revised September 2009

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Revised: September 2009

Printed in Canada.

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About this Manual

This manual is intended as a reference for customers using their Argus systems for irrigation and nutrient control. It is intended as a service to our customers in aid of better understanding the underlying principles at work in a plant nutrition program. We have collected this information over many years from numerous sources including fertilizer companies, textbooks, extension pamphlets, and our own engineering and horticultural experience.

Any horticultural tables, values, amounts, or recommendations contained in this guide are for illustrative purposes only. While we have tried our best to verify the accuracy of the information in this document, there may inevitably be some mistakes, misprints, inaccuracies, or misinterpretations of the information provided.

⚠ **Argus assumes no liability for loss or damage, consequential or otherwise that may occur from the use of this information. It is your responsibility to satisfy yourself of the suitability and completeness of the information for your particular use.** Always check with your local extension advisory service or crop consultant before making any changes to your fertilizer and crop nutrition program.

⚠ When calculating, measuring, and mixing fertilizer concentrates, be aware that **a simple mathematical mistake in formulation can have potentially deadly consequences to your crop**. Always double-check your calculations and confirm proper operation of your injection system by manually checking the final result.

Should you notice an error or a misprint in this guide, please inform Argus so that we may correct it in future editions.

General Safety precautions

Proper fertilizer mixing and delivery is critical to the health of your crop. Regardless of the fertilization methods and equipment you use, we strongly recommend that you perform routine, independent checks of your nutrient solution using portable EC and pH meters, particularly at the point of discharge to the crop. We also recommend periodic complete lab analyses of your irrigation water source and prepared dilute nutrient solutions. This will help ensure the proper operation of the Argus control software, as well as confirm that your nutrient concentrates have been correctly prepared and that the appropriate setpoints have been entered in the control programs.

It is important to remember that while the Argus nutrient control software monitors for the current EC and pH, **it cannot evaluate the elemental composition of the dilute solution**. This can only be accomplished through lab analysis (although there are some hand held meters available for measuring a few of the nutrient ions). We strongly recommend you make the most of the monitoring, alarm, and data recording capabilities of your Argus system to help spot problems quickly. **If you are unable to determine the cause of an alarm or the remedy, call Argus before resuming dosing operations**.

Backflow Prevention

You must ensure that there is no possibility for injected materials to contaminate domestic potable water supplies should a drop in supply pressure occur. All fertilizer proportioning devices must be either decoupled from domestic water supplies or installed with approved backflow prevention devices. Check your local plumbing codes.

Handling Acids & Bases

Concentrated acid and base materials are dangerous, poisonous, and highly reactive. They should be handled with extreme caution. Refer to OSHA or (MSDS) Material Safety Data Sheets from your chemical supplier for proper handling and storage instructions. When diluting acids and bases, always add the concentrate to water, never add water or organic materials to the concentrate. An explosive reaction could result!

Pesticide Injection and Chemigation

The Argus nutrient control hardware and software is intended for applying liquid fertilizers and pH correcting concentrates only. **ARGUS DOES NOT RECOMMEND THE INJECTION OF PESTICIDES, SANITIZING CHEMICALS, or GROWTH REGULATING MATERIALS** through your Argus nutrient injection equipment. Since dosing strategies may employ a combination of feed forward ratiometric and sensor feedback techniques, **the absolute dilution ratio may vary.** For non-fertilizer or pH correction applications, a separate, fixed-ratio injector should be used.

Before applying non-fertilizer materials through your irrigation system, you should consult your local codes, workers compensation, health authorities, and environmental protection agencies with respect to the legality and local regulations governing this practice. Environmental responsibility and the safety of you and your employees is important!

Avoiding Mixing Errors.

Use extreme care when mixing fertilizer concentrates. Don't make mistakes! There is no way to tell, other than by lab analysis, if the correct ingredients have been added in the correct proportions. For example, manganese is required at about 1/100th of the concentration of magnesium and it is toxic to plants at high concentrations. If you mistakenly add manganese sulfate at the magnesium sulfate rate, you could kill your crop! The same applies to the other trace elements.

Some agricultural fertilizer salts are incompatible at high stock tank concentrations. If you accidentally mix two of these incompatible materials in one of your stock tanks, you will have a big mess of insoluble precipitates that could plug up everything. You don't want to do this!

The most common types of mistakes are decimal point errors when working out concentration ratios (this can throw off your results by a factor of 10, 100, or even 1000! Inaccurate estimation of the volume of stock tanks is another common source of error. **Make sure your stock tanks are accurately calibrated before using them.** You only need to do this once. You should also have some means of graduating or measuring partial volumes in the stock tanks. You can mark this on the tanks, or use a graduated measuring stick or plastic pipe section. Create clear printed mixing recipes and procedures to follow, and label each stock tank with the ingredients that go into it.

Preparing strong concentrations of soluble fertilizers usually requires lots of hot water to completely dissolve the fertilizer materials. It's a good idea to pre-dissolve chemicals in a separate mixing container that can be pumped or decanted into the stock tanks. This ensures that undissolved chemicals do not end up on the bottom of the concentrate tanks. If you use a transfer pump make sure the pump or pickup tube can be lifted off the bottom so that undissolved materials will remain in the mixing tank for further dissolving. If possible, try to eliminate random weighing errors by pre-calibrating dry measuring implements for ease of repeatability. For example, you might fashion a measuring container for your minor elements so that the same amount (i.e. 1 level scoop) can easily be added to an empty stock tank with each refill.

The following procedures are highly recommended to help you create good historical records to protect you from mistakes and resolve errors if and when they occur.

- Make sure that everyone who handles fertilizer concentrates understands what they are and how they are properly mixed.
- Work out your fertilizer calculations well in advance and check them over thoroughly. If possible, check your figures against one or more published standards to verify your accuracy.
- Keep written records of all fertilizer mixing activities. Record the date, time, operator, the amounts of water and each fertilizer chemical used in each batch of stock solution.

The sensors and alarms on your Argus system can help you to detect some types of mixing errors, but not all. You simply cannot afford even a single major error in nutrient mixing.

Security & Safety

Your fertilizer mixing area should be secure and lockable. No one likes to think the unthinkable, but imagine what a vandal could do with a bottle of herbicide, or even the minor elements you have on hand. Your fertilizers must also be kept dry. Many fertilizers are hygroscopic and will take up moisture in high humidity environments (like greenhouses!). This will lead to measurement errors when weighing fertilizers since they may contain an unknown amount of water. Besides, soggy fertilizers are a corrosive mess!

Finally, keep your fertilizers away from other chemicals and fuels. You don't want to accidentally make an explosive!

Irrigation Water Quality

Liquid feeding programs always begin with the water. If your source water isn't suitable for horticulture, you'll have no end of problems producing a quality crop. While there are a number of things that can be done to improve the quality of irrigation source water, it's always best to start with the best water possible. That said, we realize that you seldom have a choice where you obtain your water.

Recirculation of water, where practical, can help reduce the total amount of water you need, but it places even greater demands on the initial water quality, since non-fertilizer salts and other materials tend to accumulate in closed or partially closed systems.

Many water supplies contain metals such as iron and manganese that are well in excess of plant requirements. Others contain high amounts of sodium, calcium, sulfur, and other minerals.

Your source water should be essentially free of pesticides, heavy metals, organic matter, and other contaminants. Occasionally, specific contaminants such as herbicides may be present that can damage your crops. Surface water supplies and shallow wells are particularly vulnerable to contamination. Poor water quality can also lead to mineral precipitates and clogged dripper lines. In addition to dissolved materials, water supplies often need to be filtered for particulate materials that might interfere with nutrient dosing and delivery to the crop.

Some regions may even have water that is 'too pure'. Such water supplies may require intentional buffering with bicarbonates to help stabilize the pH of nutrient solutions and planting media.

Water Analysis

Every nutrient feeding program should begin with a complete water analysis. The table below is adapted from the British Columbia Ministry of Agriculture's Irrigation Water Quality for BC greenhouses. Many other regional recommendations are also available. The table illustrates a typical range of values that are acceptable for irrigation water in greenhouses.

Table 1 - Water Quality Target Parameters

Parameter	Upper Range	Optimum Range
pH		5 –7 pH
EC – Plugs & Seedlings & Cuttings	0.75 mS *	<0.25 mS
EC – General production	1.25 mS	<0.25 mS
SAR (Sodium Absorption Ratio)	4	0 - 4
Alkalinity	200 mg/l **	<100 mg/l
Bicarbonate Equivalent	150 mg/l	30 – 50 mg/l
Calcium	120 mg/l	40 – 120 mg/l
Magnesium	25 mg/l	6 – 24 mg/l
Iron	5 mg/l	1 – 2 mg/l
Manganese	2 mg/l	0.2 - 0.7 mg/l
Boron	0.8 mg/l	0.2 - 0.5 mg/l
Zinc	2 mg/l	0.1 - 0.2 mg/l
Copper	0.2 mg/l	0.08 – 0.15 mg/l
Molybdenum	0.07 mg/l	0.02 – 0.05 mg/l
Fluoride	1 mg/l	< 0.3 mg/l
Sulfate	240 mg/l	24 – 240 mg/l
Chloride	140 mg/l	< 50 mg/l
Sodium	50 mg/l	< 30 mg/l

***mS = milliSeimens**

***mg/l = milligrams per liter = parts per million**

Many of the natural constituents of water are essential plant nutrients although they may not be in a form that can be utilized by plants. Other minerals that are not used by plants, such as sodium, will tend to accumulate in recirculating nutrient solutions and in planting media. This can contribute to high electrical conductivity (EC) problems, particularly if the planting media is not adequately leached. Growers who sell their potted crops every few weeks can sometimes get away with a lot more, because they 'export' many of the accumulating problems before they become critical. Closed loop substrate vegetable or cut flower growers may not be so lucky.

There are numerous methods for removing or reducing undesirable constituents in water supplies. The range of available treatment methods for each constituent is well beyond the scope of this document and many are not practical for horticulture production. As clean water supplies become scarcer, the water supply and treatment industry is booming. There are many reputable companies, and some not so reputable. If you have water quality problems, seek out an established water quality consultant (preferably someone who isn't selling anything) to examine your situation and suggest alternatives. We strongly recommend you work with someone who has a good understanding of irrigation water requirements.

Many 'problem' water sources can be mitigated by simply blending them with captured rainwater to dilute and reduce the concentration of the problem materials. Other problems may require specific treatments such as iron and manganese removal. Reverse osmosis is an expensive option that can be used to reduce all minerals to acceptable levels. It may be the only option in some situations.

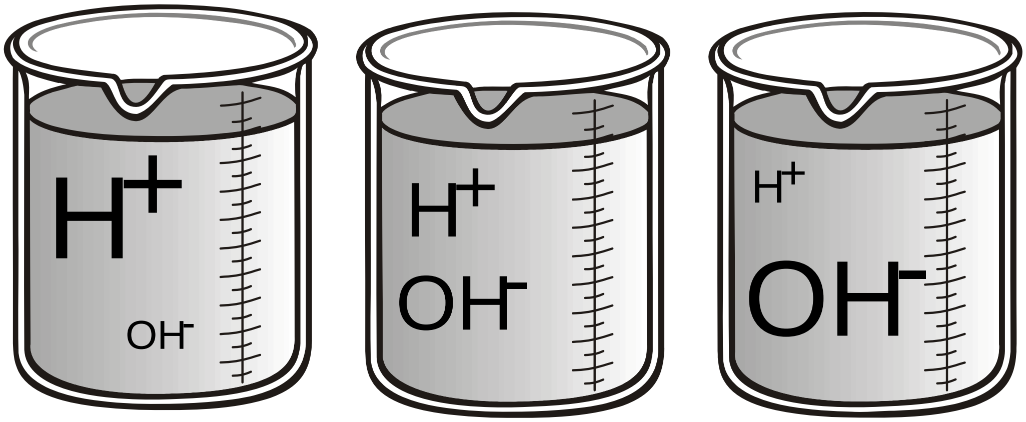
As a minimum, you must factor in the initial pH, alkalinity, and electrical conductivity of your supply water when setting up and operating an automated nutrient injection system. These topics are each discussed in this document.

Understanding pH Control

What is pH?

pH is a measure of the relative concentration of hydrogen ions (H^+) to hydroxide ions (OH^-). The greater the number of H^+ ions in relation to OH^- the more acidic the solution becomes. The greater the ratio of OH^- ions to H+, the more basic the solution becomes. PH is measured on a scale of 1-14. A reading below 7 means that there are more H^+ ions and a reading above 7 indicates more OH^- ions. At pH 7 there are the same number of H+ ions as OH- ions so the pH is **neutral**, neither acid nor base.

Figure 1 - Relative Balance of Hydrogen/Hydroxide Ions



Acids and Bases

Any substance that increases the concentration of hydrogen ions (lowers the pH) when added to water is called an **acid**. A substance that reduces the concentration of hydrogen ions (raises the pH) when added to water is called a **base** or an **alkali**. Some substances enable solutions to resist pH changes when an acid or base is added. These substances are called **buffers**. Buffers are very important in helping to maintain a relatively constant pH in a feeding solution and in the root zone after the water has been applied to the crop.

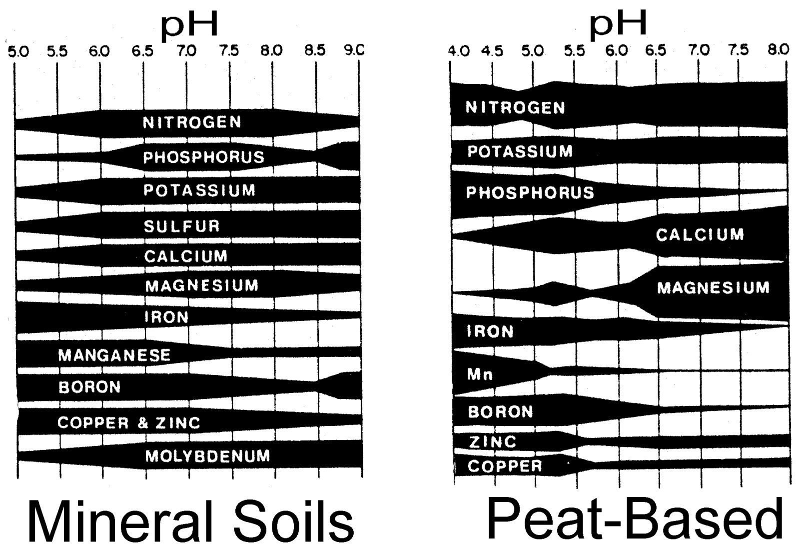
Most greenhouse water supplies have sufficient alkalinity that they require routine acid addition to correct the pH to the normal 5.8-6.2 feeding range. At this level, the irrigation water will tend to have a neutral effect on media pH, although this depends on the buffering capacity of the media. Some growers use very pure water from rain and surface sources. In theses situations, they may need to apply a combination of acid and base materials to stabilize and buffer the pH.

Why does pH Matter?

Improper management of media pH can result in poor growth and reduced plant quality in greenhouses and nurseries. The pH or soil reaction has a primary influence on the solubility and availability of plant nutrients. Many crops have a narrow range of pH tolerance. If the pH of the soil medium falls above or below this tolerance zone, they may not grow properly due to nutrient deficiency or toxicity.

For general greenhouse production, a pH of 6.2-6.8 is considered ideal for mineral soils, and 5.8-6.2 is recommended for peat or bark media. Of course, this depends upon the crops grown. Poinsettias are tolerant of variable pH, while seed geraniums are quite particular, and a pH of 5.7 or below can sometimes result in iron toxicity problems. The availability of most fertilizer elements is affected to some extent by the media pH. Calcium and magnesium become more available as the pH increases, while iron, manganese, and phosphorus become less available. A one unit pH drop can increase the solubility of manganese by as much as 100 times, and the solubility of iron by as much as 1000 times. The following illustration shows the relationship between pH and the relative availability for the major and minor elements for peat and soil based media.

Figure 2 - The Effect of pH on Nutrient Availability



Why adjust Irrigation pH?

By carefully modifying the pH and alkalinity of your irrigation and feed solutions, you can help maintain the desired plant growth and quality. There are other reasons to monitor and control pH in your irrigation water and nutrient solutions:

1. Solution pH affects the availability of nutrients
2. Correct pH will help ensure that dissolved fertilizer concentrates remain in solution when mixed in the water supply
3. Acid injection can be used to neutralize excess alkalinity in water supplies

Understanding The pH Scale

The pH scale measures the relative concentration of Hydrogen Ions (H+) and Hydroxyl ions (OH-) in a solution. Technically, the pH of a solution is defined as a negative logarithm of the hydrogen ion concentration. The ‘p’ is the mathematical symbol for a negative logarithm and the ‘H’ is the symbol for hydrogen. The pH scale measures this, and places a value on it ranging from 0 to 14. Since it is a log scale, each number on the scale is 10 times greater (or smaller) than the next. A lower pH number corresponds to a higher concentration of hydrogen ions (H+) relative to hydroxyl ions (OH-). A higher pH number corresponds to a relatively lower concentration of hydrogen ions. The table below shows the relative amounts of H+ ions to OH- ions at each number on the pH scale.

Table 2 - The pH Scale

		H+ Ion Concentration in Moles/Liter @25°C	OH- Ion Concentration in Moles/Liter @25°C	Relative H+ Concentration	Common Examples
More Acidic ↑	🟥	(10^{0}) 1	(10^{-14}) 0.00000000000001	10,000,000	Concentrated Acids: Nitric, Sulfuric,
	🟥	(10^{-1}) 0.1	(10^{-13}) 0.0000000000001	1,000,000	Stomach acid (hydrochloric acid)
	🟧	(10^{-2}) 0.01	(10^{-12}) 0.000000000001	100,000	Lemon Juice, Vinegar, Beer, Cola
	🟧	(10^{-3}) 0.001	(10^{-11}) 0.00000000001	10,000	Grapefruit & Orange Juice
	🟧	(10^{-4}) 0.0001	(10^{-10}) 0.0000000001	1,000	Tomato Juice, Acid rain
	🟨	(10^{-5}) 0.00001	(10^{-9}) 0.000000001	100	Black Coffee, Rain Water
	🟨	(10^{-6}) 0.000001	(10^{-8}) 0.00000001	10	Milk, Saliva, Urine
Neutral	🟨	(10^{-7}) 0.0000001	(10^{-7}) 0.0000001	1	Distilled Water, Human Blood
More Basic ↓	🟩	(10^{-8}) 0.00000001	(10^{-6}) 0.000001	1/10	Eggs, Sea Water
	🟩	(10^{-9}) 0.000000001	(10^{-5}) 0.00001	1/100	Baking Soda (Bicarbonate)
	🟩	(10^{-10}) 0.0000000001	(10^{-4}) 0.0001	1/1,000	Milk of Magnesia
	🟩	(10^{-11}) 0.00000000001	(10^{-3}) 0.001	1/10,000	Ammonia Solution
	🟩	(10^{-12}) 0.000000000001	(10^{-2}) 0.01	1/100,000	Soapy water
	🟩	(10^{-13}) 0.0000000000001	(10^{-1}) 0.1	1/1,000,000	Bleach, Oven Cleaner
	🟩	(10^{-14}) 0.00000000000001	(10^{0}) 1	1/10,000,000	Liquid drain cleaner, Caustic Soda

Understanding Alkalinity and Buffering Capacity

The effects of both pH and alkalinity are important to the nutrition and root health of your crops. Understanding these principles will help take some of the guesswork out of managing media and solution pH.

