Understanding pH management and plant nutrition
Part 3: Fertilizers

Bill Argo, Ph.D.
Blackmore Company, Tel: 800-874-8660, Int’l 734-483-8661, E-mail: bargo@blackmoreco.com

Originally printed in 2003 in the Journal of the International Phalaenopsis Alliance, Vol. 13 (2).

When you select a water-soluble fertilizer for your plants, the primary goal should be to supply your plants with a sufficient amount of essential plant nutrients for good growth and flowering. The problem is that there are probably as many misconceptions about fertilizers as there are fertilizers labeled as “orchid special”.

The “best” fertilizer to use on your plants is the one that not only supplies nutrients, but also complements the alkalinity and nutrient content of your irrigation water. In this article, we will help you understand how selecting a fertilizer will affect the pH and nutrient levels in the substrate. You will learn why water-soluble fertilizers are classified as acidic, neutral, or basic based on their fertilizer reaction in the substrate. Finally, with the information given in this article, you should be able to decide for yourself which fertilizers will work best for your growing conditions.

Solution pH and the effect that fertilizer has on substrate-pH two different aspects of water-soluble fertilizers

There is a great deal of confusion when it comes to understanding the difference between the pH of the fertilizer solution and the effect that fertilizer has on substrate pH, and why they are important to the health of your plants.

Just like with water pH, the pH of the fertilizer solution is a direct measurement of the balance between acidic hydrogen ions (H^+) and basic hydroxide ions (OH^-), and can be measured with a pH meter. The pH of a solution can range between 0 (very acidic) and 14 (very basic). At a pH of 7.0, the concentrations of H^+ and OH^- are equal, and the solution is said to be neutral. When the pH is above 7.0, the concentration of OH^- is higher than H^+, and the solution is said to be basic or alkaline (not to be confused with alkalinity). When the solution is below 7.0, the concentration of H^+ is higher than OH^-, and the solution is said to be acidic.

The effect that a water-soluble fertilizer has on substrate pH is dependent on the reactions that take place once the fertilizer has been applied to the crop and are based on the type of nitrogen contained in the fertilizer. There are three types of nitrogen used in water-soluble fertilizers: ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N) and urea (Figure 1). Uptake of ammoniacal nitrogen causes the substrate-pH to decrease because H^+ (acidic protons) are secreted from roots in order to balance the charges of ions inside the plant with the solution surrounding the outside of the roots. Urea is easily converted into ammoniacal nitrogen in the substrate and therefore can be thought of as another source of ammoniacal nitrogen. In contrast, uptake of nitrate nitrogen increases substrate-pH because OH^- or HCO_3^- (bases) are secreted by plant roots in order to balance nitrate uptake.

Another important fertilizer reaction is a process called nitrification. Several types of bacteria in container substrates (including inert substrates like coir, bark, peat, rockwool, and scoria) convert ammoniacal nitrogen to nitrate nitrogen. Nitrification releases H^+ (acidic protons), causing the substrate-pH to decrease.

Consider the difference in the amount of acidity supplied by a solution with a pH of 5.0 verses the amount of acidity supplied by 100 ppm of ammoniacal nitrogen. A solution with a pH of 5.0 would supply about 0.01 mEq/liter of acidic hydrogen ions to the substrate. If all the 100 ppm ammoniacal nitrogen were converted into nitrate nitrogen through nitrification, the maximum amount of acidity produced would be 14.2 mEq/liter of acidic hydrogen, or about 1,400 times more acidity than would be supplied by a solution with a pH of 5.0. Put another way, applying 100 ppm of

