Understanding pH management and plant nutrition
Part 5: Choosing the "best" fertilizer

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Over the last year, since the AOS article came out on MSU "Magic" fertilizer, I have been inundated with calls of people trying to get the fertilizer. Usually, I like to talk with them to get a little information so that I can recommend which of the fertilizers (there now are 4 formulas) will work best for their situation. In this last article of the series, I would like to answer several of the common questions that people are asking.

Q) My water alkalinity is 7.8, which fertilizer will work best?

A) Most often, when you hear that the alkalinity is 7.8, the person has actually measured the pH of the solution. Water pH and water alkalinity are not the same thing.

Water pH is a measure of the hydrogen ion concentration in the irrigation water, and will affect the solubility of chemicals and fertilizers in solution. However, in the range of water pH commonly measured in nature (between 5 and 8), there is only a minute amount of acid or base, not nearly enough to influence substrate pH.

In comparison, water alkalinity is a measure of the acid buffering capacity of the water. Because alkalinity is composed of bases (like bicarbonates, carbonates), the effect it has on substrate pH is similar to that of limestone. In addition, the concentration of base supplied by alkalinity commonly found in irrigation water is much higher than that supplied by pH alone. For these reasons, alkalinity (not pH) is the primary factor affecting substrate pH.

However, alkalinity can not be measured with a pH meter, and the pH of the solution will give you no idea how much alkalinity is in the water. In addition, the measurement of total alkalinity is not commonly done by municipal water companies or by water treatment companies. Instead, a water sample should be sent out to a commercial or university laboratory that specializes in testing for greenhouses or nurseries. The cost for these types of tests will range from $25 to over $100 per sample, so it pays to shop around.

The reason that knowing what the alkalinity concentration in the water is important is because it is the balance between the alkalinity of the water and the percent ammoniacal nitrogen in the fertilizer that will determine the ideal fertilizer for your location. See part 3 of this series for more information on fertilizers and how to balance the fertilizer with the alkalinity of the water.

Q) What else should I test for besides alkalinity?

A) Besides alkalinity, you want to know the electrical conductivity (EC) or total dissolved solids (TDS) which gives you an idea of the total salt concentration in the water. It is also good to know the exact concentration of two plant nutrients, calcium (Ca), magnesium (Mg), as well as the concentration of ions that may give you problems, boron (B), chloride (Cl), sodium (Na), sulfur (S or SO_4-S), and iron (Fe). Any laboratory that will test for alkalinity should also these for these ions.

The reason that knowing the concentration of calcium, magnesium, or sulfur is important is that you want to supplement or balance the concentrations of these nutrients in the water with those found in the fertilizer. In addition, you water to check the concentration of waste ions to see if the water is suitable for growing plants, or if it needs additional treatment (for example, RO purification).

Q) How do commercial growers apply fertilizer?

A) Commercial greenhouse growers will typically apply fertilizer one of two ways. The first is to apply the fertilizer based on the concentration of a specific nutrient, usually nitrogen. The formulas for calculating how much fertilizer to add to a given volume of water to get a specific nutrient concentration is found in Table 1.

The other way fertilizer is applied to a crop is based on the electrical conductivity (EC) of the fertilizer solution.

Q) What is the relationship between electrical conductivity (EC) and the fertilizer concentration?

A) Electrical conductivity is really a measure of how much or how little electrical current can move through water. Electrical current can not move through pure water. When a salt is dissolved in water, it can break apart into positively charged cations and negatively charged anions. For example sodium chloride (NaCl) dissolving in water will break apart into sodium cations (Na^+) and chloride anions (Cl^-). Because these cations and anions have an electrical

Table 1. The amount of fertilizer required to obtain specific concentrations of nitrogen in the fertilizer solution. To convert to grams, multiply the value by 28.