In horticulture, we have traditionally used a pH reading to make amendments to our growing media and irrigation water. However, pH alone is not the best indicator of the *effect* that a given irrigation source will have on the media pH. For that, you must also know the **buffering capacity** or **alkalinity** of the media and the irrigation source. Alkalinity levels indicate the relative ability of the media to resist or neutralize the effects of acids. Alkalinity acts as a buffer to acidic materials. **The higher the alkalinity, the greater the amounts of acid that will be required to produce a desired pH drop.**

To clear up some possible confusion, when we use the term ‘alkalinity’ we do not mean ‘alkaline’, which is the opposite of acidic. We mean the relative ability of a given water source to *resist* changes in pH due to the addition of acids.

pH and alkalinity are related but separate measurements. pH measures the hydrogen ion concentration and alkalinity indicates a solution's ability to neutralize acids. The alkalinity level determines how your irrigation water will influence the pH of the growing media. You would naturally expect that an irrigation water source with a relatively high pH would tend to raise the media pH over time. However, if the water has very low alkalinity, it may not have a significant effect on the media pH despite its high initial pH. By contrast, if we used irrigation water with a high alkalinity level, say 150-ppm bicarbonate, a greater effect on media pH can be expected.

Generally, the higher the alkalinity of the irrigation water, the faster the root media pH will rise. Irrigation sources from rainwater normally contain little or no bicarbonates or other dissolved minerals, so the alkalinity level is very low. Pure, distilled water has zero alkalinity. Water from wells can range from 50 ppm to more than 500 ppm due to dissolved minerals. Although some alkalinity is fine, higher levels can be toxic to some plants over time and will tend to increase media pH to undesirable levels. Some water sources have extremely high alkalinity and are not suited for irrigation purposes without treatment. In such cases, the water must be diluted with rainwater to bring the bicarbonate into the desired range, or the alkalinity must be reduced by adding acid concentrates.

Dissolved bicarbonates and carbonates are the major contributors to alkalinity in irrigation water. These include:

- Calcium bicarbonate (Ca (HCO3) 2)
- Sodium bicarbonate (NaHCO3)
- Magnesium bicarbonate (Mg (HCO3) 2)
- Calcium carbonate (CaCO3-).

Both limestone (calcium carbonate) and bicarbonates will raise pH by the production of carbonate. Over time, water sources with high alkalinity will tend to increase pH, while sources with low alkalinity may tend to decrease pH, depending on the media temperature, the rate of leaching and fertilization and the nature of the fertilizers used.

If insufficient bicarbonate is available naturally, the pH of irrigation water and nutrient solutions may be unstable. Materials such as potassium bicarbonate can be added to provide a modest background level (40-100 ppm) of bicarbonate that will help to buffer the nutrient solution. Acids are then added if required, to achieve the desired final solution pH. This results in nutrient solutions that are relatively pH stable with sufficient buffering capacity to stabilize the pH of the root media or slowly correct it over time if the media pH is low.

Alkalinity units may be expressed in different ways:

1. **Calcium Carbonate Equivalent ($CaCO_3$)** - this unit of measure for total alkalinity is generally reported as milligrams per liter (= parts per million) of total alkalinity as equivalent calcium carbonate (abbreviated mg/L as). Sometimes this unit is reported as meq/l (milliequivalents per liter). The conversion between these units is as follows:

   1 meq/l $CaCO_3$ = 50.04 mg/l = 50.04 ppm

2. **Bicarbonate Equivalent (HCO_3-)** - sometimes laboratories will report alkalinity as bicarbonate using ppm (mg/L) or meq/L. The conversion between these units is as follows:

   1 meq/l HCO3- = 61 mg/L = 61 ppm

3. To convert between calcium carbonate equivalent and bicarbonate equivalent:

   122 ppm HCO_3- = 100 ppm $CaCO_3$

The table below shows the effect of alkalinity on the relative amount of an unspecified acid needed to achieve a desired pH. Even though the first water source has a higher initial pH, it requires much less acid than the second source to adjust the pH to the desired level. This is because it has a much lower alkalinity level.

Table 3 – Example Acid Requirement

	Initial pH	Initial Alkalinity	Final pH	Acid Required/ 1000 Gallons
Water Source 1	9.5	70 meq/L	5.8	470 ml (16 0z)
Water Source 2	8.2	300 meq/L	5.8	1920 ml (65 oz)

Alkalinity Testing

When you have your water tested by a laboratory, they will normally test for alkalinity. Do-it-yourself alkalinity test kits are also available from scientific supply companies.

Measuring pH

There are several methods available for measuring pH, but the most useful and practical is an accurate pH meter. Follow the instructions included to preserve the accuracy and life of your instrument. These meters typically use a liquid filled glass probe, although some are now using flat sensor technology.

Your Argus Multi-Feed unit will also use one or more pH sensors. Refer to the documentation that accompanied your equipment for proper care and maintenance of these sensors.

Water and nutrient solution samples can be measured directly or preferably after a few hours of settling time. Dissolved CO_2 in water supplies can cause slightly lower readings until the sample has come to equilibrium with the air.

When testing media, freshly mixed samples of media should be watered and allowed to stand for 24 hours before a reading is taken to release some of the lime and fertilizers. The preferred method for testing media pH is to obtain several representative samples of a crop and to measure each separately. Multiple measurements will give greater accuracy in reading, and will show the degree of variability of pH across several locations. A saturated media extract or a 1:1 soil to distilled water ratio is fine for measuring media pH.

pH Sensor Life and Maintenance

pH sensors are extraordinarily accurate when you consider the phenomenal span over which they measure. Remember, the pH scale is logarithmic. However, due to their design, and the nature of their measurement principle, they are somewhat more delicate than and not as long-lived as many other sensors. They may also require regular cleaning and recalibration in some situations. Depending on the nature of the materials you are measuring and the ambient conditions, pH probes should last about one year with good handling, and sometimes longer.

Once a probe can no longer be calibrated, or the reading reaction time becomes slow or erratic, it should be replaced. Occasionally, local water conditions or special applications may shorten the useful life of the probe to a few months. Generally, we find that new probes often do not require recalibration for many months. When the probe starts to develop calibration errors, it’s usually time to replace it.

To check the calibration of your probe you need to test the readings between two buffer solutions (usually pH 4 and pH 7). If your probe reads correctly in each solution then it does not require recalibration. Procedures for checking the calibration and for recalibrating the probes in the Argus program are provided with your probes. The pH sensor setup screens in your Argus software contain settings for testing and recalibrating your pH sensors. You can use pH 4 and 7 buffer solutions to check the calibration accuracy of the pH probes after cleaning, and consider replacing them if the error is too large. However, we generally recommend against repeated recalibrations your pH sensors. If simple cleaning does not return the sensor to fast, accurate responsiveness it is likely time to replace it.

pH Reaction Time

A common problem when adjusting pH is the process reaction time. Typically, it can take several minutes or even hours after the addition of a pH amending substance for the pH to fully stabilize. This is because the added acid or base materials take time to react fully and come to equilibrium with the other constituents in the water. In addition, the source water may contain dissolved CO_2 that can lower the pH readings until it has come to equilibrium with ambient pressures. Therefore, if you measure the pH immediately after acid addition, you will see an effect, but it may not be the final effect. This may cause problems for automatic pH control, since the feedback sensors are located just after the point of injection so they are not necessarily accurate indicators of the full effects of the injections.

When adjusting the pH of nutrient solutions you need to monitor the downstream pH as well as the pH immediately after injection. To do this, you should collect some adjusted irrigation water at the delivery point (drippers etc.). Measure the pH immediately and then let it stand for an hour or two and take another reading. Compare these readings to the pH that is measured at the injection point. You should also collect some leachate from the root zone and measure its pH. This will give you a picture of the pH dynamics of your system. Depending on your findings, you may need to adjust your pH injection target at the injector or add additional pH buffering materials to your irrigation water before you can achieve the desired results for your crop. The table below illustrates some possible pH readings at various measurement points:

Table 4 - pH Sample Variation by Location

Sampling Point	Measured pH
Before acid injection	7.8
Post acid injection	6.0
Drippers	5.7
Drippers after 2 hours	6.1
Leachate	5.8

Some growers will collect these readings on a scheduled basis and build up a history for each crop and growing season. This information can be very useful when determining control set points in the future.

Factors Affecting pH

Understanding the relationship of alkalinity to pH makes it easier to change the media pH when needed. Regular pH testing of the root media is necessary to monitor the condition of the root media and to identify the need for amendment.

For any liquid feeding program, it is important to monitor the pH in the root zone as well as the pH of your irrigation water and nutrient solutions. Although the pH of your nutrient solution is important, it is the pH in the root zone that is critical for proper growth and development of your plants. Root zone pH is influenced by many factors. These variables can affect the final pH, the rate of pH change, and the amount of modifying action required. They include the effects of:

- Soil temperature
- Fertilizer materials (may raise, lower or buffer pH)
- Soil amendments such as gypsum, sulfur and lime
- Root volume & metabolic activity
- Soil microorganisms
- pH and alkalinity of the irrigation water
- Leaching fraction
- Buffering capacity of both the soil medium, and the irrigation source
- Media cation exchange capacity

It is always best to catch pH problems early, before drastic steps are needed. If it becomes necessary to raise or lower the pH in the media, it is wise to start conservatively to avoid overshooting the tolerance range in the other direction. Wild pH swings can be worse than the original problem!

Working with Acids and Bases

Safety Precautions when Handling Acids and Bases

Always consult the manufacturer's **Material Safety Data Sheet** (MSDS) for the particular acid or base you are using. These sheets provide details of the specific health and safety hazards of the chemicals and the steps you must take to handle them safety. They also provide first aid information and what to do in the case of a spill or other accident.

Make sure that everyone who handles these materials is familiar with the hazards and safe handling procedures.

When handling acids or bases, you need to suit up for business. You'll need approved gloves, and boots, a face shield, an approved respirator, and a full-length acid-proof apron. You should have an eye wash station and emergency shower handy. Check with your local worker's safety office for a complete list of the safety items and procedures for handling strong acids or bases. This applies whether you pre-dilute the materials or not. As long as you have them on the premises, there are likely to be local regulations governing their handling and storage.

Always add the concentrate slowly to a larger volume of clean, cold water. **Never add water to strong acids or bases.**

Altering pH in the Root Zone

A sudden and drastic change in pH is usually undesirable. It can upset the balance of microorganisms living in the root zone, lead to nutrient deficiency or toxicity, ammonia release, and root death. To avoid the need for large pH changes you should regularly monitor the pH in the root zone and take corrective actions early. If large changes are required, it is often best to make them gradually over several days or weeks.

Aside from direct manipulation of the pH and alkalinity of the nutrient solution, other treatments and conditions will cause the pH to be raised or lowered in the root zone. They will often retard or accelerate the effects of adjustments to the nutrient solution. Again, it's critical to monitor the root zone pH when undertaking any pH corrective actions.

Methods for Raising pH

The following treatments will cause the pH of the root solution to rise over time. These techniques are provided as examples. You should check with your crop nutrition advisor before trying any of these methods.

- **Heavy leaching** tends to reduce salts and raise pH, provided the water pH is higher than the soil. This also will help to remove any pH-related toxic levels of minor elements such as manganese or iron.
- **Hydrated lime** has been used to raise pH in existing crops by dissolving 1 kg per 100 liters fresh water. After leaving the mixture overnight, the clear solution is drenched onto the crop. This method is not particularly practical for large scale applications and does not work very well with hard water sources.
- **Potassium bicarbonate** will raise the alkalinity of a nutrient solution. This will in turn help to raise media pH over time. 1-kg/100 liters will add about 600-ppm bicarbonate to water plus about 400-ppm potassium. However, it is best not to raise the pH too quickly due to

the possibility of ammonia release. Lower rates of bicarbonate (60-180 ppm or 1-3 kg/1000 liters) with each watering are effective at raising pH over time.

- **Potassium hydroxide (KOH)** or caustic potash is a highly caustic material that is sometimes used to adjust the pH upwards in nutrient solutions. Use the same precautions when handling strong base materials such as potassium hydroxide as you would for strong acids. Most growers prefer to use the milder potassium bicarbonate treatment when raising pH.

Methods of lowering pH

- **Acid** additions are the most common method of reducing pH. They work best if used as a regular component of the feed solution to prevent the media from becoming too alkaline.
- **Ammonium sulfate** will lower pH slowly but effectively due to the action of nitrifying bacteria. The crops treated should be ammonium tolerant, the solution pH should not be less than 6.2, and the temperature should be above 15°C.
- Fine-ground **elemental sulfur** at 5 g per 15 cm pot or 15 g per 2-3 gallon container has been recommended by some sources as a gradual way of bringing down pH. The action of soil bacteria is responsible for the change, usually in about 10-15 days.

Residues and Precipitates

One reason for maintaining specified pH levels in nutrient solutions is to avoid the formation of mineral deposits in irrigation lines since some dissolved chemicals will precipitate if the pH is too high or low. However, sometimes the materials used for pH correction can cause residues on plant leaves and greenhouse surfaces. Sulfuric and phosphoric acids tend to leave more deposits than nitric acid, but nitric acid is more hazardous to handle and can elevate EC levels at high injection rates.

Acids used for pH control

The three most common acids used for alkalinity correction and pH adjustment are phosphoric, sulfuric, and nitric. Of these, phosphoric is the least hazardous to use, however, all require special handling and safety precautions. As well as providing pH correction, each acid supplies an essential plant nutrient (phosphorus, sulfur, and nitrogen). You may need to consider this nutrient contribution in your feeding program.

You can sometimes save money by purchasing more concentrated acid formulations, but they are also much more hazardous to use and can be very hard on injection equipment. They will eat your concrete floors if spilled and require great care in handling and mixing. In particular, you must avoid introducing water or organic materials into highly concentrated acids because a violent explosion could occur. You need special containers, piping, fittings, and injection equipment materials for these acids. In particular, avoid nitric acid formulations above 85% (also called fuming nitric acid) as it will produce noxious fumes in the open air.

When selecting acids, try to specify food grade or technical grade. This will avoid undesirable impurities such as lead, arsenic, selenium etc. that may be present in some industrial formulations. Phosphoric acid (food or hydroponic grade) is the most benign acid to use in commercial quantities, and you can often use it to supply all or part of your phosphorus requirements as well as for pH correction. The following table describes the properties of some acids commonly used for pH control in nutrient systems.

Table 5 - Properties of Acids

	Phosphoric Acid	Sulfuric Acid	Nitric Acid
Chemical Formula	H_3PO_4*	H_2SO_4	HNO_3
Atomic Weight (at 100%)	98	98	63
Typical Strength	75%	93%**	62%
Specific Gravity	1.685	1.835	1.381
Neutralizing Power [-1]	45	136.0	52.13
Plant Nutrients [-2]	24% P	30% S	14 % N
Amount needed to remove 1 ppm alkalinity from 100 US gallons	.70 ml	.23 ml	.56 ml
Notes	*H_3PO_4 does not fully dissociate, so only about 1/3 of the P may be available	**Battery acid (approx. 33-35% S) is also used	

[-1] This is the amount of alkalinity (mg/liter $CaCO_3$) neutralized when 1 fl. oz. of acid is added per 100 gallons of water.

[-2] These values are calculated from the molecular weight of each acid in its pure form. For example:

100 % H_3PO_4 = 3 H * 1.00794: 3.02382 (3.0857% of mass)
1 P * 30.97376: 30.97376 (31.6074% of mass)
4 O * 15.9994: 63.9976 (65.3069% of mass)
Total: 97.9952 g/mol

Taking the 'P' component from above and correcting for the 75% concentration of the commercially available acid: 31.6074% P * .75 = 23.7% P

Calculating How Much Acid You Need

We highly recommend you have a soil and water testing laboratory test your nutrient solution for acid requirement (AR value) before you design your pH control program. Let the lab know the acid concentrate material and strength that you intend to use, and your target pH range. If you prefer, you can do this test yourself, by carefully measuring the volume of acid concentrate required to lower you're a specified volume of irrigation water to the target pH level.

Here are the steps to follow:

1. **Safety first!** Make sure you use the necessary protective eyewear, gloves, and clothing before handling acids. Consult the material safety data sheet for each product. Use glass or chemical-safe measuring devices and containers. Avoid metals and organic materials such as wood. If you don't feel confident handling acids have a lab perform this test for you.
2. Using distilled water; make a **1% stock solution** of your acid concentrate. For example, half-fill a 1-liter measuring vessel with distilled water. Then carefully measure and add 10 ml of the concentrated acid. Stir the mixture well, top up the container to the 1-liter mark and give it a good final mixing. You now have a 1% stock solution of your acid. This diluted stock solution will make it easier to perform the test. If you use US, or Imperial, or any other type of measuring system, you simply need to add 1 part of the concentrated acid by volume to 99 parts distilled water to get a 1% solution. If you use tap water, the alkalinity of the tap water may slightly influence the test result.
3. Measure 10 liters of dilute (crop-feed strength) nutrient solution or irrigation water into a container. This is your **test solution**. You are going to measure how much of your **acid stock solution** it takes to correct the test solution to your target pH.
4. Using an accurate, calibrated, portable pH meter, measure the pH of the test solution and write it down.
5. Using a 10 ml pipette or other measuring device, carefully add 1.0 ml of your **1% acid stock solution** to the test solution and stir well.
6. Write down the amount you just added and stir the contents. Measure the pH and write the value down as well. Depending on the alkalinity of your test solution, the measured pH may have dropped drastically, just a little, or perhaps not at all. *(Note: If even this small first amount sent the pH below your target, then it's back to the drawing board. Try diluting your acid stock solution a further 100x and start over with a fresh batch of test solution.)* Use this as your guide for further acid additions. Each time you add another volume of acid, record the amount you add and record the resulting pH reading. You want to add just the right amount to achieve your desired pH. After you reach this point, make a note of it and continue adding acid volumes until you reach a pH level of about 4.
7. You should perform this test 3 times for accuracy. If your results agree fairly well from one test to another then you are likely doing a consistently good job. However, you might be making consistent errors as well!
8. With your test results in hand, you can now make a table of your results and calculate the acid concentration ratio that is needed. Let's assume you had the following results:
   Initial pH: **7.9** Target pH: **6.0**
   Acid stock solution strength: **1% solution of 75% H_3PO_4 (food grade phosphoric acid)**.
   Test solution volume: **10 Liters**
   Amount of acid stock solution added to achieve pH 6.0: **35 ml**
   a. Since the test solution was diluted by 100x from its original strength, the first thing we must do is divide our 35 ml by 100 to find out how much of the actual concentrated phosphoric acid (75%) we used:
      35 ÷ 100 = 0.35 ml acid concentrate per 10 liters or **.035ml/l**

b. That's a very small amount, so we'll multiply it by 1000 to get the rate per 1000 liters:

0.035 ml/l x 1000 l = **35 ml acid concentrate per 1000 liters**

c. Next we can calculate the injection ratio of acid to nutrient solution:
35 ml: 1000 Liters
= .035 liters: 1000 liters
= **1 liter: 28571 liters**

d. Therefore, the injection ratio is about 1: 29,000. We'll need 1 liter of 75% phosphoric acid for every 29,000 liters of dilute solution.

e. To find out how much phosphorus this supplies we need to look back at the properties table for acids. We're adding .035ml/l of 75% phosphoric acid. The specific gravity of 75% phosphoric acid is 1.6, so 0.035ml weighs 0.056 grams (0.035 x 1.6). 0.056 grams per liter is 56 parts per million (1 gram per liter = 1000 ppm). From the acid properties table, 75% phosphoric acid contains 24% P. Therefore, the amount of P delivered will be 56 x 0.24 or about 14 ppm. Since phosphoric acid does not fully dissociate in solution, the actual amount of phosphorus available in phosphate form may be somewhat less.