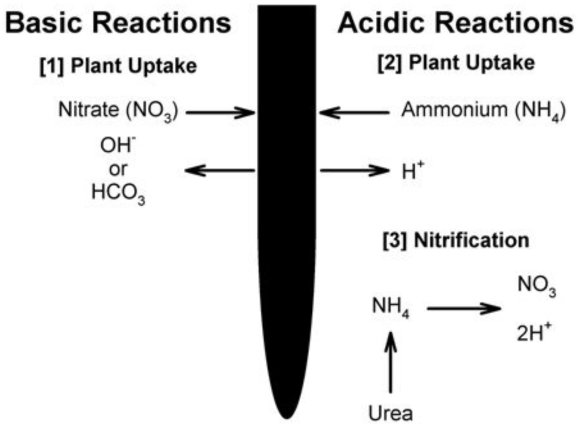

Figure 1. The effect of different forms of nitrogen on medium-pH. Nitrate nitrogen (NO_3-N) only effects medium-pH through plant uptake [1]. Ammoniacal nitrogen (NH_4-N) effects medium-pH through both plant uptake [2] and nitrification [3]). Urea must first be converted into ammoniacal nitrogen before it can be taken up by the plant [2] or go through nitrification [3].

Table 1. The nitrogen content of selected commercially-available granular and liquid water-soluble fertilizers. The alkalinity concentration that provides a stable substrate pH should be viewed as an approximate guideline only. Use these values as a starting point. Any changes to the fertilizer program should be based on the actual measured pH of the crop.

N-P_2O_5-K_2O Formula	% NH_4-N	% Urea-N	% NO3-N	Fertilizer reaction[1]	Proportion of the total nitrogen in the ammoniacal form (NH_4-N + urea-N)	Alkalinity Conc. (in ppm CaCO3) that provides a stable substrate pH
Granular fertilizers						
21-7-7 ^{GC,SC}	9.1%	11.9%	-	A 1520	100%	250 or more
9-45-15 ^{GC,SC}	9.0%	-	-	A 940	100%	
30-10-10 $^{GC,GM, SC}$	2.1%	24.7%	3.2%	A 1039	89%	
20-20-20 $^{GC,GM, SC}$	3.9%	10.5%	5.6%	A 680	72%	
6-30-30 ^{GM}	2.7%	-	3.3%	NA	45%	150 to 200
10-30-20 $^{G, SC}$	4.4%	-	5.6%	A 425	43%	
20-10-20 $^{GC,GM, SC}$	8.0%	-	12.0%	A 430	40%	
21-5-20 ^{SC}	6.5%	1.9%	12.6%	A389	40%	
19-4-23-2 Ca ^{GC}	5.7%	-	13.6%	A 140	30%	75 to 150
17-5-17-3 Ca-1 Mg ^{GC}	4.2%	-	12.8%	A 0	25%	
15-5-15-5 Ca-2 Mg ^{SC}	1.2%	2.1%	11.8%	B 141	21%	
15-3-20-3 Ca-1 Mg ^{GC}	2.4%	-	12.6%	B 75	16%	50 or less
14-4-14-5 Ca-2 Mg ^{GC}	2.0%	-	12.0%	B 200	14%	
13-2-13-6 Ca-3 Mg $^{GC, SC}$	0.8%	-	12.2%	B 380	6%	
13-3-15-8 Ca-2 Mg ^{GC}	0.7%	-	12.5%	B 420	5%	
Liquid fertilizers						
10-5-5-2 Ca-0.5 Mg ^{DG}	3.7%	-	6.3%	NA	37%	150 to 200
7-9-5-2 Ca-0.5 Mg ^{DG}	2.6%	-	4.4%	NA	37%	
7-7-7-2 Ca-0.5 Mg ^{DG}	2.1%	-	4.9%	NA	30%	75 to 150
3-12-6-2 Ca-0.5 Mg ^{DG}	0.7%	-	2.3%	NA	23%	

[1] Pounds of acidity (A) or basicity (B) per ton of fertilizer.