	Amount of fertilizer (in ounces) per 100 gallons to get the desired nitrogen concentration			**Amount of fertilizer (in ounces) per 5 gallons to get the desired nitrogen concentration**		
	100 ppm N	***200 ppm N***	***300 ppm N***	***100 ppm N***	***200 ppm N***	***300 ppm N***
30-10-10	4.4	8.9	13.3	0.2	0.4	0.7
21-7-7	6.4	12.7	19.1	0.3	0.6	1.0
21-5-20	6.4	12.7	19.1	0.3	0.6	1.0
20-20-20	6.7	13.3	20.0	0.3	0.7	1.0
20-10-20	6.7	13.3	20.0	0.3	0.7	1.0
19-4-23-2 Ca	7.0	14.0	21.1	0.3	0.7	1.1
17-5-17-3 Ca-1 Mg	7.8	15.7	23.5	0.4	0.8	1.2
15-5-15-5 Ca-2 Mg	8.9	17.8	26.7	0.4	0.9	1.3
15-3-20-3 Ca-1 Mg	8.9	17.8	26.7	0.4	0.9	1.3
14-4-14-5 Ca-2 Mg	9.5	19.1	28.6	0.5	0.9	1.4
13-2-13-6 Ca-3 Mg	10.3	20.5	30.8	0.5	1.0	1.5
13-3-15-8 Ca-2 Mg	10.3	20.5	30.8	0.5	1.0	1.5
10-30-20	13.3	26.7	40.0	0.7	1.3	2.0
9-45-15	14.8	29.6	44.5	0.7	1.5	2.2
6-30-30	22.2	44.5	66.7	1.1	2.2	3.3

To calculate the amount of fertilizer needed to get a specific nitrogen concentration

Step #1	Multiply the desired nitrogen concentration (in ppm N) by the gallons of fertilizer you want.
Step #2	Multiply the percent nitrogen in the formula by 75
Step #3	Divide the value from Step #1 by the value from Step #2.

Example: How much 20-10-20 do you need to add to 5 gallons to get a fertilizer solution with 100 ppm N

Step #1	100 x 5 = 500	You need to add 0.33 ounces (about 9 grams) of 20-10-20 added to 5 gallons of water to get a fertilizer solution with 100 ppm N.
Step #2	20 x 75= 1,500	
Step #3	500 ÷ 1,500 = 0.33	

For people who are only measuring out small quantities of fertilizer, 1 US teaspoon holds about 0.2 ounces (about 6 grams) of fertilizer. Below is the concentration of nitrogen (in ppm total nitrogen) obtained when mixing ¼, ½, 1, or 3 teaspoons into a gallon of water with different fertilizers.

	Amount of fertilizer added per gallon of solution			
	¼ teaspoon	***½ teaspoon***	***1 teaspoon***	***3 teaspoon***
30-10-10	120	240	475	1425
21-7-7	85	165	225	1000
21-5-20	85	165	225	1000
20-20-20	80	160	320	950
20-10-20	80	160	320	950
19-4-23-2 Ca	75	150	300	900
17-5-17-3 Ca-1 Mg	70	135	270	810
15-5-15-5 Ca-2 Mg	60	120	240	710
15-3-20-3 Ca-1 Mg	60	120	240	710
14-4-14-5 Ca-2 Mg	55	110	220	660
13-2-13-6 Ca-3 Mg	50	105	210	620
13-3-15-8 Ca-2 Mg	50	105	210	620
10-30-20	40	80	160	475
9-45-15	35	70	145	425
6-30-30	25	50	95	285

charge, they can allow an electrical current to move through the water. So, the greater the amount of salt dissolved in the water, the higher the electrical conductivity.

However, not all salts dissociate (break apart) the same when dissolved in water. Some salts, like sodium chloride will dissociate completely to form ions, while others, like magnesium sulfate (Epson salts or $MgSO_4$) will dissolve, but will not totally dissociate. When equal amounts of sodium chloride and magnesium sulfate are dissolved in water, the sodium chloride will have the higher EC. Some salts, like urea, will dissolve completely but don't form ions, and so their presence in water doesn't affect EC.

Fertilizers are nothing more than combination of salts, but because each formula is different, there is a unique relationship between the concentration you are applying with a specific fertilizer and the EC. For example, 20-10-20 is composed of ammonium nitrate, monoammonium phosphate, and potassium nitrate

Table 2. The relationship between electrical conductivity (EC) and the fertilizer concentration (in ppm total nitrogen) when dissolved in pure water. Values for EC are given in mS/cm[2].