If you have some chemistry experience, you may be wondering why we didn't first prepare a "normal" molar solution before performing our test. Normality is defined as the number of equivalents of solute per liter of solution. In acid-base reactions, one equivalent of an acid is that amount of an acid that will furnish one mole of hydrogen ions, or that will react with one mole of hydroxide ions. Similarly, one equivalent of a base is that amount of a base that will furnish one mole of hydroxide ions or react with one mole of hydrogen ions.

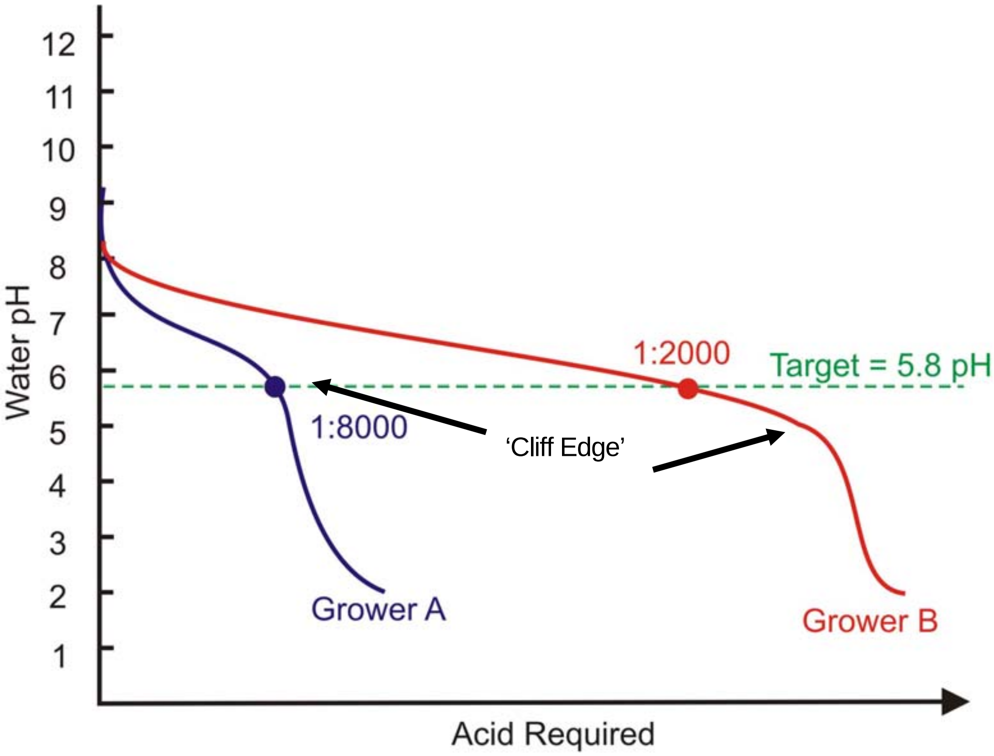
For our purposes, we're just trying to find out how much of the commercial acid concentrate it takes to adjust the pH of a given volume of nutrient solution. The simplest way to do this is to perform a straight-line dilution of the original concentrate as described above.

Acid Titration Curves

Below is an example of the measured titration curves for two water sources. The colored lines show the pH readings as progressively more acid is added. The water from Grower A (the blue line) starts at 9.3 pH, but since it has low alkalinity (70 mg/l), it takes a relatively small amount of acid, about 1 part battery acid per 8000 parts of water to achieve the target pH. Notice that the pH drops dramatically just after the target pH is reached. The target is on a cliff edge – a tiny of additional acid will produce a precipitous drop in the pH. The stronger the acid, the more difficult it will be to inject the precise amount required. One possibility for increasing dosing accuracy for this water is to pre-incorporate some potassium bicarbonate to increase its buffering capacity and move the target away from the "cliff edge".

Grower B's water starts at pH 8.3 but it has over 300 mg/l alkalinity. It takes 4 times more acid to correct it to the 5.8 pH target, about 1part battery acid to only 2000 parts of water. This water is relatively easy to control with dosing, since there is a larger margin of error before the pH drops sharply. *Note: these numbers are for comparison purposes only. The actual injection ratios will depend on the type and strength of the acid used.*

Figure 3 - Acid Titration Chart



Pre-dilution of Acid/Base Concentrates

⚠ Before you purchase your injection system, you should decide if you are going to pre-dilute your acid/base, since it can affect the sizing of the acid injectors

Acid and base concentrates are always hazardous. You must always treat them with extreme caution. There are several advantages (and some disadvantages) to pre-diluting your concentrates before injection.

Advantages of Pre-dilution

First, super-concentrated acid or base materials can be very hard on equipment and dangerous to handle. If water or organic materials are accidentally introduced into a concentrated acid container, an explosion could occur. Diluted acids are not nearly as prone to this problem.

Second, concentrated acids are thicker and heavier than water. They are more difficult to mix. Pre-dilution helps with mixing, since the specific gravity is reduced and the acid is less concentrated and viscous. The diagram below shows a problem that can occur when acid concentrates are added to a dilute tank that does not have sufficient agitation. The heavier acid concentrate falls to the bottom where it accumulates, and is picked up by the irrigation supply pipe instead of being mixed with the tank water. If your pH feedback sensor is located in the tank rather than the irrigation supply pipe, you would not even know that this was happening!

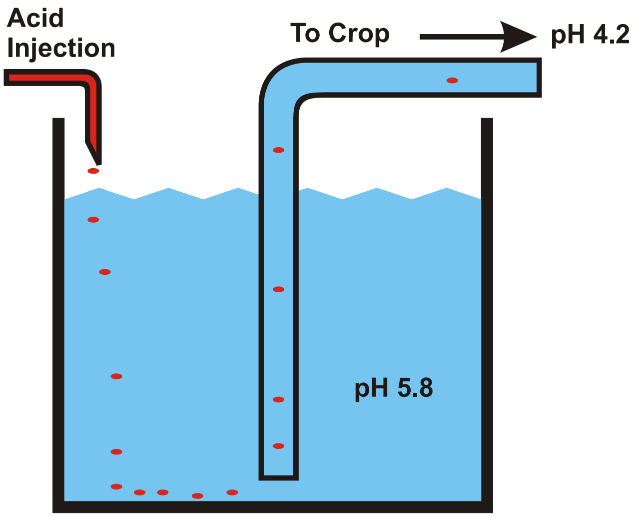


Figure 4 – The Effect of Poor Agitation

Note: The above situation is not a problem with Argus Multi-Feed systems, since the venturi injection system provides excellent mixing of all administered concentrates.

Pre-dilution can improve the *distribution* of acid along the moving water stream, since more pulses of dilute acid will be added for a given effect. These more frequent pulses will be spread more evenly down the irrigation line as compared to infrequent pulses of high strength acid. You can generally achieve smoother and better pH control by using more pulses of a relatively weaker acid stock solution instead of less pulses of a super concentrated acid.

Let's look at an example that requires an injection ratio of 1: 28,000 when a highly concentrated acid is used. This means that for every 1 part of concentrated acid that is injected, 28,000 parts of water must flow through the system. If the smallest pulse that can be delivered is 1 ml (and that is really small!), then 28000 ml (or 28 liters) must pass through for every dosing pulse. To illustrate this point, if the concentrate were injected directly into a flowing 2-inch pipe then the acid pulses would be 42 feet apart in the water stream! This can lead to a 'striping' problem, where the correct amount of concentrate has been added, but it isn't thoroughly mixed with all the water in the irrigation line before delivery to the crop. It also makes it difficult to use any sort of feedback control sensor, because a downstream pH sensor will be intermittently flooded and starved with the acid concentrate.

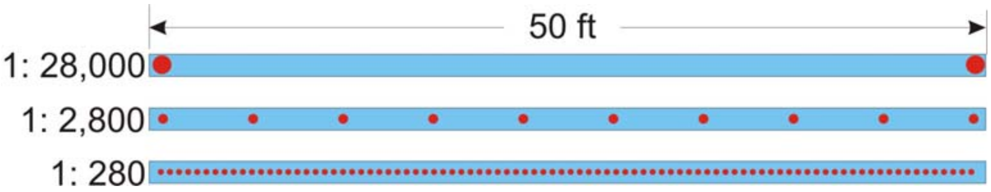


Figure 5 – The 'Striping' Effect

This diagram represents the number of 1-ml pulses needed to achieve the same pH drop in a flowing 2" pipe using various concentrations of directly injected phosphoric acid. At full strength, the acid concentrate can only be injected at a rate of 1 part acid to 28,000 parts water. If we first pre-dilute the concentrate by 10 times, adding 1 part of the full strength acid to nine parts water, the injection ratio required will be 1: 2,800. We'll need to inject 10 times more pulses into the same volume of water to achieve the same pH drop. If we further dilute the acid stock solution by another 10 times, the injection ratio will be 1: 280 and we will use 100 times more pulses to deliver the same pH drop. Often, pre-diluting acid concentrates by just 10 times is enough to solve mixing and striping problems.

Disadvantages of Pre-dilution

While pre-dilution of acid concentrates is usually advantageous for injection efficiency, mixing accuracy, and equipment life, it does involve some risks. Instead of drawing the acid directly from the shipping container, you need a suitable mixing tank to prepare a diluted acid stock solution. This tank must naturally be acid resistant and have a strong, firm-fitting lid to prevent anyone from accidentally falling in or being splashed. The empty concentrated acid containers should be suitable, but they may not be large enough to avoid frequent refilling.

Pre-diluting acid requires extra labor and must be done carefully to avoid injury. Keep in mind that **you must always add the acid to a larger volume of clean water, never add water to acid**. Also, if you splash acids on a concrete floor during mixing, even diluted acids, you won't have a floor for much longer.

Soluble Fertilizers used for Liquid Plant Feeding

The Essential Plant Nutrients

The following table lists the elements required for plant growth. When preparing liquid feeding formulas, you normally keep track of all of the water-soluble fertilizer elements, with the exception of chlorine and sulfur. These two elements are often in abundance, either naturally, or as co-constituents of other soluble fertilizers. However, sometimes you may also want to track these as well to avoid chloride or sulfate toxicity.

Table 6 - Typical Elemental Concentrations

Nutrients From Air and Water			
Carbon	C		
Hydrogen	H		
Oxygen	O		

Water Soluble Nutrients from Soils, Soil Amendments, and Fertilizers			
Element	Symbol	Ionic Uptake Forms	Typical Concentration in Liquid Feeds (ppm)
Nitrogen	N	NO_3^- NH_4^+	100 - 300
Phosphorus	P	$H_2PO_4^-$	30 - 80
Potassium	K	HPO_4^{2-}	100 - 300
Calcium	Ca	Ca^{2+}	100 - 200
Magnesium	Mg	Mg^{2+}	30 - 80
Sulfur	S	SO_4^{2-}	40 - 80
Iron	Fe		1 - 5
Manganese	Mn		.5 - 1
Chlorine	Cl		N/A
Boron	B		.3 - .7
Copper	Cu		.3 - .7
Zinc	Zn		.3 - .7
Molybdenum	Mo		.01 - .03

Law of Limiting Factors

Justus von Liebig is generally credited as the "father of the fertilizer industry". He formulated the law of the minimum:

If one crop nutrient is missing or deficient, plant growth will not be optimum, even if the other elements are abundant.

Liebig compared crop potential to the capacity of a barrel with staves of unequal length. The capacity (growth potential) is limited by the length of the shortest stave (in the illustration it is nitrogen). The Nitrogen stave must be lengthened to increase the barrel’s capacity. When that stave is lengthened, another one becomes the limiting factor.

The goal of a plant nutrition management program is to make sure that all of the essential plant nutrients are supplied in optimum quantities. Like all “laws”, this one is a bit simplistic, and there are other considerations, but it certainly applies as a general principle.

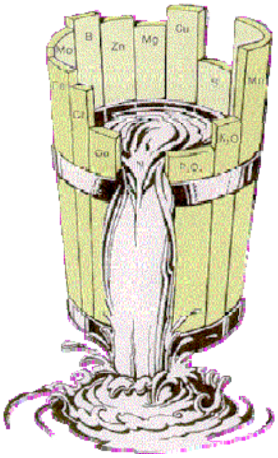


Figure 6 - Law of Limiting Factors

Fertilizer Antagonisms

For optimum growth, it is not enough to simply have an abundance of available nutrients. Plant nutrients also need to be made available in the correct ratios to one another. This is because certain elemental fertilizer ions compete with others for uptake. Most liquid feeding recipes try to achieve a balance between these competing elements.

Table 7 - Common Nutrient Antagonisms in Crops

Common Nutrient Antagonisms in Crops	
An Excess of:	May cause a deficiency of:
Nitrogen	Potassium
Potassium	Nitrogen, Calcium, Magnesium
Sodium	Potassium, Calcium, Magnesium
Calcium	Magnesium, Boron
Magnesium	Calcium
Iron	Manganese
Manganese	Iron

Composition of Soluble Fertilizers

The following table is a list of common fertilizers used to prepare liquid feeding solutions and their properties. Note: formulations may vary.

Table 8 - Composition of Soluble Fertilizers

Fertilizer	Chemical Composition	Percent Nutrients*	Molecular Weight	Max Solubility gm/l **
Nitric Acid (as 100%)	HNO_3	22 N	63	
Phosphoric Acid (as 100%)	H_3PO_4	32 P	98	
Sulfuric Acid (as 100%)	HSO_4	47 S	97	
Calcium Nitrate	$Ca(NO_3)_2 . 4H_2O$	15.5 N, 19 Ca	236	1020
Potassium Nitrate	KNO_3	13 N, 38 K	101	130
Ammonium Nitrate	NH_4NO_3	35 N	80	1340
Urea	$CO(NH_2)_2$	46 N	60	670
Magnesium Nitrate	$Mg(NO_3)_2 . 6H_2O$	11 N, 9 Mg	256	423
Monopotassium Phosphate	KH_2PO4	23 P, 28 K	136.1	330
Monoammonium Phosphate	$NH_4H_2PO_4$	26 P, 12 N	115	430
Potassium sulfate	K_2SO_4	42 K, 18 S	174	80
Magnesium sulfate	$MgSO_4 . 7H_2O$	10 Mg, 13 S	246	850
Potassium chloride	KCl	53 K	75	280
Potassium Bicarbonate	KHCO3	39 K	100	
Calcium Hydroxide	$Ca(OH)_2$	54 Ca	74	
Iron Chelate EDTA	Fe - EDTA	13 Fe		
Iron Chelate DTPA	Fe - DTPA	6 Fe		
Iron Chelate EDDHA	Fe - EDDHA	5 Fe		
Manganese Chelate	Mn -EDTA	13 Mn		
Manganese Sulfate	$MnSO_4 . H_2O$	28 Mn, 13 S	169	1050
Borax	$Na_2B_4O_7 . 10H_2O$	11 B	381	30
Solubor	$Na_2B_80_{13} \cdot 4H_2O$	20.5 B	413	
Copper Sulfate	$CuSO_4 . 5H_2O$	25.5 Cu, 13 S	245	320
Copper Chelate EDTA	Cu - EDTA	14 Cu		
Zinc Sulfate	$ZnSO_4 . 7H_2O$	23 Zn	288	700
Zinc Chelate	Zn - EDTA	14 Zn		
Sodium Molybdate	$Na_2MoO_4 . 2H_2O$	39 Mo	242	
Ammonium Molybdate	$(NH_4)_2Mo_2O_7$	56 Mo	340	
Calcium Chloride	CaCl	35 Ca	76	600
Ammonium sulfate	$(NH_4)_2SO_4$	21 N, 20 S	132	710
Diammonium phosphate	$(NH4)2\ HPO_4$	21 N, 23 P	115	250
Potassium Hydroxide	KOH			

* Assumes 100% purity   ** Maximum solubility in cold water. The presence of other dissolved salts can reduce solubility

Electrical Conductivity of Fertilizer Solutions

Soluble Salts

Root-absorbed nutrients that are used by plants are the ions of specific salts that are dissolved in water. This is true whether the source material is organic or inorganic in nature. Plant root cells are able to collect and accumulate many of these essential ions from the surrounding soil water using special chemical receptors. In a few instances, ions such as calcium and boron are carried directly in with the flow of water into the root.

Fertilizer salts dissociate into positively charged **cations** and negatively charged **anions** when they are dissolved in water. It is the concentration of these ions that affects the **electrical conductivity** of the water. This conductivity can then be measured as a rough indicator of the presence of dissolved fertilizer ions. The illustration below shows what happens when Potassium Chloride (KCl) is dissolved in water.

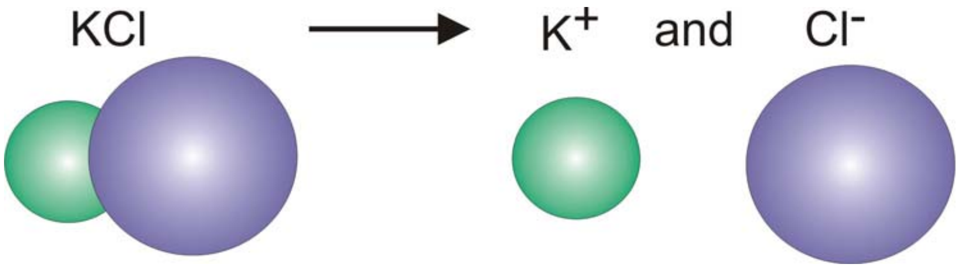


Figure 7 - Dissociation

In addition to affecting the electrical conductivity of the water solution, dissolved ion content also affects the ability of plant roots to take up water. Under normal circumstances, there is a higher concentration of salts on the inside of plant root cells than in the surrounding root solution. This enables water uptake by means of **osmosis** as water moves through the selectively permeable root cell membranes from the area with a lower salt concentration to a higher concentration. As the conductivity of the solution surrounding the roots increases, it becomes more difficult for plants to absorb water. Therefore, high conductivity (soluble salts) levels can lead to water stress and wilting, poor nutrient uptake, and a number of other growth problems.