DG = Dyna Gro, GC = GreenCare, GM = Grow-more, SC = Scotts (Peters)

To Calculate the proportion of the total nitrogen in the ammoniacal form

$$\frac{\%\ NH_4\text{-N} + \%\ \text{Urea-N}}{\%\ \text{Total Nitrogen}} = \text{Proportion of the total nitrogen in the ammoniacal form}$$

Example: 20-20-20

$$\frac{3.9\%\ NH_4\text{-N} + 10.5\%\ \text{Urea-N}}{20\%\ \text{total nitrogen}} = 72\%\ \text{of the total nitrogen is in the ammoniacal form}$$

ammoniacal nitrogen has the potential to supply the same amount of acidity as a solution with a pH of 1.8. The acidity produced by a solution with a pH of 5.0 would be equivalent to the nitrification of 0.14 ppm ammoniacal nitrogen (almost undetectable).

While the effect that different nitrogen forms have on the substrate pH is more complicated than this simple example, it does give you an idea why the nitrogen form of the fertilizer has a much greater effect on the substrate-pH than does the solution pH.

The main problem with predicting how the nitrogen form affects substrate pH is that the key reactions are not consistent. For example, the application nitrate nitrogen (NO_3-N) can cause the substrate-pH to increase, but only if it is taken up by the plant. If plants are small, or are stressed and not growing, nitrate has little influence on substrate-pH. The application of ammoniacal nitrogen (NH_4-N) can cause the substrate-pH to decrease even if the plant is small or is not growing, because in addition to plant uptake, nitrification will occur independently of the plant. However, nitrification is inhibited by low substrate-pH (starting at around 5.5), low substrate temperature (less than 60^oF or 15^oC), and lack of oxygen through water-logging.

Finally, you never apply either all nitrate nitrogen or all ammoniacal nitrogen to your plants. Most fertilizer is a mixture of salts containing different forms of nitrogen and so the overall reaction produced by the fertilizer will depend on the ratio of the different nitrogen forms. There are also other factors that either magnify or buffer the reaction of the fertilizer including the substrate (cation exchange capacity, residual lime, decomposition – to be covered in a later article) and the irrigation water.

Water alkalinity also influences the fertilizer reaction.

When discussing how water-soluble fertilizer affects substrate-pH, it is important to understand that water-soluble fertilizer cannot be applied without irrigation water. The best guide when selecting an appropriate water-soluble fertilizer is to balance the proportion of nitrogen in the ammoniacal form (acid) against the irrigation water alkalinity (base) (see Table 1). Although other factors affect substrate-pH, research has shown that it is the balance between the ammoniacal nitrogen in the fertilizer and water alkalinity that has the greatest effect on substrate-pH on long-term crops.

Table 2. Fertilizer salts used to produce selected commercially-available granular and liquid water-soluble fertilizers.

N-P_2O_5-K_2O Formula	Derived from
Granular fertilizers	
21-7-7 ^{GC,SC}	KCl, $NH_4H_2PO_4$, $(NH_4)_2SO_4$, urea,
9-45-15 ^{GC,SC}	KCl, $NH_4H_2PO_4$
30-10-10 $^{GC,GM, SC}$	KNO_3, $NH_4H_2PO_4$, Urea
20-20-20 $^{GC,GM, SC}$	KNO_3, $NH_4H_2PO_4$, Urea
6-30-30 ^{GM}	KNO_3, $NH_4H_2PO_4$, KH_2PO_4, KCl
10-30-20 $^{G, SC}$	NH_4NO_3, KNO_3, $NH_4H_2PO_4$,
20-10-20 $^{GC,GM, SC}$	NH_4NO_3, KNO_3, $NH_4H_2PO_4$,
21-5-20 ^{SC}	NH_4NO_3, KNO_3, Urea phosphate
19-4-23-2 Ca ^{GC}	NH_4NO_3, $Ca(NO_3)_2$, $KNO_3NH_4H_2PO_4$
17-5-17-3 Ca-1 Mg ^{GC}	NH_4NO_3, $Ca(NO_3)_2$, KNO_3, $Mg(NO_3)_2$, $NH_4H_2PO_4$
15-5-15-5 Ca-2 Mg ^{SC}	NH_4NO_3, $Ca(NO_3)_2$, KNO_3, $Mg(NO_3)_2$, Urea phosphate
15-3-20-3 Ca-1 Mg ^{GC}	NH_4NO_3, $Ca(NO_3)_2$, KNO_3, $Mg(NO_3)_2$, $NH_4H_2PO_4$
14-4-14-5 Ca-2 Mg ^{GC}	NH_4NO_3, $Ca(NO_3)_2$, KNO_3, $Mg(NO_3)_2$, $NH_4H_2PO_4$
13-2-13-6 Ca-3 Mg $^{GC, SC}$	$Ca(NO_3)_2$, KNO_3, $Mg(NO_3)_2$, $NH_4H_2PO_4$
13-3-15-8 Ca-2 Mg ^{GC}	$Ca(NO_3)_2$, KNO_3, $Mg(NO_3)_2$, $NH_4H_2PO_4$
Liquid fertilizers	
10-5-5-2 Ca-0.5 Mg ^{DG}	NH_4NO_3, $Ca(NO_3)_2$, KNO_3, $MgSO_4$, $NH_4H_2PO_4$, KH_2PO_4, H_3PO_4, KCl
7-9-5-2 Ca-0.5 Mg ^{DG}	
7-7-7-2 Ca-0.5 Mg ^{DG}	
3-12-6-2 Ca-0.5 Mg ^{DG}	