	Fertilizer concentration in ppm total nitrogen					
Formula[1]	***50***	***100***	***150***	***200***	***300***	***400***
30-10-10	0.07	0.14	0.21	0.28	0.42	0.56
21-7-7	0.28	0.56	0.84	1.12	1.68	2.23
21-5-20	0.29	0.58	0.93	1.16	1.86	2.33
20-20-20	0.20	0.40	0.60	0.80	1.20	1.60
20-10-20	0.33	0.66	0.99	1.32	1.98	2.63
19-4-23-2 Ca	0.34	0.68	1.02	1.36	2.04	2.72
17-5-17-3 Ca-1 Mg	0.32	0.64	0.96	1.28	1.92	2.56
15-5-15-5 Ca-3 Mg	0.39	0.78	1.17	1.56	2.34	3.12
15-3-20-3 Ca-1 Mg	0.35	0.70	1.05	1.40	2.10	2.80
14-4-14-5 Ca-2 Mg	0.35	0.70	1.05	1.40	2.10	2.80
13-3-15-8 Ca-2 Mg	0.40	0.80	1.20	1.60	2.40	3.20
13-2-13-6 Ca-3 Mg	0.34	0.68	1.02	1.36	2.04	2.72
10-30-20	0.48	0.95	1.42	1.90	2.85	3.80
9-45-15	0.60	1.20	1.80	2.41	3.60	4.82

NOTE: There can be some slight differences between the values of the same formulation from different companies. You should always obtain a fertilizer chart from your manufacturer.

[1] N-P_2O_5-K_2O formula

[2]The terms conductivity, soluble salts, or electrical conductivity (EC) are all used to describe the amount of salt contained in a solution. There are also a variety of units used to measure EC including micromhos (µmho), millimhos (mmhos), microsiemens (µS), millisiemens (mS), or decisiemens. 1000 µmho/cm = 1000µS/cm = 1mmho/cm = 1mS/cm = 1dS/m.

Frequently, you are not using a pure water source without any conductivity. Therefore, you need to take the water into account when determining the relationship between EC and fertilizer concentration. Examples are given below.

Calculate ppm Nitrogen from a 20-10-20 fertilizer solution with a total EC of 1.8 mS/cm and an using irrigation water with an EC of 0.5 mS/cm.

EC of fertilizer solution	-	EC of water	=	EC of only the fertilizer
1.8 mS/cm	-	0.5 mS/cm	=	1.3 mS/cm

From the chart above, 20-10-20 with an EC of 1.3 mS/cm would give a concentration of about 200 ppm N.

To predict the EC of 20-10-20 at 200 ppm N using an irrigation water with an EC of 0.5 mS/cm.

EC of 20-10-20 at 200 ppm N	+	EC of water	=	EC of fertilizer solution
1.3 mS/cm	+	0.5 mS/cm	=	1.8 mS/cm

For growers that use proportioners or injectors, sometimes the EC of the fertilizer solution coming out of the hose is not what you expect. The problem can be caused by an incorrect dilution rate from the injector (either broken or not properly adjusted) or the fertilizer stock concentration is wrong.

To check the fertilizer concentration, take a small amount from the stock solution, dilute this in water to the target ratio, and check the EC. For example, in you think that your injectors is set at 1:100, then put 10 milliliters into 1 liter of water (this will also give a 1:100 dilution). If the EC of the solution is where is should be, then it is an injector problem. If the EC of the hand-diluted solution is off-target, then the stock concentration is not correct.

(along with a small amount of micronutrients, and dye). Dissolving 1 gram of 20-10-20 in 1 liter of pure water will give you a solution with a concentration of 200 ppm nitrogen and an EC of about 1.3 mS/cm. 20-20-20 is composed of monoammonium phosphate, potassium nitrate, and urea. Dissolving 1 gram of 20-20-20 in 1 liter of pure water will also give you a solution with a concentration of 200 ppm nitrogen but the EC will only be 0.8 mS/cm. 30-10-10 is also composed of monoammonium phosphate, potassium nitrate, and urea. Dissolving 1 gram of 30-10-10 in 1 liter of water will give you a solution with a concentration of 300 ppm nitrogen, but the EC will only be about 0.4 mS/cm.