Understanding Osmosis

When a semi-permeable membrane separates solutions of different salinity, osmosis will cause water to pass through the membrane in the direction of the more concentrated solution. Osmosis is essentially a type of diffusion with a semi-permeable membrane in the way. If you drop a salt tablet into a beaker of water, the tablet will dissolve and salt ions (sodium and chloride) will eventually diffuse fairly evenly throughout the solution. If you first divide the water into two halves using a semi-permeable membrane (through which water can pass but salt can't), and then drop a salt tablet into one side, an interesting effect will occur. The salt will dissolve as before, making one side saltier than the other. However, since the salt can't move through the membrane, only one side will become salty. The water on both sides is free to move through the membrane, but as the salt dissolves, the water on the non-salty side will begin to move through the membrane to the saltier side in an effort to achieve equilibrium saltiness. You'll soon end up with more water on one side of the membrane than the other.

This is how most plant roots absorb water. To accomplish this, the cell contents must contain a higher concentration of dissolved solutes, comprised mainly of dissolved sugars, than the water that surrounds the roots. Whenever the salinity in the solution surrounding the roots is too high, plant roots cannot absorb the water they need for proper support and growth. This is why most crops cannot grow in salt water

Understanding Reverse Osmosis

The process of reverse osmosis requires pressure to force the concentrated fluid through a semi permeable membrane that filters out the large molecules but allows water molecules to pass. Commercial systems usually employ some sort of cross-flow mechanism on the concentrated side to flush and purge the ions from the membrane and prevent the concentrations from accumulating to the point of clogging the membrane. Therefore, reverse osmosis systems usually need to flush some of the supply water to dispose of the concentrated salts that remain on the supply side of the semi-permeable membrane.

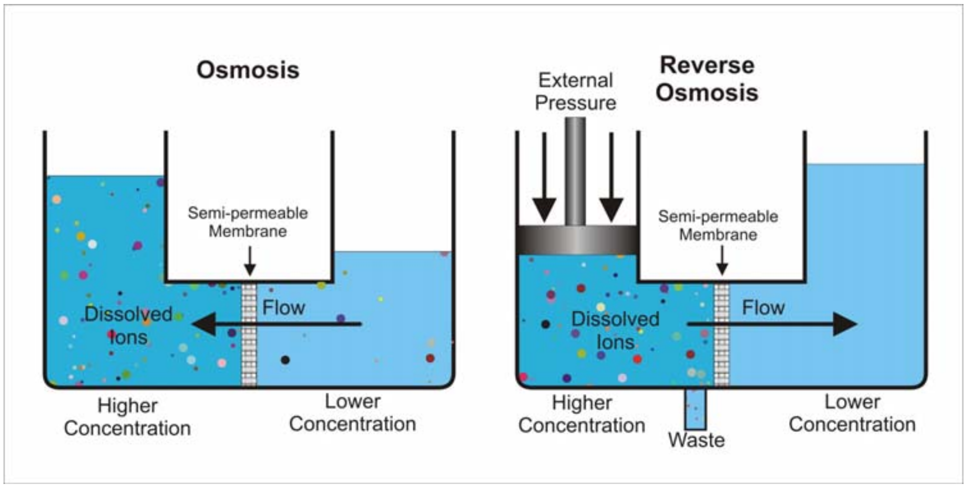


Figure 8 - Osmosis and Reverse Osmosis

What is Electrical Conductivity?

In horticulture, electrical conductivity or EC refers to the ability of a nutrient solution to conduct an electrical current between two electrodes. EC is the opposite of resistivity, the resistance of a solution to the flow of electrical current. The more dissolved fertilizer ions in a solution, the greater the conductivity. Pure distilled water contains essentially no dissolved mineral ions and has the lowest conductivity. Salt solutions such as soluble fertilizers and seawater, contain relatively higher amounts of dissolved salts, and therefore have a higher EC. Since the conductivity of a fertilizer solution increases with dissolved fertilizer content, EC measurement can be used as a means of indirect measurement of the concentration of fertilizer solutions.

Limitations of EC Measurement

We routinely use conductivity measurements to check the strength of fertilizer solutions, and the amount of dissolved salts in the root zone. However, it is important to understand that there are a number of limitations to this type of measurement.

1. First, we are not actually measuring the amount of nitrogen, phosphorus etc. - we are taking an indirect measurement of an effect that is caused when salts are dissolved in water.
2. Each fertilizer material has a different **Salt Index** (see the following section on measuring EC). This means that different mixtures of dissolved compounds will produce different EC readings.
3. **Not all dissolved salts are fertilizers.** An EC meter indicates the total dissolved salts whether they are fertilizers or not. For example, you could measure two solutions; one containing only dissolved table salt and the other containing a mixture of hydroponic fertilizers. With an EC meter, you could not tell which solution contained the fertilizer. Likewise, it is impossible to tell from an EC measurement alone, what proportion of the measured EC is attributable to fertilizer, and what proportion may be non-fertilizer salts. This is particularly important in closed recirculation nutrient systems where non-fertilizer salts will tend to accumulate over time, since they are not used by the plants.

So why do we use EC if it has all these limitations? Well, it’s mostly due to the lack of a better method. Ion-specific electrodes have been developed to measure the specific amounts of each fertilizer ion, but to date they are not practical to use in commercial situations. This is due to a combination of cost, sensor life, calibration issues, and interference problems that can occur when other ions are present in the measured solution.

In summary, **EC measurement is only useful when we are relatively certain of the chemical composition of the solution we are measuring**.

Units of Measure for Electrical Conductivity

The standard SI (international) unit of measure for electrical conductivity is the **Siemens (S).** Another commonly used unit of measure is the **mho** (ohm spelled backwards). Luckily, these units are equivalent:

1 Siemens = 1 mho

In horticulture, it is normal to measure ECs between about 0.5 – 3.0 mS (millisiemens) for dilute fertilizer solutions. Pure water supplies and very dilute concentrations of dissolved minerals are often measured in microSiemens µS.

The measurements are related as follows:

1 mho = 1 Siemens = 1,000 milliSiemens (mS) = 1,000,000 microSiemens (µS)

EC meters for horticulture should be capable of measuring between 100 µS and 10 mS.

Measuring EC

EC is normally measured by passing a small alternating (AC) current through a solution between two electrodes and measuring the resistivity. AC current is used to prevent ion migration (i.e. electroplating) to the two electrodes.

Since electrical conductivity measures the total solutes in a solution, it does not discriminate between dissolved plant foods and other minerals. Many non-fertilizer compounds are commonly present in water supplies and planting media. Several materials such as table salt (NaCl) and sodium bicarbonate can contribute to the total EC. Therefore, when measuring EC it's important to know what you are measuring. Only a complete lab analysis or separate ion-specific measurements can determine the elemental nature of the dissolved minerals that contribute to the EC of a particular solution.

At the concentrations that are important for horticulture, the relationship between EC and ion concentration is reasonably linear. Therefore, twice the concentration of a given ion will produce about twice the EC reading. For example, if the EC of 1 gram of calcium nitrate dissolved in 1 liter of distilled water is 1.15 mS per gram, then the EC of 2 grams per liter will be 2.30 mS, and so on.

Due to fertilizer impurities, difference in formulations and the presence of adsorbed (chemically bonded) and absorbed water, the EC values for a solution made from each chemical may vary from one source to another.

When determining the increase in EC produced by the fertilizer, you must subtract the initial EC reading of your water supply.

For reference, you can easily calibrate your own fertilizer source materials and the resulting recipes by making a test mixture at the desired concentration. For example, if the EC of your mixed fertilizer is 2.2 mS in its standard diluted state (1x), then it should read about 4.4 mS at 2 times the original strength, and 1.1 mS at ½ the recipe strength, assuming distilled water as the source.

Whenever you make stock concentrates, the EC of the concentrated fertilizer materials may be well beyond the measuring range of your EC meter. This is not a problem, since **you can easily check the strength of a concentrate solution by simply diluting it by the number of times it has been concentrated**. For example, to check the EC of a 200x concentrate, simply add a measured amount of the concentrate into a volume of water that when combined is 200x larger. In this case you could add 1 part of concentrate to 199 parts of water to make a 200x dilution).

If you use equal volumes from 2 concentrate tanks to make up your feed solution, you will need to dilute equal amounts from each tank into the dilute volume of water (for a 200 times dilution you would add 1 part 'A' concentrate plus 1 part 'B' concentrate to 198 parts of water). Once you have completed the dilution and thoroughly mixed the result, you can use your EC meter to measure the final result. Your stock solution is correctly mixed if the EC is close to your expected target.

Total Dissolved Solids and TDS Meters

Sometimes electrical EC values are translated into Total Dissolved Solids or TDS. TDS units are often used by the water quality industry. They are not often used for horticulture. TDS is acquired by taking the EC value and performing a calculation to estimate the TDS value. The actual TDS depends upon the chemical makeup of the dissolved salts. Unless the exact formulation is known, it is only an estimate of the nutrient concentration. There are at least three different conversion factors used in TDS meters to determine TDS and different manufacturers use different conversion factors. Therefore, you could test the same solution with different meters and get different TDS readings even though the same EC would be measured. For horticultural solutions, TDS meters that use a conversion factor of 700 (700 x EC in milliSiemens) tend to provide the best correlation.

Salt Index

Soluble minerals vary widely in their effect upon EC. Some, such as potassium chloride, produce a relatively large increase in EC, while others such as calcium nitrate produce a smaller effect. Each has a unique effect upon conductivity at a given temperature and concentration. For mixtures of materials, the resulting EC is reasonably additive at the concentrations used for horticulture. That is, if a quantity of a material that produces an EC of 2.0 mS is combined with another that produces an EC of 1.0 mS, the resulting solution EC will be about 3.0 mS. The following table shows the relative salt index of some common compounds used to make soluble fertilizer recipes. This index is an arbitrary value based on the solubility of Sodium Nitrate (100). Other materials are rated relative to this standard.

Table 9 - Salt Index of Fertilizers

Compound	Chemical Formula	Relative Salt Index Sodium Nitrate = 100
Ammonium nitrate	NH_4NO_3	105
Ammonium sulfate	$(NH_4)_2SO_4$	69
Calcium nitrate	$Ca(NO_3)_2$	65
Diammonium Phosphate	$NH_4H_2PO_4$	34
Magnesium sulfate	$MgSO_4.7H_2O$	44
Monoammonium Phosphate	$(NH_4)_2HPO_4$	30
Monopotassium Phosphate	KH_2PO_4	8
Potassium chloride	KCl	116
Potassium nitrate	KNO_3	74
Potassium Sulfate	K_2SO_4	46
Sodium nitrate	$NaNO_3$	100
Urea	$CO(NH_2)_2$	75

Fertilizer Compatibility

Most soluble fertilizers suitable for liquid feeding are compatible at their dilute concentration. However, certain chemicals will react at higher concentrations (usually greater than 20x the feed strength) to form insoluble precipitates. These precipitates can tie up the intended nutrients and clog your irrigation equipment. In general, calcium nitrate must not be concentrated with magnesium, phosphorus, or sulfur containing materials. This is the primary reason for using double or multi-head injection systems. Use the following table to keep separate incompatible fertilizer preparations at high concentrations from each other.

Table 10 - Fertilizer Antagonisms

	Urea	Ammonium nitrate	Ammonium sulfate	Calcium nitrate	Potassium Nitrate	Potassium chloride	Potassium sulfate	Monopotassium phosphate	Diammonium phosphate	Ammonium Phosphate	Magnesium Sulfate	Trace Sulfates	Trace Chelates	Phosphoric Acid	Nitric Acid
Urea															
Ammonium nitrate															
Ammonium sulfate															
Calcium nitrate			🟥												
Potassium nitrate															
Potassium chloride															
Potassium sulfate			🟨			🟨									
Monopotassium phosphate				🟥											
Diammonium phosphate				🟥											
Ammonium Phosphate				🟥											
Magnesium Sulfate				🟥			🟨			🟥					
Trace Element Sulfates				🟥			🟨			🟥					
Trace Element Chelates				🟨						🟨					
Phosphoric Acid				🟥								🟨	🟥		
Nitric Acid												🟥			
Sulfuric acid				🟥			🟨								

☐ Compatible 🟥 Not Compatible 🟨 Reduced Solubility

(Adapted from Soil and plant Laboratory inc., Bellevue, WA.)

The Jar Test

Aside from the known fertilizer compatibility problems listed in the table, unforeseen chemical reactions can sometimes occur even at dilute feed strengths due to pH, the presence of other minerals, organic impurities, as well as chlorine, bromine, or other water-borne pesticide treatments. Before mixing any new preparations in quantity, you should always perform a “Jar Test”. Make up a small quantity of the new formulation and pour some into a clear jar. Leave the jar overnight and observe the contents in the morning. If any precipitation has formed, or the mixture has become cloudy, it is likely that your ingredients are not compatible.

Measuring Fertilizer Concentration

Since it is generally far more convenient to work with parts per million (mg/l) when calculating fertilizer recipes and stock solutions than molar values or mill equivalents (meq), we use ppm in this document. You may sometimes encounter other units when discussing nutrient concentration, since there are several ways of expressing the concentration of dissolved materials in water solutions. They can sometimes be a source of confusion and consternation when it comes to understanding and using nutrient recipes. Briefly, here are the types of concentration units you may encounter.

Weight per Weight (Parts per Million)

This is the older method used for describing concentrations. It is still used in many parts of the US and Canada, but has been replaced by other methods in much of the rest of the world. It is not particularly accurate since it doesn't take into account the different sizes of the ions and molecules in various mixtures. However, it is easier to work with fertilizer recipes that use parts per million (or the weight per volume equivalent - mg/L) since we do not need to know anything about ions or atomic weights to calculate fertilizer formulations using these units.

Quick ppm Calculation

Here's a quick calculation you can perform once you know the elemental percentage of nutrients in a fertilizer. Multiply the elemental percentage number of the element by 10. For example, if the nitrogen analysis is listed as 20%, then the multiply 20 x 10. The answer (in this case 200) is the ppm N concentration at:

1 gram per liter

or 1 lb 100 Imp gal

or 1 lb per 120 US gal

Weight per Volume (Grams, Milligrams, or Micrograms per Liter)

This method is used to describe the mass of a given substance per volume of liquid. Since the specific gravity of most fertilizer solutions is very close to 1.00, this is the same as weight per weight for all practical purposes.

gm/l = grams per liter (1 gm/l = 1000 ppm)
mg/l = milliliters per liter (1 mg/l = 1 ppm)
µg/l = micrograms per liter (1 µg/l = .001 ppm)

Note than mg/l is equivalent to parts per million.

Equivalent Weight Units (meq/l - milliequivalents per liter)

This is a unit of measurement favored by chemists. It recognizes that different ions have different weights and charges. This method is sometimes used in nutrient recipes, but more often in water quality testing. The relationship between meq/l and ppm is not straightforward since the atomic weight and the valence of the substance must be taken into account when calculating meq/l. For example, to convert 3 meq/l of bicarbonate (HCO_3-) to parts per million, you need to know that the atomic weight of bicarbonate is 61 and that the valence is 1. Therefore 61/1 x 3 meq/l = 183 ppm bicarbonate. In any given solution, the total meq/l of anions should equal the total meq/l of cations.

Moles and Millimoles

This method of expressing concentration is routinely used in horticulture in many European countries and is often used by agricultural chemists and researchers since it more accurately expresses what is going on in the solution from a molecular point of view. A mole is a specific number: 6.023×10^{23}. Each element on the periodic table has a unique atomic weight. That number corresponds to the weight of one mole (6.023×10^{23} atoms) of that element. For example, the atomic weight of elemental nitrogen is 14. Therefore, one mole of nitrogen (6.023×10^{23} atoms) weighs 14 grams. The atomic weight of oxygen is 16; so one mole of oxygen weighs 16 grams, and so on. Chemists use this method because an equal number of moles of any substance will contain the same number of molecules. This makes it is possible to calculate the amounts of substances that will react chemically with one another.

At horticultural concentrations, most of the elements we feed are expressed in millimoles (1 mmol = 1/1000th of a mole) or micromoles (1 µmol = 1/1000000th of a mole). Parts per million (mg/l) divided by the ionic weight of the nutrient equals millimoles per liter. For micromoles (µmol/l) divide by 1000.

For example, to find the weight of one millimole of potassium nitrate:

The chemical formula for potassium nitrate is KNO_3. Therefore, add up the molecular weights:

$$\begin{array}{rl} \text{(K)} & 39 \times 1 \\ + \text{(N)} & 14 \times 1 \\ + \text{(O)} & \underline{16 \times 3} \\ & 101 \end{array}$$

One mole (6.023×10^{23} atoms) of KNO_3 weighs 101 grams. One millimole is 1/1000 of a mole; so one millimole of KNO_3 weighs 0.101 grams or 101 mg. You can use the following table to convert between molar values and ppm (mg/l). Note that the some elements are shown in the ionic forms that they occur in when dissolved in solutions:

Table 11 - Moles to parts per million

Ion	Symbol	1mmol/l
Nitrate	NO_3 -N	14 ppm
Ammonium	NH_4 -N	14 ppm
Phosphorus	P	31 ppm
Potassium	K	39 ppm
Calcium	Ca	40 ppm
Magnesium	Mg	24 ppm
Sodium	Na	23 ppm
Chlorine	Cl	35.5 ppm
Sulfate	SO_4 -S	32 ppm
Bicarbonate	HCO_3	61 ppm

Ion	Symbol	1µmol/l
Iron	Fe	0.056 ppm
Manganese	Mn	0.055 ppm
Boron	B	0.011 ppm
Copper	Cu	0.064 ppm
Zinc	Zn	0.065 ppm
Molybdenum	Mo	0.096 ppm

Working With Feeding Formulas Based on Molar Values

You can convert recipes based on molar values into ppm values.

To get parts per million, multiply the millimoles of the material per liter x the atomic weight of the element of interest.

Example: if a fertilizer recipe calls for 3.5 mmol calcium per liter what is this in parts per million calcium?

Step 1: The atomic weight of Calcium is 40.

Step 2: 3.5 mmol x 40 = 140 ppm Ca

Step 3: Assuming you plan to use calcium nitrate as your calcium source, you can now calculate how much fertilizer to dissolve to achieve this concentration:

Calcium nitrate contains 19% Ca

$$\frac{(140\ \text{ppm} / 0.19\ \text{Ca}) \times 1\ \text{liter}}{1000}$$

= 0.74 gm/l calcium nitrate to get 140 ppm Ca

Step 4: Multiply this result by the number of liters of final dilute solution to calculate the total weight of fertilizer required.

Make Your Own or Purchase Premixed Fertilizers?

Premixed concentrates relieve you of the responsibility for calculating, weighing, and preparing fertilizer recipes from scratch. Today there are premixed ‘complete’ feeds available in nearly any chemical combination. Some manufacturers have even figured out how to mix normally incompatible materials such as calcium and magnesium into a single dry concentrate.