[1] Actual P and K are the actual expected values obtained in a solution at 100 ppm nitrogen and are how the values would be represented if a laboratory analysis were performed on the solution. To calculate actual P as P2O5, multiply value by 2.3, to calculate actual K as K2O, multiply value by 1.2.

DG = Dyna Gro, GC = GreenCare, GM = Grow-more, SC = Scotts (Peters)

Ammonium nitrate (NH_4HO_3), ammonium sulfate ($(NH4)_2SO_4$), calcium nitrate ($Ca(NO_3)_2$), magnesium nitrate ($Mg(NO_3)_2$), monoammonium phosphate ($NH_4H_2PO_4$), monopotassium phosphate (KH_2PO_4), phosphoric acid (H_3PO_4), potassium chloride (KCl), potassium nitrate (KNO_3),

To understand how the alkalinity concentration in the water and the percentage of ammoniacal nitrogen in the fertilizer interact to affect substrate-pH, picture a balance with water alkalinity on one side pushing the pH up (i.e. liming effect), and on the other side, with the ammoniacal nitrogen pushing the pH down (i.e. acidic nitrogen).

If either of these factors is out of balance, then the substrate-pH will be affected. For example, using a fertilizer very high in ammoniacal nitrogen (like 30-10-10) with low alkalinity water (like RO or rain water) is very effective at driving the substrate-pH down because there is nothing to neutralize all the acidic hydrogens (H^+) being produced through nitrification or plant uptake. Another example would be using a fertilizer low in ammoniacal nitrogen (like 13-3-15) with a high alkalinity water source (like well water commonly found in the Midwest of the United States). In this case, there would be little if any acidic hydrogens (H^+) produced to neutralize the liming effect of the water alkalinity, plus the large amount of nitrate nitrogen uptake would also add to the liming effect.

It is important to note that the two things that affect substrate-pH the most (water alkalinity and ammoniacal nitrogen) can not be directly measured with a pH meter. Water alkalinity must be measured with an alkalinity test (see Part 2 of this series for a list of commercial laboratories that do alkalinity testing). The percentage of ammoniacal nitrogen in the fertilizer needs to be calculated based on the information supplied on the fertilizer bag (See Table 1).

What about potential acidity or basicity?

Many water-soluble fertilizer labels state the potential acidity or basicity of the fertilizer in units of equivalent pounds of calcium carbonate ($CaCO_3$, or agricultural lime) per ton of fertilizer. Potential acidity or basicity indicates the type of reaction produced, while calcium carbonate equivalency indicates the strength of that reaction.