When you purchase ready-made preparations, you are paying for the high degree of quality control that goes into the making of these formulations, and the convenience of not having to mess with complex fertilizer recipes. However, the nutrient composition of premixed formulations can be limiting, and the cost can be very high.

Growers with very specific nutrient requirements or who require frequent changes to the chemical makeup of their feeds or want to save substantial amounts of money often prefer to mix their own formulations.

With either pre-mixed or custom prepared fertilizers, you can still change the overall concentration or EC of the feeds. This is essentially a management choice. You can obtain good results with either method as long as you understand the limitations and risks. For information on mixing your own formulations see **Preparing a Complete Fertilizer Solution** on page 42.

Fertilizer Source Selection

Designing fertilizer formulas is perhaps as much art and economics as straight science. There is no such thing as the perfect formula. Each formula will have its advantages and problems. Don’t loose sight of the main objective: plant growth and quality. Any choices you make that might ignore this objective (low fertilizer cost, for example) must be carefully considered to ensure you are not saving a dollar while loosing ten dollars in crop returns!

You may have a number of fertilizer salts to choose from while developing your feeding formula. Some materials can be used in limited quantities but may cause problems with growth, pH or residual salts if used in large amounts. Some materials are far more expensive than other alternatives.

Generally, you should start by calculating your formula for the most restrictive items first, and adjusting around these with the less restrictive sources. You may even need to accept some small changes in your final formula if you are having too much trouble reaching your targets without resorting to your least favored sources. For example, calcium nitrate is often the only practical choice for a calcium source so you must start with it and accept the resulting nitrate nitrogen that it also provides. A good fertilizer recipe often consists of a number of compromises. Here are a couple of guidelines:

a. Try to limit ammonium and urea sources to avoid soft growth and high pH buildup

b. Select chloride free or low chloride materials to reduce salt build up in your recirculating system

You may also need to alter the chemical composition of your recipes depending on the specific crops, planting media and growing temperatures.

Fertilizer Calculations

In this document we primarily use the metric system since it is far easier to calculate dilutions and volumes using a system based on a decimal system of measurement (base 10). You may choose to use US or Imperial measurement for your own calculations. As a check on your calculations we have also provided some fertilizer dilution tables for the commonly used fertilizer salts in **Appendix 2** of this document.

To calculate fertilizer dilutions you need to know four things:

1. **PPM (parts per million required**
   (For example, 200 ppm N)

   This is the dilute strength concentration of a particular element in the crop feed . When using blended or 'complete' fertilizers, you normally calculate the amount to dissolve based on the concentration of nitrogen (N) required. The other elements in the mix ‘go along for the ride’. You decide the chemical *composition* when you select a specific formulation of pre-mix fertilizer. This is why fertilizer suppliers offer you so many premix formulations.

2. **Elemental Content**

   The fertilizer label lists the elemental content of each fertilizer constituent as a percentage. The exceptions are for P and K. By convention, phosphorus is usually expressed as P_20_5 (phosphoric anhydride) and potassium is given as K_2O (potash). For nutrient recipes, these two numbers must first be converted to their true elemental content. Let’s look at the following commercial pre-mix soluble fertilizer:

20	–	20	–	20
(N)		(P_2O_5)		(K_2O)

   - P_20_5 divided by 2.291 = P (elemental phosphorus content)
   - K_20 divided by 1.205 = K (elemental potassium content)

     Therefore, the common fertilizer 20 - 20 - 20 is actually 20 - 9 -17 when expressed as elemental content.

3. **Liters Required**

   This is the quantity of *dilute strength* fertilizer solution that you plan to prepare. (If you plan to use a fertilizer concentrate injector you can work how much concentrated stock solution to prepare dividing the dilute solution volume by the dilution ratio of the injector system. Do this after you have calculated the total amount of fertilizers to be dissolved)

4. **The Concentration Factor**

   This number is how many times the stock solution is to be concentrated when compared to the dilute solution. For example, for a 200:1 stock solution the concentration factor is 200.

With the above information you can calculate the amount of fertilizer to be dissolved and the quantity of stock solution to prepare. We can do this in 2 steps:

STEP 1: Find the amount of Fertilizer needed:

$$\frac{(\text{ppm required} \ / \ \text{elemental content}) \times \text{liters of dilute solution required}}{1000}$$

= grams per liter required (dilute solution)

(If you are using a measurement system other than metric, grams per liter is also equivalent to lbs/100 Imp Gallons or lbs/120 US Gallons)

STEP 2: Calculate the stock solution volume:

$$\frac{\text{Liters of dilute solution required}}{\text{Concentration Factor}} = \text{Liters of Stock Concentrate to prepare}$$

Some Example Fertilizer Calculations

EXAMPLE 1

You would like to make up 500 liters of a 200-ppm nitrogen solution using a commercially available 20-20-20 soluble fertilizer mix. How much fertilizer do you need to use?

Using the above formula:

$$\frac{(\text{ppm required} \ / \ \text{elemental content}) \times \text{liters required}}{1000} = \text{Grams Required}$$

- ppm required = **200 N**
- Elemental Content = 20%N or **0.20**
  (always use the decimal value for percent i.e. 0.20 for 20%)
- Liters required = **500**

$$\frac{(200 \text{ ppm N} \ / \ .20 \text{ elemental content}) \times 500 \text{ liters required}}{1000} = 500 \text{ grams}$$

Therefore, the amount of 20-20-20 required to make 500 liters of a 200 ppm N solution is 500 grams. Since a stock concentration was not specified in the above example, we would dissolve the 500 grams into the full 500 liters.

EXAMPLE 2

You wish to make up 4000 liters (final solution) of calcium nitrate (15.5-0-0- 19Ca) at 140 ppm Ca concentration. You plan to inject this as a 200:1 concentrate.

Step 1

- ppm required = **140** Ca
- Elemental Content = 19% or **0.19**
- Liters required = **4000**

$$\frac{(140\ \text{ppm} / .19) \times 4000)}{1000} = 2950\ \text{grams required}$$

Therefore, the calcium nitrate required to produce 4000 liters of a 140 ppm Ca solution = **2950 grams**

Step 2

Liters of dilute solution required / concentration factor = liters of stock concentrate to prepare

Therefore, 4000 liters of dilute solution / 200 concentration factor = 20 liters of stock concentrate.

Here's one for bonus points! From, Example 2, how much nitrogen (in ppm) will the 2950 gm of calcium nitrate add to the water?

Answer:
One quick way to work this out is as a ratio of the parts per million of calcium that are provided. We divide the unknown value (the % nitrogen) by the known value (the % calcium). Then we multiply by the ppm of the known amount (140 ppm Ca):

- Unknown (%N) = 0.155 N
- Known (%Ca) = 0.19 Ca
- PPM of known amount = 140 Ca

(0.155 / 0.19) x 140 = 114 ppm (unknown % / known %) x PPM known

Therefore, 114 ppm N is supplied as well as 140 ppm Ca.

EXAMPLE 3

You plan to use diammonium phosphate (21-53-0) to supply 30 ppm of phosphorus to a bedding plant feed. Your tank holds 1000 liters.

- ppm required = **30 P**
- Elemental Content = First convert the 53% P205 to elemental P (53% / 2.291 = 23.1% P or **.231**)
- Liters required = **1000**

$$\frac{(30\ \text{ppm} / 0.231) \times 1000\ \text{liters}}{1000}$$

The diammonium phosphate required to produce 1000 liters of 30 ppm P solution = 130 grams

Preparing a Complete Fertilizer Solution

We have shown you how to work out the quantities of fertilizer required to produce different final solution strengths and we have shown you how to work out the strength of companion elements that are added coincidentally. Now let's apply these rules to produce a complete nutrient solution from individual fertilizer constituents.

The first thing you need is a recipe. Often these recipes describe the required element concentrations in PPM or molar values. It's up to you to choose your fertilizer sources and calculate the quantities of each required to add to your stock tanks. Here is an "all-purpose" recipe in parts per million that can be used for many crops.

Table 12 - A Standard Recipe

Recipe:	Standard Feed	
Element	**Target ppm**	**Tally**
Nitrogen	200	
Phosphorus	40	
Potassium	200	
Calcium	140	
Magnesium	35	
Sulfur	45	
Iron	2.0	
Manganese	1.0	
Boron	.5	
Copper	.5	
Zinc	.1	
Molybdenum	.01	

Here are some typical fertilizers from which you can build a complete feed:

Table 13 - A Fertilizer Materials List

Materials List		**Recipe:**	Standard Feed
		Dilute Volume:	1000 l
Fertilizer	**Chemical Formula**	**Analysis**	**Grams Required**
Ammonium nitrate	NH_4NO_3	34 - 0 - 0	
Calcium nitrate	$CaNO_3$	15.5 - 0 - 0 – 19 Ca	
Magnesium sulfate	$MgSO_4$	0 - 0 - 0 – 10 Mg – 13 S	
Potassium nitrate	KNO_3	13 - 0 - 44	
Potassium chloride	KCl	0 - 0 - 60	
Monopotassium phosphate	KH_2PO_4	0 - 53 - 34	
Iron chelate	Fe - EDTA	13% Fe	
Manganese chelate	Mn - EDTA	12% Mn	
Solubor	$Na_2B_80_{13} \cdot 4H_2O$	20.5% B	
Zinc chelate	Zn - EDTA	14.2% Zn	
Copper sulfate	$CuSO_4$	25% Cu	
Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$	46% Mo	

Using some or all of the above fertilizers, you need to determine how many grams of each material will be needed to supply the specified concentrations of each nutrient in a **1000 liter batch of dilute solution**.

Here's how: First, make a tally column on the recipe table beside the target parts per million for each element. We will use this tally column to track the results of each calculation we complete.

You must establish a specific order for calculating fertilizer quantities. We must do this because the companion elements in most of these fertilizer sources influence their respective elemental supply. We must account for these influences so we are not pushed 'over the top' by some of these companion elements. The best way to do it is to start with the fertilizer materials that provide more than one element, and finish up with the single element sources. Even so, you sometimes have to go back and re-adjust some of the calculations to keep the companion element influences under control.

1. Since there is only one source of calcium, we know we'll need to get all of our calcium from calcium nitrate. There are no other options, so let's start with calcium nitrate and solve for calcium first:

   $$\frac{(140 \textit{ ppm Ca required} / .19 \textit{ elemental constant}) \times 1000 \textit{ liters})}{1000} = \textbf{737 grams calcium nitrate}$$

   Next, since calcium nitrate also supplies nitrogen, we need to calculate the companion element contribution from this same quantity of calcium nitrate addition:

   (Unknown % / known %) x ppm known = ppm unknown

Answer: (0.155 N / 0.19) Ca x 140 ppm Ca = **114 ppm N**

You can now enter these amounts onto your tables:

Table 14 - Recipe Solved for Calcium

Recipe:	Standard Feed	
Element	**Target ppm**	**Tally**
Nitrogen	200	114
Phosphorus	40	
Potassium	200	
Calcium	140	140
Magnesium	35	
Sulfur	45	
Iron	2.0	
Manganese	1.0	
Boron	.5	
Copper	.5	
Zinc	.1	
Molybdenum	.01	

Table 15 - Materials List Solved for Calcium

Materials List		**Recipe:**	Standard Feed
		Dilute Volume:	1000 l
Fertilizer	**Chemical Formula**	**Analysis**	**Grams Required**
Ammonium nitrate	NH_4NO_3	34 - 0 - 0	
Calcium nitrate	$CaNO_3$	15.5 - 0 - 0 – 19 Ca	737 g
Magnesium sulfate	$MgSO_4$	0 - 0 - 0 – 10 Mg – 13 S	
Potassium nitrate	KNO_3	13 - 0 - 44	
Potassium chloride	KCl	0 - 0 - 60	
Monopotassium phosphate	KH_2PO_4	0 - 53 - 34	
Iron chelate	Fe - EDTA	13% Fe	
Manganese chelate	Mn - EDTA	12% Mn	
Solubor	$Na_2B_80_{13} \cdot 4H_2O$	20.5% B	
Zinc chelate	Zn - EDTA	14.2% Zn	
Copper sulfate	$CuSO_4$	25% Cu	
Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$	46% Mo	

1. Using the same calculations as above, we'll calculate the amount of magnesium sulfate (Epsom salts) required to supply 35 ppm of magnesium, and determine the ppm of the companion element (sulfur), supplied by this quantity of magnesium sulfate. List both ppms in your recipe tally column and record the number of grams of magnesium sulfate required on your fertilizer materials sheet as you did for the calcium nitrate.

2. Next, calculate the amount of monopotassium phosphate required to supply the 40-ppm phosphorus requirement. Remember to use the P_2O_5 conversion factor and be sure to include the ppm supplied by the companion element (potassium), using the conversion factor for K_20. You should now have satisfied the full requirements for calcium, phosphorus, and magnesium, and partial requirements for potassium and nitrogen *(don't worry if the sulfur is a little off the target mark. You probably don't need to worry about sulfur unless it is much higher or lower than your recipe specifies. If in doubt, discuss this with your crop consultant).* If your calculations have been correct so far, your tables should now look like this:

Table 16 - Recipe Tally

Recipe:	Standard Feed	
Element	**Target ppm**	**Tally**
Nitrogen	200	114
Phosphorus	40	40
Potassium	200	49
Calcium	140	140
Magnesium	35	35
Sulfur	45	46
Iron	2.0	
Manganese	1.0	
Boron	.5	
Copper	.5	
Zinc	.1	
Molybdenum	.01	

Table 17 - Partial Materials list

Materials List		**Recipe:**	Standard Feed
		Dilute Volume:	1000 l
Fertilizer	**Chemical Formula**	**Analysis**	**Grams Required**
Ammonium nitrate	NH_4NO_3	34 - 0 - 0	
Calcium nitrate	$CaNO_3$	15.5 - 0 - 0 – 19 Ca	737 g
Magnesium sulfate	$MgSO_4$	0 - 0 - 0 – 10 Mg – 13 S	350 g
Potassium nitrate	KNO_3	13 - 0 - 44	
Potassium chloride	KCl	0 - 0 - 60	
Monopotassium phosphate	KH_2PO_4	0 - 53 - 34	174 g
Iron chelate	Fe - EDTA	13% Fe	
Manganese chelate	Mn - EDTA	12% Mn	
Solubor	$Na_2B_80_{13} \cdot 4H_2O$	20.5% B	
Zinc chelate	Zn - EDTA	14.2% Zn	
Copper sulfate	$CuSO_4$	25% Cu	
Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$	46% Mo	

3 Now calculate the amount of potassium nitrate required to supply the balance of the potassium requirement. Subtract the ppm of potassium already supplied from the total required. Using this value, calculate the amount of potassium nitrate required and then calculate the companion element's contribution to the nitrogen total. If the addition of this companion nitrogen pushes you 'over the top' of the nitrogen target, you will need reduce the amount of potassium nitrate used until it just meets your nitrogen target. You then have to look for other sources of potassium that don't also contain nitrogen to complete the supply of potassium. Potassium chloride or potassium sulfate are two candidates. If, on the other hand, you reach your potassium target using potassium nitrate and the companion nitrogen has not pushed you over your nitrogen target, you can make this up with some ammonium nitrate.

Continue this process to calculate all fertilizer quantities required to deliver the major and secondary elements at the specified strengths. Since the trace elements supply only one element of significance, it's a simple matter of calculating the amounts of each to meet the targets. The tables on the next page show the completed recipe.

Here is the completed recipe tally:

Table 18 - Completed Recipe

Recipe:	Standard Feed	
Element	**Target ppm**	**Tally**
Nitrogen	200	114
Phosphorus	40	40
Potassium	200	49
Calcium	140	140
Magnesium	35	35
Sulfur	45	46
Iron	2.0	2.0
Manganese	1.0	1.0
Boron	.5	.5
Copper	.5	.5
Zinc	.1	.1
Molybdenum	.01	.01

Here is the completed materials list for the recipe. Notice that we did not require any potassium chloride to complete the recipe:

Table 19 - Completed Materials List

Fertilizer	Chemical Formula	Analysis	Grams Required
Ammonium nitrate	NH_4NO_3	34 - 0 - 0	103
Calcium nitrate	$CaNO_3$	15.5 - 0 - 0 – 19 Ca	737
Magnesium sulfate	$MgSO_4$	0 - 0 - 0 – 10 Mg – 13 S	350
Potassium nitrate	KNO_3	13 - 0 - 44	394
Potassium chloride	KCl	0 - 0 - 60	
Monopotassium phosphate	KH_2PO_4	0 - 53 - 34	174
Iron chelate	Fe - EDTA	13% Fe	15
Manganese chelate	Mn - EDTA	12% Mn	3.6
Solubor	$Na_2B_80_{13} \cdot 4H_2O$	20.5% B	2.4
Zinc chelate	Zn - EDTA	14.2% Zn	0.7
Copper sulfate	$CuSO_4$	25% Cu	2.0
Sodium molybdate	$Na_2MoO_4 \cdot 2H_2O$	46% Mo	0.02

It is good practice to look at your final feeding formula and compare it to other recipes you have used in the past. Major differences between formulas may indicate a calculation error that would otherwise go unnoticed with possibly drastic consequences. You can also use the fertilizer tables in **Appendix 2** as a check on your calculations.

Now that we know how to develop a recipe or formula for building our own dilute feed solutions, we can use this knowledge to develop special feeds to produce a specific crop response, save on fertilizer costs, minimize salt buildup in recirculating systems, or meet any other nutritional objective.

Spreadsheets and Automated Fertilizer Recipe Calculators

Now that we've shown you the hard way to calculate fertilizer formulas, you might be interested in some automated tools for doing this.

- If you own an **Argus Titan** control system, the nutrient control software has provisions for automatically calculating and saving recipes based on your elemental ppm targets and the declared contents in the stock concentrate tanks.
- A number of free (free means use at your own peril!) calculators have been developed to help with calculating fertilizer recipes from materials on hand. One of these is a simple MS Excel spreadsheet program called 'Fertical.xls' developed by David Flood in the early 1990's. You can obtain a copy of it from Argus, or from the British Columbia Ministry of Agriculture website: *http://www.agf.gov.bc.ca/ornamentals/factsheets.htm*
- Other on-line calculators can be found on the internet, although many of these are meant for home use (teaspoons/gallon) etc.
- In addition to free calculators there is a software program called 'Nutron 2000' available for sale from Suntec New Zealand Ltd. *(www.suntec.co.nz)*

Working with Concentration Ratios

To avoid confusion, it is generally best to work out the concentrations of fertilizers that are needed in the dilute feed solution and then calculate how much is required to make the concentrated stock solutions. You can use the examples from the **Fertilizer Calculations** section of this document and the **Fertilizer Dilution** tables in **Appendix 2** as a guide when preparing stock concentrates. For A/B style nutrient injection applications, it is best to use the same concentration factor for all stock tanks if you can, because your stock tanks will then draw down at the same rate (this provides a quick visual check of proper operation: all tanks should be at the same level) and all will require refilling at the same time, which is convenient for scheduling stock solution mixing.

To achieve the proper final dilution strength, here is how the concentrates are diluted:

Table 20 - Dilution Ratios

Single Head Concentrate:	for a 100x dilution	for a 150x dilution	for a 200x dilution
1 part concentrate	+ 99 parts water	+ 149 parts water	+ 199 parts water

Two Heads Concentrates:	for a 100x dilution	for a 150x dilution	for a 200x dilution
1 part ‘A’ + 1 part ‘B’	+ 98 parts water	+ 148 parts water	+ 198 parts water

Three Heads Concentrates:	for a 100x dilution	for a 150x dilution	for a 200x dilution
1 part ‘A’ + 1 part ‘B’ + 1 part ‘C’	+ 97 parts water	+ 147 parts water	+ 197 parts water

Note: the concentrates must not ‘meet’ until after they are injected into the water, or you run the risk of insoluble precipitates forming. These precipitates can plug up everything! Each concentrate is individually injected into the water through its own injector.

Nutrient Injection Basics

All soluble fertilizer materials used for liquid feeding should be 'greenhouse grade', technical grade or food grade. These grades will dissolve readily in water, and contain a minimum amount of impurities.

Regardless of whether you decide to use a commercial pre-mix formula or make your own, you need to mix the correct amounts of fertilizer into the irrigation water to produce the final dilution strength. How do you do this?

Batch Mixing

The simplest way to produce the final feed strength is to directly mix all the ingredients in a large holding tank. Accurate measurement of each ingredient (including water) will ensure great accuracy. With a moderate tank mixing, it is relatively easy to achieve excellent uniformity. This process is known as batch mixing and it is arguably the simplest, safest, and most accurate way to achieve the final dilution strength. The mixing process is completely decoupled from the distribution process, allowing dilute solution to be removed from the tank at practically any flow rate without affecting the concentration accuracy. As an added bonus, this volume of ready-made feed acts as a safety reserve in case you run out of chemicals or have problems with your primary water supply.

Unfortunately, this dilution system is also the most labor intensive and inflexible. It is usually very difficult, and often impossible to change the properties of premixed solution in a large tank. If you decide to change the concentration or the chemical composition of your feed, you must either wait until the current batch is used up, discard it, or if possible, perform rather complicated calculations to adjust its make up. Large tanks can also be expensive and they can take up a lot of real estate. You cannot water during the tank filling and mixing process, unless you use a second tank to separate the mixing process from the holding and delivery tank. This involves more space and cost.

We still recommend batch systems where very high mixing accuracy is required or where irrigation water volumes are low. Research projects often work with 'garbage pail' reservoirs and small submersible pumps to get the job done. In these applications, the limitations of batch systems are minimal.

Automatic dilution systems

Most fertilizer mixing systems use a progressive dilution strategy that allows you to manually mix relatively small tanks of high strength stock solutions that are then diluted with much larger volumes of water to produce the final dilution ratio. This strategy overcomes many of the limitations of the straight batch mixing process, but adds additional complexity and costs, while also introducing errors that result in less accurate control and increased risk of failure. In spite of these limitations and risks, the advantages far outweigh the disadvantages in most applications. Most growers use some form of progressive dilution with appropriate alarms and safeties to protect against catastrophic failures.

These dilution systems can be broken into several categories:

1. Open dilute tank systems with re-pressurization pumps
2. Pressurized systems that preserve supply line pressure
    a. Simple ratio-metric injectors driven by line pressure
    b. Waste water or pneumatic pressure operated systems driven by water flow meters
    c. Venturi based systems driven by line pressure or pumps

Dilute Blending Tank Control

With the advent of injection technologies and automation, it became possible to have a continuous process where a small open blending tank is continuously ‘topped up’ with water and concentrated stock solutions. Concentrated stock solutions are automatically proportioned into the tank in proportion to the added water volume and corrected to the EC and pH Targets. This design has proved to be a very safe method of nutrient injection that provides generally good accuracy and mixing. With good automatic controls it is possible to shrink the blending tank volume down to just a few minutes of nutrient supply volume. Although the nutrient addition and mixing process is not as fully decoupled from the delivery system (as compared to the batch method), relatively high turndown delivery rates are still possible since the irrigation system draws from the ready-mixed solution in the blending tank and the tank volume acts as a buffer against short term changes. All open dilute tank systems require a separate re-pressurizing pump to deliver the tank solution to the irrigation system. In installations where the raw water supply comes in at adequate pressure and flow, this pump would otherwise not be required. Pressurized in-line injection systems become the preferred solution in those instances

Pressurized In-line Injection

In-line injection systems preserve the pressure and flow characteristics of the water supply system, eliminating the need for a re-pressurizing pump. Most in-line systems also reduce the size or completely eliminate the blending tank (it is expensive to provide a pressurized water tank). Concentrated stock solutions are continuously added to the water as it passes through an injector system and mixing occurs in the downstream section of the irrigation supply pipe (or small mixing tank, if one is supplied). Injection volumes are based on flow rates, EC and pH set point targets with sensor feedback, or a combination of the two.

With in-line injection, it is possible to rapidly change both the dilute solution concentration *and* relative chemical composition. However, low buffer volumes and poor blending can result in greater errors and poor final product uniformity. These problems can become very large at high turndown rates.

The Problem of Turndown

All in-line or continuous mixing systems have turndown limitations, some more than others. To demonstrate: imagine you have a high-flow rate in-line system that runs at 2000 liters per minute when the irrigation zones are being watered. Now imagine you sometimes wish to hand water at 10 liters per minute using the same system. The flow rate turn down ratio is 2000/10 or **200x**. Your injector system needs to operate at both flow rates.

That’s not the end of the problem. What if you also require a system that is capable of supplying fertilizers from the same stock solutions over a range of 0.5 to 5.0 mS? That’s another 10x turndown. The combined flow and concentration turndown requirement is 10 x 200 or 2000 times! It is very difficult (and expensive) to engineer a system that can work well over such a wide turn down range.

The Argus Multi-Feed system has been designed to capitalize on the convenience of in-line injection while minimizing most of the problems. It uses a combination of feed forward (flow based) and Feedback (sensor based) technologies to provide even dosing over a wide turndown range.

‘Complete’ Feeds

Normally these single-bag mixtures contain most of the fertilizer materials needed for sustained growth. However they may be missing a few elements due to problems of incompatibility in dry and liquid concentrate form. For example, most formulations of 20-20-20, or 20-10-20 contain a balance of all the major and minor elements required *except* for magnesium and calcium. This may not be needed for potted crops that contain significant amounts of dolomitic limestone in the potting soil.

In the past few years, newer feeds have emerged that truly are complete. They contain significant amounts of all the fertilizer elements including calcium and magnesium. With these fertilizers, it is possible to use a single head injection system for some applications. pH adjustment may still be required.

‘A/B’ Mixes

Two separate concentrated stock solutions are required to produce a complete dilute feed solution. One tank, usually called the ‘A’ tank contains calcium nitrate, and sometimes other compatible materials such as half the total potassium nitrate requirement (this practice overcomes the low solubility of potassium nitrate by ‘sharing’ the solubility load between both stock tanks). The ‘B’ tank generally contains the rest of the concentrates required to make up the fertilizer formula. The Argus Multi-Feed injection system is specifically designed for A/B and other multi-head applications. Using the same target values that we calculated in Table 20 - Dilution Ratios on page 51, here are amounts of fertilizer required for an A/B style mix concentrated at 200:1 in the stock tanks:

Table 21 - Materials for the A and B Tanks

Tank A	
Fertilizer	**g/100 liters @200:1 concentration**
Calcium Nitrate	14737
Potassium Nitrate (1/2 of total)	3940
Iron Chelate 13%	301

Tank B	
Fertilizer	**g/100 liters @200:1 concentration**
Potassium Nitrate (1/2 of total)	3940
Magnesium Sulfate	7000
Monopotassium Phosphate	3472
Ammonium Nitrate	2059
Manganese Sulfate	71
Solubor	49
Zinc Chelate	14
Copper Sulfate	39
Ammonium Molybdate	.36

When equal amounts from the above tanks are diluted (each at 200 times) to the final feed strength, the resulting solution will have the following elemental concentrations:

Table 22 - Concentration of the Dilute Feed

Element	ppm
Nitrogen	200
Phosphorus	40
Potassium	200
Calcium	140
Magnesium	35
Sulfur	45
Iron	2.0
Manganese	1.0
Boron	.5
Copper	.5
Zinc	.1
Molybdenum	.01

‘Single Element’ Dosing

Single element dosing is the ‘holy grail’ of the fertilizer injection world. This is more properly called single salt dosing, because as we have seen, many fertilizer salts contain more than one element which makes it much more complicated to control the relative amounts of each element in a fertilizer blend. With single element dosing, the goal is to have individual control over the concentration of each of the major fertilizer salts. Individual control opens up the possibility of the injection system dynamically producing almost any feed composition or concentration, *without any changes to the stock solutions*. One injection system, and a suitable number and selection of stock concentrates can now produce almost any feed.

Single element dosing requires a larger number of stock tanks with an individual proportioning injector control for each stock solution to achieve the desired recipes. Trace elements and occasionally some of the less important macro elements might still share one or two tanks for economic or management reasons. (It is expensive to build and manage injection systems with many individual injectors.) Since many fertilizer salts contain two essential elements, the permutations and combinations of stock solutions required to achieve a given recipe can become quite complex. In addition, because of the large number of dosing heads, and the uneven draw down of the individual stock tanks, it can be difficult to confirm that each fertilizer salt is being dosed in the correct proportions. Clogged suction lines, filters or other operating problems are more difficult to spot and correct. Better auditing (expensive sensors) of system operation and more frequent (expensive) lab analysis of the system output may be the only way to ensure accurate dosing. Like most things in life, you can’t have it all!

Argus has engineered some highly specialized nutrient control systems capable of single-salt dosing. These systems can be quite expensive, particularly when the system has built-in injector performance testing and automated troubleshooting. If you require this type of control, call Argus to discuss your specific application and needs. *In general, we recommend you select the simplest design consistent with your horticultural objectives.* You will save on capital and operating costs and you will have a more reliable system that is easier to operate. Unfortunately, you will also give up some control flexibility.

Stock Concentrate Tanks & Fittings

Materials Selection

Stock tanks and fittings must be made from corrosion resistant materials. Avoid using any metals except for stainless steel, Hastaloy-C or other metals ***specifically compatible*** with the chemicals you are using.

The table on the next page is adapted from information published by Cole Palmer and the Little Giant Pump Company. For long-term use, you should try to use only materials that are rated as excellent. Use this as a guide only. Some ratings of chemical behavior listed in this chart were evaluated at a 48-hr exposure period. Consider other factors such as impact resistance and UV light exposure when selecting and locating stock tanks and fittings.

Table 23 - Chemical Resistance of Selected Materials

Material	Ammonium Sulfate	Borax	Calcium Chloride	Calcium Hydroxide	Calcium Nitrate	Copper Sulfate 5%	Copper Sulfate >5%	Magnesium Sulfate	Potassium Hydroxide	Magnesium Nitrate	Manganese Sulfate	Nitric Acid 5-10%	Nitric Acid 50%	Nitric Acid >50%	Phosphoric Acid <40%	Phosphoric Acid >40%	Potassium Bicarbonate	Potassium Nitrate	Potassium Chloride	Potassium Sulfate	Sulfuric Acid 10%	Sulfuric Acid 10-75%	Sulfuric Acid 75-100%	Urea	Zinc Sulfate
304 stainless steel	B	A	C	B	C		B	A	B	B	B	A	A	A	D	D	B	A	B	B	D	D	C	B	B
316 stainless steel	B	A	B	B	B	B	B	B	A	B	B	A	A	A	C	D	B	A	A	A	B	D	D	B	A
ABS plastic	A	N/A	B	N/A	A	N/A	N/A	B	A	B	B	B	C	D	B	C	A	N/A	A	B	B	B	N/A	B	A
Acetal (Delrin®)	B	B	D	D	D	D	D	B	A	A	A	D	D	D	D	D	C	A	A	B	D	D	N/A	A	C
Aluminum	A	B	D	C	B	D	D	B	D	B	B	A	D	D	C	C	D	B	D	C	D	D	D	B	D
Brass	D	N/A	N/A	N/A	N/A	D	D	A	D	N/A	D	D	D	D	D	D	N/A	D	D	D	N/A	N/A	N/A	N/A	B
Bronze	D	B	A	D	B	B	D	A	D	A	A	A	A	A	B	B	B	D	B	A	B	B	B	B	B
Buna N (Nitrile)	A	B	A	A	A	A	A	A	B	A	A	D	D	D	D	D	A	A	A	A	A	B	C	B	A
Carbon graphite	A	A	A	A	A	A	A	A	C	N/A	A	A	D	D	A	B	A	A	A	A	A	A	C	A	A
Carbon Steel	D	A	N/A	D	B	D	D	B	D	C	B	D	D	D	D	D	B	D	D	B	D	D	D	B	D
Cast iron	D	A	C	A	B	D	D	A	B	D	A	D	D	D	D	D	A	B	A	A	C	D	D	N/A	D
Ceramic Al203	A	N/A	A	A	A	A	N/A	N/A	D	A	A	A	A	A	A	A	A	A	N/A	A	A	A	A	B	D
ChemRaz (FFKM)	A	A	A		A	A	A	N/A	C	N/A	A	N/A		B	N/A	A	A	A	A	A	A	A	A	N/A	A
Copper	D	B	B	N/A	N/A	B	N/A	A	B	B	B	D	D	D	D	D	B	D	B	B	D	D	D	N/A	B
CPVC	A	A	A	A	A	A	A	A	A	A	A	A	B	D	A	A	A	A	A	A	A	A	C	A	A
EPDM	A	A	A	A	A	A	A	A	A	A	A	A	D	D	B	B	A	A	A	A	A	B	B	A	A
Epoxy	A	A	A	A	A	A	A	A	A	A	N/A	A	D	D	A	B	A	A	A	A	A	A	C	N/A	A
Fluorocarbon (FKM)	D	A	A	A	A	A	A	A	B	A	A	A	A	A	D	A	A	A	A	A	A	A	A	A	A
Hastelloy-C®	B	B	A	A	B	A	A	B	B	A	A	A	A	B	A	A	B	B	A	B	B	B	B	B	A
Hypalon®	A	A	A	A	A	C	C	A	A	A	N/A	B	D	D	B	B	N/A	A	A	A	A	B	C	N/A	A
Hytrel®	B	A	A	B	N/A	A	A	N/A	D	N/A	N/A	C	D	D	N/A	N/A	N/A	B	B	B	A	N/A	C	N/A	N/A
Kalrez	A	A	A	A	A	A	A	A	A	N/A	A	A	A	A	N/A	A	A	A	A	A	A	A	A	N/A	A
Kel-F®	A	A	A	A	A	A	A	A	B	N/A	A	A	A	A	A	A	A	A	A	A	A	A	A	N/A	A
LDPE	A	A	B	A	A	A	A	A	A	A	A	B	B	C	A	B	A	A	A	A	A	A	B	A	A
Natural rubber	A	A	A	B	A	C	C	B	B	A	A	D	D	D	B	B	A	C	A	A	A	C	D	N/A	B
Neoprene	A	A	A	A	A	A	A	A	B	A	A	B	D	D	B	B	A	B	A	A	B	B	D	B	A
NORYL®	A	A	A	A	A	A	A	A	A	A	A	A	B	B	A	A	A	A	A	A	A	A	A	A	A
Nylon	A	A	A	A	A	D	D	A	C	A	A	D	D	D	B	B	A	A	A	A	C	D	D	A	A
Polycarbonate	A	N/A	N/A	D	A	A	A	A	D	A	A	A	B	C	A	A	N/A	N/A	A	A	A	B	D	D	A
Polypropylene	A	B	A	A	A	A	A	A	A	A	N/A	A	B	D	A	A	A	A	A	A	A	A	C	A	A
Polyurethane	A	B	A	D	D	N/A	N/A	D	D	B	A	D	D	D	D	D	D	D	A	A	D	D	D	B	B
PPS (Ryton®)	A	A	A	A	A	A	A	A	A	A	A	B	C	C	A	A	A	A	A	A	A	A	A	A	A
PTFE (Teflon®)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
PVC	A	A	C	B	A	A	A	A	B	A	C	A	B	B	B	B	A	A	A	A	A	A	D	D	A
PVDF (Kynar®)	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	B	B	A	A	A	A	A	A	A	A
Silicone	A	B	A	A	B	A	A	A	C	N/A	A	C	D	D	C	D	A	C	A	A	C	D	D	B	A
Titanium	A	B	A	A	B	A	A	A	D	A	A	A	A	A	C	C	A	A	A	A	D	D	D	A	A
Tygon®	A	N/A	N/A	B	A	N/A	N/A	B	B	N/A	A	D	D	D	D	D	A	A	A	A	B	N/A	D	B	A
Viton®	A	A	A	B	A	A	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

A Excellent B Good C Fair D Poor – Severe Effect

Calculating and Calibrating Stock Tank Volumes

Calibrate your mixing equipment and stock concentrate tanks carefully prior to use. The primary regulator of dilute solution composition and strength is the accuracy of the stock solution concentration. Feed back correction based on EC measurements can detect a general over or under strength condition, but it cannot detect or compensate for errors in individual stock solutions. We have seen many examples where growers have had serious errors in their concentrate mixing.

Some tanks come pre-calibrated with measurements cast into the tank wall, but even then it always pays to run a calibration test, since even small errors in volume will affect the accuracy of the final solution strength (2% volume error = 2% stock strength error = 2% final dilute feed error) If your tank has a *perfectly* cylindrical shape, you can calculate the volume by using one of the formulas provided below. You can also measure and graduate the tank by finding the volume per inch or centimeter along its height.

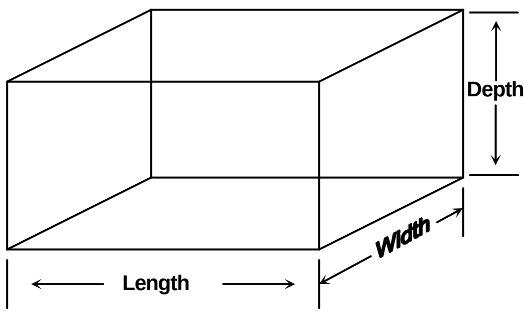
Calibration procedure: fill the tank in increments using a smaller measuring vessel of known volume. For example, if you use an accurate 5-gallon or 20-liter measuring bucket to fill a larger stock tank, you can count how many buckets it takes to fill the tank, and make permanent graduation marks on the side of tank or on a calibration stick after each bucket (or multiple of buckets) are added. You will then be able to accurately estimate the contents of the tank at any level. If you want good system accuracy, **perform this calibration test with considerable care**. **Use the same calibrating bucket and the same procedure to calibrate each of your stock tanks**. That way, if you do have errors in your calibration procedure, they will at least be applied consistently to all stock solutions.