For example, 20-10-20 has a potential acidity of 430 lbs. per ton of fertilizer. If one ton of 20-10-20 were applied to a field soil, we would estimate that 430 pounds of $CaCO_3$ (lime) would be required to neutralize the long-term acidity produced from the fertilizer.

There are several problems when trying to relate potential acidity or basicity and calcium carbonate equivalency to growing plants in pots containing an inert substrate. The original values come from a method first presented in 1933 using field soil (pH-independent CEC), rather than inert substrates like peat or bark. The calculated values are based on assumptions related to how much of each nutrient remains in the soil profile, is used by the plant, or is leached from the field soil. The equivalent value of pounds $CaCO_3$ per ton of fertilizer has little meaning in soilless culture where fertilizer applications are typically based on the concentration of nitrogen in parts per million contained in a nutrient solution, not the total weight of the fertilizer applied to a pot. Finally, the alkalinity of the irrigation water is not taken into account when calculating acidity or basicity. At best, the potential acidity or basicity and calcium carbonate equivalency should be interpreted as a general tendency of the fertilizer to raise or lower medium-pH over time.

Macronutrients.

The second way a water-soluble fertilizer affects nutrition management is through the direct effect it has on nutrient concentrations is in the root medium. A complete fertilizer program provides several "macronutrients" (needed in large quantities) including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S).

Blended water-soluble fertilizers that contain nitrogen, phosphorus, and potassium are formulated by combining two or more fertilizer salts (Table 2). Fertilizer “salts” in this case mean any chemicals that contain plant nutrients in a water-soluble form. Ammonium phosphate is an example of a fertilizer salt, and in water this salt dissolves into separate ammonium and phosphate ions. The ammonium provides the plant with N and phosphate provides P.

There are many water-soluble sources of nitrogen, some of which only supply nitrogen like urea and ammonium nitrate. However, for most other nutrients, the choices are limited. For example, calcium nitrate is the only form of water-soluble calcium. There is also typically only one source of potassium, potassium nitrate. Monoammonium phosphate is the usual source of phosphorus. Magnesium is supplied either as magnesium nitrate or magnesium sulfate. Sulfur is supplied by ammonium sulfate or magnesium sulfate.

Because of limitations in the number of fertilizer salts used to blend fertilizers, the ratio of macronutrients (N-P-K-Ca-Mg) directly affects the percent ammoniacal nitrogen. For example, fertilizers that are high in calcium tend to also be high in nitrate, because calcium nitrate is the only water-soluble source of calcium. Fertilizers that are high in phosphorus are often also high in ammonium because phosphorus is usually supplied as monoammonium phosphate.

Certain fertilizers generally cannot be mixed at high concentrations. Salts containing sulfate, for example magnesium sulfate, are not compatible in the same concentrated stock solution with calcium nitrate because a reaction occurs where insoluble calcium sulfate (gypsum) will form as a precipitate . If a blended fertilizer contains both calcium and magnesium, then the sources have to be calcium nitrate and magnesium nitrate or two stock tanks must be used. Similarly calcium nitrate and monoammonium phosphate cannot be mixed in the same concentrated stock solution at high concentrations because insoluble calcium phosphate will form as a precipitate (solid). However, the amount of calcium and phosphorus that can be mixed in the same stock tank can be increased by lowering the pH of the stock tank. Commercially available fertilizers that contain calcium and phosphorus tend to have low levels of phosphorus (i.e. 13-2-13-6 Ca-3 Mg) and will also contain a weak acid to lower the pH of the concentrated stock solution.

The nutrient content of the irrigation water is also important. In some cases, it can supply a large percentage of nutrients (especially calcium and magnesium) to the plants. In other cases, the reason for choosing a specific fertilizer is to resist the effects of unwanted ions like sodium, chloride, or boron. Only when the nutrient content of an irrigation water is extremely low (like with rain water or reverse osmosis purified water) can it be ignored.

How to read a label from a fertilizer bag or bottle.