If you are satisfied with lower accuracy, calculate the volume using one of the following formulas for finding the volume of tanks with regular shapes (see **Appendix 3** for volume conversion data). Height should always be to the final fill mark and you should use the inside measurements.

Calculating Volumes of Rectangular Shapes

(this shape is not recommended because the side walls are often not well supported and the tank walls may distort as the solution level changes)

To find the volume of a rectangular shape: **Multiply: Length x Depth x Width**



Example: Length = 200 cm
Depth = 200 cm
Height = 50

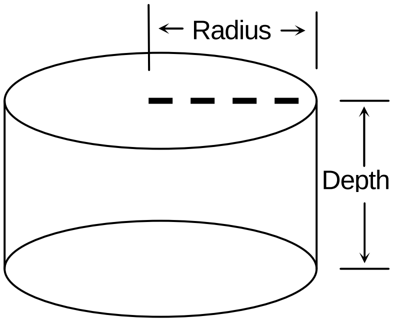
200 x 200 x 50 = 200,000 cm^3

To Convert to Liters:

200,000 cm^3/ 1000 cm^3/l = 200 liters

Cylindrical shapes (inside measurements):

To find the volume of a cylinder: π **x Radius^2 x Depth**



Example: Radius = 64 in
Depth = 36 in 463433
π (Pi) =3.1428

3.1428 x (64 x 64) x 36 = 463433 in^3

To convert to US gallons:
463433 in^3 / 231 in^3 /gal US
= 2006.2 gallons US

By varying the depth measurements on the above examples, you can find the volume at any given depth.

Other Shapes

The calculations for barrel, ellipsoid, trapezoid, and bell-ended tanks are somewhat more complex. For help calculating the volume of these shapes, there are several tank volume calculators published on the Internet that you can access with a web browser. Otherwise, use the bucket calibration technique.

Appendix 1 – Typical EC values in mS for Fertilizers

(Adapted from Grace Technical Bulletin: AHO48 3M/1/87/ CG)

ppm Nitrogen	**Ammonium Nitrate NH_4NO_3 (34% N)**	**Ammonium Sulfate NH_4SO_4 (21%N)**	**Sodium Nitrate $NaNO_3$ (16% N)**	**Potassium Nitrate KNO_3 (14%N)**	**Calcium Nitrate $CaNO_3$ (15.5% N)**
50	0.23	0.45	0.43	0.48	0.37
75	0.35	0.68	0.65	0.71	0.56
100	0.46	0.90	0.86	0.95	0.74
125	0.58	1.13	1.08	1.19	0.93
150	0.69	1.35	1.29	1.43	1.11
175	0.81	1.58	1.51	1.66	1.30
200	0.92	1.80	1.72	1.90	1.48
225	1.04	2.03	1.94	2.14	1.67
250	1.15	2.25	2.15	2.38	1.85
275	1.27	2.48	2.37	2.61	2.04
300	1.38	2.70	2.58	2.85	2.22
325	1.50	2.93	2.80	3.09	2.41
350	1.61	3.15	3.01	3.33	2.59
375	1.73	3.38	3.23	3.56	2.78
400	1.84	3.60	3.44	3.80	2.96
425	1.96	3.83	3.66	4.04	3.15
450	2.07	4.05	3.87	4.28	3.33
475	2.19	4.28	4.09	4.51	3.52
500	2.30	4.50	4.30	4.75	3.70
525	2.42	4.73	4.52	4.99	3.89
550	2.53	4.95	4.73	5.23	4.07
575	2.65	5.18	4.95	5.46	4.26
600	2.76	5.40	5.16	5.70	4.44
625	2.88	5.63	5.38	5.94	4.63
650	2.99	5.85	5.59	6.18	4.81
675	3.11	6.08	5.81	6.41	5.00
700	3.22	6.30	6.02	6.65	5.18
725	3.34	6.53	6.24	6.89	5.37
750	3.45	6.75	6.45	7.13	5.55
775	3.57	6.98	6.67	7.36	5.74
800	3.68	7.20	6.88	7.60	5.92
825	3.80	7.43	7.10	7.84	6.11
850	3.91	7.65	7.31	8.08	6.29
875	4.03	7.88	7.53	8.31	6.48
900	4.14	8.10	7.74	8.55	6.66
925	4.26	8.33	7.96	8.79	6.85
950	4.37	8.55	8.17	9.03	7.03
975	4.49	8.78	8.39	9.26	7.22
1000	4.60	9.00	8.60	9.50	7.40

ppm Mg	**Magnesium Sulfate $MgSO_4$ (10%Mg)**
50	0.38
75	0.56
100	0.75
125	0.94
150	1.13
175	1.31
200	1.50
225	1.69
250	1.88
275	2.06
300	2.25
325	2.44
350	2.63
375	2.81
400	3.00
425	3.19
450	3.38
475	3.56
500	3.75
525	3.94
550	4.13
575	4.31
600	4.50
625	4.69
650	4.88
675	5.06
700	5.25
725	5.44
750	5.63
775	5.81
800	6.00
825	6.19
850	6.38
875	6.56
900	6.75
925	6.94
950	7.13
975	7.31
1000	7.50

Appendix 2 – Fertilizer Dilution Tables

The following dilution tables can be used as a guide when preparing fertilizer recipes. Each table is for a different fertilizer material. The percentage elemental analysis is listed for each fertilizer element.

You can use these tables as a handy check on your own calculations. Keep in mind that the analysis of your own fertilizers may vary. Refer to the Fertilizer Calculations section of this document for methods of hand-calculating parts per million concentrations of fertilizer salts or strengths not listed in these tables. When using data from these tables to calculate your fertilizer quantities you must also keep a tally of any quantities of secondary or 'companion' elements that are supplied by some fertilizer materials. The quantities of these companion elements will affect the required quantities from other sources for these elements to complete your recipes.

To use the tables, locate the fertilizer material you wish to use and find the row that matches the desired ppm that you require in the dilute feeding solution. The columns to the right indicate the amount of dry fertilizer required per the indicated volumes to create stock solutions concentrates of 100x, 150x, and 200x concentration.

Metric Example

You wish to make 100 liters of a 200:1 concentration of calcium nitrate that will supply 140 PPM in the final dilute solution.

1. From the calcium nitrate table, locate the row that starts with 140 ppm.
2. Reading along the row, it takes 147 grams of calcium nitrate ***per liter*** of stock solution at 200:1 concentration.
3. You want to make 100 liters of stock solution, so 100 liters x 147 grams per liter = 14,700 grams or 14.7 kilos.

US Measure Example

You wish to make 100 US gallons of a 200:1 concentration of calcium nitrate that will supply 140 PPM in the final dilute solution.

1. From the calcium nitrate table, locate the row that starts with 140 ppm.
2. Reading along the row, it takes 147 lbs of calcium nitrate per 120 US gallons of stock solution at 200:1 concentration.
3. You only want to make 100 US gallons, so (100 / 120) x 147 lbs = 122.5 lbs required.

Imperial Measure Example

You wish to make 50 Imp gallons of a 200:1 concentration of calcium nitrate that will supply 140 PPM in the final dilute solution.

1. From the calcium nitrate table, locate the row that starts with 140 ppm.
2. Reading along the row, it takes 147 lbs of calcium nitrate per 100 imp gallons of stock solution at 200:1 concentration.

You only want to make 50 imperial gallons, so (50/100) x 147 = 73.5 lbs required.

Calcium Nitrate				
Calcium	**Nitrogen**			
19% Ca	**15.5% N**	**1:100**	**1:150**	**1:200**
ppm Ca in the diluted solution	**ppm N in the diluted solution**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
10	8	5.3	7.9	10.5
20	16	10.5	15.8	21.1
30	24	15.8	23.7	31.6
40	33	21.1	31.6	42.1
50	41	26.3	39.5	52.6
60	49	31.6	47.4	63.2
70	57	36.8	55.3	73.7
80	65	42.1	63.2	84.2
90	73	47.4	71.1	94.7
100	82	52.6	78.9	105.3
110	90	58	87	116
120	98	63	95	126
130	106	68	103	137
140	114	74	111	147
150	122	79	118	158
160	131	84	126	168
170	139	89	134	179
180	147	95	142	189
190	155	100	150	200
200	163	105	158	211
210	171	111	166	221
220	179	116	174	232
230	188	121	182	242
240	196	126	189	253
250	204	132	197	263
260	212	137	205	274
270	220	142	213	284
280	228	147	221	295
290	237	153	229	305
300	245	158	237	316

Magnesium Sulfate				
Magnesium	Sulfur			
10% Ca	13% S	1:100	1:150	1:200
ppm Mg in the diluted solution	ppm S in the diluted solution	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate
10	13	10.0	15.0	20.0
20	26	20.0	30.0	40.0
30	39	30.0	45.0	60.0
40	52	40.0	60.0	80.0
50	65	50.0	75.0	100.0
60	78	60.0	90.0	120.0
70	91	70.0	105.0	140.0
80	104	80.0	120.0	160.0
90	117	90.0	135.0	180.0
100	130	100.0	150.0	200.0
110	143	110	165	220
120	156	120	180	240
130	169	130	195	260
140	182	140	210	280
150	195	150	225	300
160	208	160	240	320
170	221	170	255	340
180	234	180	270	360
190	247	190	285	380
200	260	200	300	400
210	273	210	315	420
220	286	220	330	440
230	299	230	345	460
240	312	240	360	480
250	325	250	375	500
260	338	260	390	520
270	351	270	405	540
280	364	280	420	560
290	377	290	435	580
300	390	300	450	600

Potassium Nitrate				
Potassium	Nitrogen			
38.3 %K	13 %N	1:100	1:150	1:200
ppm K in the diluted solution	ppm N in the diluted solution	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate
10	3	2.6	3.9	5.2
20	7	5.2	7.8	10.4
30	10	7.8	11.7	15.7
40	14	10.4	15.7	20.9
50	17	13.1	19.6	26.1
60	20	15.7	23.5	31.3
70	24	18.3	27.4	36.6
80	27	20.9	31.3	41.8
90	31	23.5	35.2	47.0
100	34	26.1	39.2	52.2
110	37	29	43	57
120	41	31	47	63
130	44	34	51	68
140	48	37	55	73
150	51	39	59	78
160	54	42	63	84
170	58	44	67	89
180	61	47	70	94
190	64	50	74	99
200	68	52	78	104
210	71	55	82	110
220	75	57	86	115
230	78	60	90	120
240	81	63	94	125
250	85	65	98	131
260	88	68	102	136
270	92	70	106	141
280	95	73	110	146
290	98	76	114	151
300	102	78	117	157

Monopotassium Phosphate				
Phosphorus	**Potassium**			
23 %P	**28 %K**	**1:100**	**1:150**	**1:200**
ppm K in the diluted solution	**ppm P in the diluted solution**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
10	12	4.3	6.5	8.7
20	24	8.7	13.0	17.4
30	37	13.0	19.6	26.1
40	49	17.4	26.1	34.8
50	61	21.7	32.6	43.5
60	73	26.1	39.1	52.2
70	85	30.4	45.7	60.9
80	97	34.8	52.2	69.6
90	110	39.1	58.7	78.3
100	122	43.5	65.2	87.0
110	134	48	72	96
120	146	52	78	104
130	158	57	85	113
140	170	61	91	122
150	183	65	98	130
160	195	70	104	139
170	207	74	111	148
180	219	78	117	157
190	231	83	124	165
200	243	87	130	174
210	256	91	137	183
220	268	96	143	191
230	280	100	150	200
240	292	104	157	209
250	304	109	163	217
260	317	113	170	226
270	329	117	176	235
280	341	122	183	243
290	353	126	189	252
300	365	130	196	261

Potassium Chloride			
53% K	**1:100**	**1:150**	**1:200**
ppm K in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
10	1.9	2.8	3.8
20	3.8	5.7	7.5
30	5.7	8.5	11.3
40	7.5	11.3	15.1
50	9.4	14.2	18.9
60	11.3	17.0	22.6
70	13.2	19.8	26.4
80	15.1	22.6	30.2
90	17.0	25.5	34.0
100	18.9	28.3	37.7
110	21	31	42
120	23	34	45
130	25	37	49
140	26	40	53
150	28	42	57
160	30	45	60
170	32	48	64
180	34	51	68
190	36	54	72
200	38	57	75
210	40	59	79
220	42	62	83
230	43	65	87
240	45	68	91
250	47	71	94
260	49	74	98
270	51	76	102
280	53	79	106
290	55	82	109
300	57	85	113

Potassium Sulfate				
Potassium	**Sulfur**			
41.7% K	**18% S**	**1:100**	**1:150**	**1:200**
ppm K in the diluted solution	**ppm S in the diluted solution**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
10	4	2.4	3.6	4.8
20	9	4.8	7.2	9.6
30	13	7.2	10.8	14.4
40	17	9.6	14.4	19.2
50	22	12.0	18.0	24.0
60	26	14.4	21.6	28.8
70	30	16.8	25.2	33.6
80	35	19.2	28.8	38.4
90	39	21.6	32.4	43.2
100	43	24.0	36.0	48.0
110	47	26	40	53
120	52	29	43	58
130	56	31	47	62
140	60	34	50	67
150	65	36	54	72
160	69	38	58	77
170	73	41	61	*
180	78	43	65	*
190	82	46	68	*
200	86	48	72	*
210	91	50	76	*
220	95	53	79	*
230	99	55	*	*
240	104	58	*	*
250	108	60	*	*
260	112	62	*	*
270	117	65	*	*
280	121	67	*	*
290	125	70	*	*
300	129	72	*	*

* Solubility: 80gm / liter of cold water. The missing concentration values are beyond the cold water solubility for this material.

Diammonium Phosphate				
Phosphorus	**Nitrogen**			
23% P	**21% N**	**1:100**	**1:150**	**1:200**
ppm P in the diluted solution	**ppm N in the diluted solution**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
10	9	4.3	6.5	8.7
20	18	8.7	13.0	17.4
30	27	13.0	19.6	26.1
40	37	17.4	26.1	34.8
50	46	21.7	32.6	43.5
60	55	26.1	39.1	52.2
70	64	30.4	45.7	60.9
80	73	34.8	52.2	69.6
90	82	39.1	58.7	78.3
100	91	43.5	65.2	87.0
110	100	48	72	96
120	110	52	78	104
130	119	57	85	113
140	128	61	91	122
150	137	65	98	130
160	146	70	104	139
170	155	74	111	148
180	164	78	117	157
190	173	83	124	165
200	183	87	130	174
210	192	91	137	183
220	201	96	143	191
230	210	100	150	200
240	219	104	157	209
250	228	109	163	217
260	237	113	170	226
270	247	117	176	235
280	256	122	183	243
290	265	126	189	252
300	274	130	196	261

Monoammonium Phosphate				
Phosphorus	Nitrogen			
26.5% P	12% N	1:100	1:150	1:200
ppm P in the diluted solution	ppm N in the diluted solution	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate	grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate
10	5	3.8	5.7	7.5
20	9	7.5	11.3	15.1
30	14	11.3	17.0	22.6
40	18	15.1	22.6	30.2
50	23	18.9	28.3	37.7
60	27	22.6	34.0	45.3
70	32	26.4	39.6	52.8
80	36	30.2	45.3	60.4
90	41	34.0	50.9	67.9
100	45	37.7	56.6	75.5
110	50	42	62	83
120	54	45	68	91
130	59	49	74	98
140	63	53	79	106
150	68	57	85	113
160	72	60	91	121
170	77	64	96	128
180	82	68	102	136
190	86	72	108	143
200	91	75	113	151
210	95	79	119	158
220	100	83	125	166
230	104	87	130	174
240	109	91	136	181
250	113	94	142	189
260	118	98	147	196
270	122	102	153	204
280	127	106	158	211
290	131	109	164	219
300	136	113	170	226

Ammonium Nitrate			
34% N	**1:100**	**1:150**	**1:200**
ppm N in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
10	2.9	4.4	5.9
20	5.9	8.8	11.8
30	8.8	13.2	17.6
40	11.8	17.6	23.5
50	14.7	22.1	29.4
60	17.6	26.5	35.3
70	20.6	30.9	41.2
80	23.5	35.3	47.1
90	26.5	39.7	52.9
100	29.4	44.1	58.8
110	32	49	65
120	35	53	71
130	38	57	76
140	41	62	82
150	44	66	88
160	47	71	94
170	50	75	100
180	53	79	106
190	56	84	112
200	59	88	118
210	62	93	124
220	65	97	129
230	68	101	135
240	71	106	141
250	74	110	147
260	76	115	153
270	79	119	159
280	82	124	165
290	85	128	171
300	88	132	176

Ammonium Sulfate				
Nitrogen	**Sulfur**			
21% **N**	24% **S**	**1:100**	**1:150**	**1:200**
ppm N in the diluted solution	**ppm S in the diluted solution**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
10	11	4.8	7.1	9.5
20	23	9.5	14.3	19.0
30	34	14.3	21.4	28.6
40	46	19.0	28.6	38.1
50	57	23.8	35.7	47.6
60	69	28.6	42.9	57.1
70	80	33.3	50.0	66.7
80	91	38.1	57.1	76.2
90	103	42.9	64.3	85.7
100	114	47.6	71.4	95.2
110	126	52	79	105
120	137	57	86	114
130	149	62	93	124
140	160	67	100	133
150	171	71	107	143
160	183	76	114	152
170	194	81	121	162
180	206	86	129	171
190	217	90	136	181
200	229	95	143	190
210	240	100	150	200
220	251	105	157	210
230	263	110	164	219
240	274	114	171	229
250	286	119	179	238
260	297	124	186	248
270	309	129	193	257
280	320	133	200	267
290	331	138	207	276
300	343	143	214	286

Iron Chelate (13.3% Fe)			
13.3% Fe	**1:100**	**1:150**	**1:200**
ppm Fe in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.1	0.075	0.113	0.150
0.2	0.150	0.226	0.301
0.3	0.226	0.338	0.451
0.4	0.301	0.451	0.602
0.5	0.376	0.564	0.752
0.6	0.451	0.677	0.902
0.7	0.526	0.789	1.053
0.8	0.602	0.902	1.203
0.9	0.677	1.015	1.353
1	0.752	1.128	1.504
1.1	0.827	1.241	1.654
1.2	0.902	1.353	1.805
1.3	0.977	1.466	1.955
1.4	1.053	1.579	2.105
1.5	1.128	1.692	2.256
1.6	1.203	1.805	2.406
1.7	1.278	1.917	2.556
1.8	1.353	2.030	2.707
1.9	1.429	2.143	2.857
2	1.504	2.256	3.008
2.5	1.880	2.820	3.759
3	2.256	3.383	4.511
4	3.008	4.511	6.015
5	3.759	5.639	7.519
6	4.511	6.767	9.023
7	5.263	7.895	10.526
8	6.015	9.023	12.030
9	6.767	10.150	13.534
10	7.519	11.278	15.038

Manganese Chelate (13% Mn)			
13% Mn	**1:100**	**1:150**	**1:200**
ppm Mn in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.1	0.077	0.115	0.154
0.2	0.154	0.231	0.308
0.3	0.231	0.346	0.462
0.4	0.308	0.462	0.615
0.5	0.385	0.577	0.769
0.6	0.462	0.692	0.923
0.7	0.538	0.808	1.077
0.8	0.615	0.923	1.231
0.9	0.692	1.038	1.385
1	0.769	1.154	1.538
1.1	0.846	1.269	1.692
1.2	0.923	1.385	1.846
1.3	1.000	1.500	2.000
1.4	1.077	1.615	2.154
1.5	1.154	1.731	2.308
1.6	1.231	1.846	2.462
1.7	1.308	1.962	2.615
1.8	1.385	2.077	2.769
1.9	1.462	2.192	2.923
2	1.538	2.308	3.077
2.5	1.923	2.885	3.846
3	2.308	3.462	4.615
4	3.077	4.615	6.154
5	3.846	5.769	7.692
6	4.615	6.923	9.231
7	5.385	8.077	10.769
8	6.154	9.231	12.308
9	6.923	10.385	13.846
10	7.692	11.538	15.385

Manganese Sulfate (28% Mn)			
28% Mn	**1:100**	**1:150**	**1:200**
ppm Mn in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.1	0.036	0.054	0.071
0.2	0.071	0.107	0.143
0.3	0.107	0.161	0.214
0.4	0.143	0.214	0.286
0.5	0.179	0.268	0.357
0.6	0.214	0.321	0.429
0.7	0.250	0.375	0.500
0.8	0.286	0.429	0.571
0.9	0.321	0.482	0.643
1	0.357	0.536	0.714
1.1	0.393	0.589	0.786
1.2	0.429	0.643	0.857
1.3	0.464	0.696	0.929
1.4	0.500	0.750	1.000
1.5	0.536	0.804	1.071
1.6	0.571	0.857	1.143
1.7	0.607	0.911	1.214
1.8	0.643	0.964	1.286
1.9	0.679	1.018	1.357
2	0.714	1.071	1.429
2.5	0.893	1.339	1.786
3	1.071	1.607	2.143
4	1.429	2.143	2.857
5	1.786	2.679	3.571
6	2.143	3.214	4.286
7	2.500	3.750	5.000
8	2.857	4.286	5.714
9	3.214	4.821	6.429
10	3.571	5.357	7.143

Solubor (20.5% B)			
20.5% B	**1:100**	**1:150**	**1:200**
ppm B in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.1	0.049	0.073	0.098
0.2	0.098	0.146	0.195
0.3	0.146	0.220	0.293
0.4	0.195	0.293	0.390
0.5	0.244	0.366	0.488
0.6	0.293	0.439	0.585
0.7	0.341	0.512	0.683
0.8	0.390	0.585	0.780
0.9	0.439	0.659	0.878
1	0.488	0.732	0.976
1.1	0.537	0.805	1.073
1.2	0.585	0.878	1.171
1.3	0.634	0.951	1.268
1.4	0.683	1.024	1.366
1.5	0.732	1.098	1.463
1.6	0.780	1.171	1.561
1.7	0.829	1.244	1.659
1.8	0.878	1.317	1.756
1.9	0.927	1.390	1.854
2	0.976	1.463	1.951
2.5	1.220	1.829	2.439
3	1.463	2.195	2.927
4	1.951	2.927	3.902
5	2.439	3.659	4.878
6	2.927	4.390	5.854
7	3.415	5.122	6.829
8	3.902	5.854	7.805
9	4.390	6.585	8.780
10	4.878	7.317	9.756

Borax (11.2% B)			
11.2% B	**1:100**	**1:150**	**1:200**
ppm B in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.1	0.089	0.134	0.179
0.2	0.179	0.268	0.357
0.3	0.268	0.402	0.536
0.4	0.357	0.536	0.714
0.5	0.446	0.670	0.893
0.6	0.536	0.804	1.071
0.7	0.625	0.938	1.250
0.8	0.714	1.071	1.429
0.9	0.804	1.205	1.607
1	0.893	1.339	1.786
1.1	0.982	1.473	1.964
1.2	1.071	1.607	2.143
1.3	1.161	1.741	2.321
1.4	1.250	1.875	2.500
1.5	1.339	2.009	2.679
1.6	1.429	2.143	2.857
1.7	1.518	2.277	3.036
1.8	1.607	2.411	3.214
1.9	1.696	2.545	3.393
2	1.786	2.679	3.571
2.5	2.232	3.348	4.464
3	2.679	4.018	5.357
4	3.571	5.357	7.143
5	4.464	6.696	8.929
6	5.357	8.036	10.714
7	6.250	9.375	12.500
8	7.143	10.714	14.286
9	8.036	12.054	16.071
10	8.929	13.393	17.857

Zinc Sulfate (23% Zn)			
23% Zn	**1:100**	**1:150**	**1:200**
ppm Zn in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.01	0.004	0.007	0.009
0.02	0.009	0.013	0.017
0.03	0.013	0.020	0.026
0.04	0.017	0.026	0.035
0.05	0.022	0.033	0.043
0.06	0.026	0.039	0.052
0.07	0.030	0.046	0.061
0.08	0.035	0.052	0.070
0.09	0.039	0.059	0.078
0.1	0.043	0.065	0.087
0.2	0.087	0.130	0.174
0.3	0.130	0.196	0.261
0.4	0.174	0.261	0.348
0.5	0.217	0.326	0.435
0.6	0.261	0.391	0.522
0.7	0.304	0.457	0.609
0.8	0.348	0.522	0.696
0.9	0.391	0.587	0.783
1	0.435	0.652	0.870
1.5	0.652	0.978	1.304
2	0.870	1.304	1.739
3	1.304	1.957	2.609
4	1.739	2.609	3.478
5	2.174	3.261	4.348
6	2.609	3.913	5.217
7	3.043	4.565	6.087
8	3.478	5.217	6.957
9	3.913	5.870	7.826
10	4.348	6.522	8.696

Zinc Chelate (14.2% Zn)			
14.2% Zn	**1:100**	**1:150**	**1:200**
ppm Zn in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.01	0.007	0.011	0.014
0.02	0.014	0.021	0.028
0.03	0.021	0.032	0.042
0.04	0.028	0.042	0.056
0.05	0.035	0.053	0.070
0.06	0.042	0.063	0.085
0.07	0.049	0.074	0.099
0.08	0.056	0.085	0.113
0.09	0.063	0.095	0.127
0.1	0.070	0.106	0.141
0.2	0.141	0.211	0.282
0.3	0.211	0.317	0.423
0.4	0.282	0.423	0.563
0.5	0.352	0.528	0.704
0.6	0.423	0.634	0.845
0.7	0.493	0.739	0.986
0.8	0.563	0.845	1.127
0.9	0.634	0.951	1.268
1	0.704	1.056	1.408
1.5	1.056	1.585	2.113
2	1.408	2.113	2.817
3	2.113	3.169	4.225
4	2.817	4.225	5.634
5	3.521	5.282	7.042
6	4.225	6.338	8.451
7	4.930	7.394	9.859
8	5.634	8.451	11.268
9	6.338	9.507	12.676
10	7.042	10.563	14.085

Copper Sulfate (25.5% Cu)			
25.5**% Cu**	**1:100**	**1:150**	**1:200**
ppm Cu in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.01	0.004	0.006	0.008
0.02	0.008	0.012	0.016
0.03	0.012	0.018	0.024
0.04	0.016	0.024	0.031
0.05	0.020	0.029	0.039
0.06	0.024	0.035	0.047
0.07	0.027	0.041	0.055
0.08	0.031	0.047	0.063
0.09	0.035	0.053	0.071
0.1	0.039	0.059	0.078
0.2	0.078	0.118	0.157
0.3	0.118	0.176	0.235
0.4	0.157	0.235	0.314
0.5	0.196	0.294	0.392
0.6	0.235	0.353	0.471
0.7	0.275	0.412	0.549
0.8	0.314	0.471	0.627
0.9	0.353	0.529	0.706
1	0.392	0.588	0.784
1.5	0.588	0.882	1.176
2	0.784	1.176	1.569
3	1.176	1.765	2.353
4	1.569	2.353	3.137
5	1.961	2.941	3.922
6	2.353	3.529	4.706
7	2.745	4.118	5.490
8	3.137	4.706	6.275
9	3.529	5.294	7.059
10	3.922	5.882	7.843

Copper Chelate (14% Cu)			
14**% Cu**	**1:100**	**1:150**	**1:200**
ppm Cu in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.01	0.007	0.011	0.014
0.02	0.014	0.021	0.029
0.03	0.021	0.032	0.043
0.04	0.029	0.043	0.057
0.05	0.036	0.054	0.071
0.06	0.043	0.064	0.086
0.07	0.050	0.075	0.100
0.08	0.057	0.086	0.114
0.09	0.064	0.096	0.129
0.1	0.071	0.107	0.143
0.2	0.143	0.214	0.286
0.3	0.214	0.321	0.429
0.4	0.286	0.429	0.571
0.5	0.357	0.536	0.714
0.6	0.429	0.643	0.857
0.7	0.500	0.750	1.000
0.8	0.571	0.857	1.143
0.9	0.643	0.964	1.286
1	0.714	1.071	1.429
1.5	1.071	1.607	2.143
2	1.429	2.143	2.857
3	2.143	3.214	4.286
4	2.857	4.286	5.714
5	3.571	5.357	7.143
6	4.286	6.429	8.571
7	5.000	7.500	10.000
8	5.714	8.571	11.429
9	6.429	9.643	12.857
10	7.143	10.714	14.286

Sodium Molybdate (39% Mo)			
39% Mo	**1:100**	**1:150**	**1:200**
ppm Mo in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.01	0.003	0.004	0.005
0.02	0.005	0.008	0.010
0.03	0.008	0.012	0.015
0.04	0.010	0.015	0.021
0.05	0.013	0.019	0.026
0.06	0.015	0.023	0.031
0.07	0.018	0.027	0.036
0.08	0.021	0.031	0.041
0.09	0.023	0.035	0.046
0.1	0.026	0.038	0.051
0.2	0.051	0.077	0.103
0.3	0.077	0.115	0.154
0.4	0.103	0.154	0.205
0.5	0.128	0.192	0.256
0.6	0.154	0.231	0.308
0.7	0.179	0.269	0.359
0.8	0.205	0.308	0.410
0.9	0.231	0.346	0.462
1	0.256	0.385	0.513
1.5	0.385	0.577	0.769
2	0.513	0.769	1.026
3	0.769	1.154	1.538
4	1.026	1.538	2.051
5	1.282	1.923	2.564
6	1.538	2.308	3.077
7	1.795	2.692	3.590
8	2.051	3.077	4.103
9	2.308	3.462	4.615
10	2.564	3.846	5.128

Ammonium Molybdate (56% Mo)			
56% Mo	**1:100**	**1:150**	**1:200**
ppm Mo in the diluted solution	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 100x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 150x concentrate**	**grams per liter (lbs per 100 Imp gal) (lbs per 120 US gal) to make a 200x concentrate**
0.01	0.002	0.003	0.004
0.02	0.004	0.005	0.007
0.03	0.005	0.008	0.011
0.04	0.007	0.011	0.014
0.05	0.009	0.013	0.018
0.06	0.011	0.016	0.021
0.07	0.013	0.019	0.025
0.08	0.014	0.021	0.029
0.09	0.016	0.024	0.032
0.1	0.018	0.027	0.036
0.2	0.036	0.054	0.071
0.3	0.054	0.080	0.107
0.4	0.071	0.107	0.143
0.5	0.089	0.134	0.179
0.6	0.107	0.161	0.214
0.7	0.125	0.188	0.250
0.8	0.143	0.214	0.286
0.9	0.161	0.241	0.321
1	0.179	0.268	0.357
1.5	0.268	0.402	0.536
2	0.357	0.536	0.714
3	0.536	0.804	1.071
4	0.714	1.071	1.429
5	0.893	1.339	1.786
6	1.071	1.607	2.143
7	1.250	1.875	2.500
8	1.429	2.143	2.857
9	1.607	2.411	3.214
10	1.786	2.679	3.571

Appendix 3 – A Table of Relative Proportions

PPM	Proportion	Percent	US fl oz per 1000 US gal	UK fl oz per 1000 UK gal	ml / l000 Liters
0.01	1:100,000,000	0.000001	0.0013	0.0016	0.01
0.02	1:50,000,000	0.000002	0.0026	0.0032	0.02
0.03	1:33,333,333	0.000003	0.0038	0.0048	0.03
0.04	1:25,000,000	0.000004	0.0051	0.0064	0.04
0.05	1:20,000,000	0.000005	0.0064	0.0080	0.05
0.06	1:16,666,667	0.000006	0.0077	0.0096	0.06
0.07	1:14,285,714	0.000007	0.0090	0.0112	0.07
0.08	1:12,500,000	0.000008	0.0102	0.0128	0.08
0.09	1:11,111,111	0.000009	0.0115	0.0144	0.09
0.1	1:10,000,000	0.00001	0.0128	0.0160	0.10
0.2	1:5,000,000	0.00002	0.0256	0.0320	0.20
0.3	1:3,333,333	0.00003	0.0384	0.0480	0.30
0.4	1:2,500,000	0.00004	0.0512	0.0640	0.40
0.5	1:2,000,000	0.00005	0.0640	0.0800	0.50
0.6	1:1,666,667	0.00006	0.0768	0.0960	0.60
0.7	1:1,428,571	0.00007	0.0896	0.1120	0.70
0.8	1:1,250,000	0.00008	0.1024	0.1280	0.80
0.9	1:1,111,111	0.00009	0.1152	0.1440	0.90
1	1:1,000,000	0.0001	0.1280	0.1600	1
2	1:500,000	0.0002	0.2560	0.3200	2
3	1:333,333	0.0003	0.3840	0.4800	3
4	1:250,000	0.0004	0.5120	0.6400	4
5	1:200,000	0.0005	0.6400	0.8000	5
6	1:166,667	0.0006	0.77	0.96	6
7	1:142,857	0.0007	0.90	1.12	7
8	1:125,000	0.0008	1.02	1.28	8
9	1:111,111	0.0009	1.15	1.44	9
10	1:100,000	0.001	1.28	1.60	10
15	1:66,667	0.0015	1.92	2.40	15
20	1:50,000	0.002	2.56	3.20	20
25	1:40,000	0.0025	3.20	4.00	25
50	1:20,000	0.005	6.40	8.00	50
100	1:10,000	0.01	12.80	16.00	100
200	1:5,000	0.02	25.60	32.00	200
250	1:4,000	0.025	32.00	40.00	250
500	1:2,000	0.05	64.00	80.00	500
1000	1:1,000	0.1	128.00	160.00	1000
2000	1:500	0.2	256.00	320.00	2000
2500	1:400	0.25	320.00	400.00	2500
3333	1:300	0.333	426.67	533.33	3333
5000	1:200	0.5	640.00	800.00	5000
6250	1:160	0.625	800.00	1000.00	6250
7812	1:128	0.78125	1000.00	1250.00	7813
10000	1:100	1	1280.00	1600.00	10000

Appendix 4 – Useful Conversion Factors

Appendix 4a - Volume

To convert from:	To:	Multiply by:
cubic feet of water	pounds of water of water	62.43
cubic feet of water	kilograms of water	28.32
gallons US of water	pounds of water	8.33
gallons US of water	kilograms of water	3.78
gallons UK of water	pounds of water	10
gallons UK of water	kilograms of water	4.54
liters of water	kilograms of water	1
cubic feet	cubic inches	1728
cubic feet	cubic meters	0.02831685
cubic feet	gallons US	7.48
cubic feet	gallons UK	6.2
cubic feet	cubic meters	0.02831685
gallons US	fluid ounces US	128
gallons US	fluid ounces UK	133
gallons US	gallons UK	.833
gallons US	liters	3.785
gallons US	cubic inches	231
gallons UK	fluid ounces UK	160
gallons UK	fluid ounces US	154
gallons UK	gallons US	1.2
gallons UK	liters	4.556
gallons UK	cubic inches	277.4
fluid ounces US	fluid ounces UK	1.040842
fluid ounces US	liters	0.02957353
fluid ounces US	milliliters	29.57353
fluid ounces UK	fluid ounces US	0.9607604
cubic centimeters	liters	0.001
cubic centimeters	milliliters	1
cubic meters	liters	1000
cubic meters	gallons US	264
cubic meters	gallons UK	220
cubic meters	cubic feet	35.32
cubic meters	cubic yards	1.308
liters	cubic centimeters	1000
liters	cubic meters	0.001
liters	cubic inches	61.024
liters	gallons US	0.264
liters	gallons UK	0.220
liters	fluid ounces US	33.814
liters	fluid ounces UK	35.195

Appendix 4b - Length

To convert from:	To:	Multiply by:
inch	feet	0.08333333
inch	yards	0.02777778
inch	centimeters	2.54
inch	meters	0.0254
feet	inches	12
feet	yards	0.3333333
feet	centimeters	30.48
mile	feet	5280
mile	meters	1609.344
feet	meters	0.3048
centimeter	feet	0.0328083
centimeter	inches	0.3937008
centimeter	meters	0.01
centimeter	yards	0.0109361
meter	centimeter	100
meter	feet	3.28083
meter	inches	0.08333333

Appendix 4c – Mass

To convert from:	To:	Multiply by:
pounds	kilograms	0.4536
pounds	ounces	16
pounds	grams	454
ounces	kilograms	0.02835
ounces	grams	28.35
ounces	pounds	0.0625
kilograms	ounces	35.27392
kilograms	pounds	2.2
kilograms	grams	1000
grams	kilograms	0.001
grams	pounds	0.0022046
grams	ounces	0.0352736
grams	milligrams	1000

Appendix 3c – Pressure

From:	To:									
	atmospheres Multiply by:	bars	millibars	millimeters of mercury	Inches of mercury	kilopascal	pounds per square inch	torr	Kilograms per square centimeter	Feet of Water
atmospheres	1	1.0133	1013.25	760	29.921	101.325	14.69595	760	1.033227	33.90
bars	0.9869	1	1000	750.06	29.53	100	14.50377	750.0617	1.019716	33.46
millibars	0.000987	0.001	1	0.75006	0.7501	1000	0.145038	7.500617	0.010198	.03346
millimeters of mercury	0.001316	0.0013	1.333224	1	0.0394	0.133324	0.01934	1	0.00136	0.0446
inches of mercury	0.0334	0.0339	33.8639	25.4	1	3.38639	0.4912	25.4	0.03453	1.133
kilopascal	0.00987	0.01	10	7.5006	0.2953	1	0.14504	7.5006	0.0102	
pounds per square inch	0.06805	0.0689	68.9476	51.7149	2.0360	6.8948	1	51.7149	0.0703	2.307
torr	0.001316	0.0013	1.333224	1	0.0394	0.13332	0.01934	1	0.00136	0.0446
kilograms per square centimeter	0.96784	0.9807	980.665	735.5592	28.959	98.0665	14.22334	735.5592	1	32.81
feet of water	0.0295	0.0299	29.8909	22.42	.8827	2.9891	0.4335	22.42	0.03048	1

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