All fertilizer labels should contain three numbers representing the percentage (by weight) of nitrogen, phosphorus, and potassium contained in the fertilizer. For nitrogen, the value listed represents the actual percentage of nitrogen contained in the fertilizer. However, for historical reasons, fertilizers sold in the United States (and much of the rest of the world) list the percentage of phosphorus as P_2O_5 and potassium is listed as K_2O. To calculate the actual percentage of phosphorus, multiply the listed value by 0.43, and for potassium, multiply the percentage by 0.83. For example, 20-20-20 really contains 20% nitrogen, 8.6% phosphorus (actual P), and 16.6% potassium (actual K).

Nutrients other than nitrogen, phosphorus, or potassium are voluntarily listed on the label under the “guaranteed analysis” section and the values listed represent the actual percentage in the fertilizer. To be listed on the label, they either have to reach a minimum level (Ca at 1%, Mg at 0.5%, S at 0.5%, Fe at 0.1%, Mn, Zn, Cu at 0.05%, B at 0.02%), or they can be in the fertilizer but left off the label, or the label can contain “For continuous liquid feed programs” which exempts the fertilizer from the minimum critical level on micronutrients.

Micronutrients

Micronutrients (iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), and molybdenum (Mo)) are also required by plants for acceptable growth. In the past, Field soils were the primary source of micronutrients, and so the additional application was not often necessary. However, since the switch to inert substrates for growing plants in containers, the application of micronutrients has become a necessity.

The sources of micronutrients used in water soluble fertilizers typically come in two forms, inorganic salts (all micronutrients) or chelates (only iron, manganese, zinc, and copper). Inorganic salts are material that dissolve in water to form ions that are available to the plant. For example, iron sulfate will dissolve into separate iron (Fe) and sulfate (SO_4) ions. Chelates are organic molecules that envelop the ion and protect if from interacting with other ions in the soil solution that may make it unavailable to the plant.

There are many chelating molecules available, but only three that are in common use in horticulture, EDTA, DTPA, and EDDHA. These abbreviations refer to the chemical structure of the organic molecule. The difference in the chelates is how tightly the ion is bound. In general, manganese, zinc, and copper chelates are only found in the EDTA form. In comparison, there are three forms of iron chelate, but the most common also is the EDTA form.

Resin-coated fertilizer

Resin-coated fertilizers are water-soluble fertilizers covered by a resin or plastic membrane that limits the solubility of the fertilizer salts. In general, resin coated fertilizer contain high levels (50%) of ammoniacal nitrogen (NH_4-N) and no calcium (Ca), and typically little if any magnesium (Mg).

The initial release of nutrients from resin-coated fertilizers occurs because of imperfections in the coating of a percentage of the prills. Mixing equipment that damages the coat on the prills will also cause a high initial release. To test for initial release, put some resin-coated fertilizer in a glass of water and allow to sit overnight. If there the EC of the solution increases, then there is an initial release. This initial release should be thought of as a starter fertilizer.

The long term release of nutrients from resin-coated fertilizer is affected by only one thing, temperature. In general, the higher the temperature, the higher the release rate, and the lower the temperature, the lower the release rate.

Resin coated fertilizers are typically sold based on release durations. For example, Osmocote 14-14-14 has a release rate of 3-4 months. At an average temperature of 68^{o}F (20^{o}C), 14-14-14 will release 80% of the fertilizer salts contained in the prills over 3-4 months. However, if the average temperature of the substrate is much above 68^{o}F, then 14-14-14 may only last 2-3 months. High greenhouse temperatures have been known to cause excessive release of nutrients from resin-coated fertilizer resulting in salt buildup in the substrate.

Conclusion

Understanding how to fertilizer your plants starts with understanding what is in the bag or bottle of fertilizer and what is in your water. However, this still doesn't guarantee success. Proper fertilization of your plants is more than just selecting the "right" fertilizer. It also applying the fertilizer correctly. In the next article, we will discuss different factors that affect the concentration of fertilizer that you apply to your plants, and some of the concepts about fertilizers that may or may not be correct.