Don't forget that the irrigation water also has an EC, which needs to be taken into account when determining the relationship between the EC and concentration of a fertilizer solution. For example, dissolving 1 gram per liter of 20-10-20 in pure water (no EC) will give a solution with an EC of 1.3 mS/cm. However, dissolving 1 gram of 20-10-20 in water with an EC of 0.5 mS/cm will give a solution with an EC of 1.8 mS/cm. See Table 2 for more information on the relationship between EC and fertilizer concentrations.

Table 3. Relationship between electrical conductivity (EC) of selected fertilizer dissolved in pure water at a constant concentration of 100 ppm total nitrogen and total dissolved solids (TDS) measurements. The exact value that you get will depend on the TDS conversion constant used by the meter.

Formula	EC value at 100 ppm N (mS/cm)	TDS conversion constants (ppm = 1 mS/cm)				
		420 ppm	***500 ppm***	***640 ppm***	***700 ppm***	***1000 ppm***
30-10-10	0.14	59 ppm	70 ppm	90 ppm	98 ppm	140 ppm
20-20-20	0.40	168 ppm	200 ppm	256 ppm	280 ppm	400 ppm
20-10-20	0.66	277 ppm	330 ppm	422 ppm	462 ppm	660 ppm
15-5-15	0.78	327 ppm	390 ppm	500 ppm	546 ppm	780 ppm
13-3-15	0.80	336 ppm	400 ppm	512 ppm	560 ppm	800 ppm

At a concentration 100 ppm total nitrogen from 20-10-20, the TDS measurement can range from 277 ppm to 660 ppm, depending on the constant used by the TDS meter. To calculate a TDS for nitrogen concentrations other than those presented above, multiply the corresponding EC from Table 1 by the constant for your meter. Examples are given below.

Calculate the expected TDS measurement of 20-10-20 at 100 ppm total nitrogen (in pure water) using a meter with a costant of 1000 ppm = 1 mS/cm.

EC of fertilizer solution at 100 ppm total nitrogen	x	Constant	=	TDS of the fertilizer
0.66 mS/cm	x	1000	=	660 ppm TDS

Predict the nitrogen concentration of 20-10-20 dissolved in pure water with a TDS measurement of 660 ppm

TDS measurement	÷	Constant	=	EC of fertilizer solution
660 ppm	÷	1000	=	0.66 mS/cm

An EC of 0.66 mS/cm corresponds to a total nitrogen concentration of 100 ppm N.

Irrigation water will also affect the TDS value. For example, a water with an EC of 0.5 mS/cm will show a TDS measurement of 500 ppm (if the constant used by the meter is 1000 ppm). At 100 ppm N from 20-10-20 (and using the same meter), the TDS measurement of the fertilizer solution would be:

TDS measurement of the fertilizer	+	TDS measurement of the water	=	TDS of the fertilizer solution
660 ppm	+	500 ppm	=	1160 ppm

Calculate the TDS supplied by only the fertilizer when the fertilizer solution (water + fertilizer) has a TDS of 1160 ppm, the water has a TDS of 500 ppm, and the constant used by the meter is 1000.

TDS measurement of the fertilizer solution	+	TDS measurement of the water	=	TDS of the fertilizer
1160 ppm	+	500 ppm	=	660 ppm

To determine the constant being used by your TDS meter, simply look at the measurable range of the meter for EC and TDS (most TDS meters are combination TDS and EC meters). For example, if the range of the meter for EC is 0 to 10 mS/cm and TDS is 0 to 10,000 ppm, then you know the constant being used is 1000 (1 mS/cm = 1000 ppm). Another way is to purchase a standard EC solution and measure the TDS of the solution. For example, a common standard EC solution used for calibrating meters has an EC of 1.41 mS/cm. A TDS meter using a constant of 1000 would measure 1410 ppm with a standard solution of 1.41 mS/cm.

Q) What is the difference between electrical conductivity (EC) and total dissolved solids (TDS)?

A) The measurement of EC and TDS are closely related. An EC meter will measure the electrical conductance of the fertilizer solution. A TDS meter will measure the EC of the fertilizer solution and then convert the measurement into parts per million (ppm) by multiplying the EC by a constant. In article 2 of this series, I said that the constant is usually 1 mS/cm = 1000 ppm salt. On further examination, I found five different constants being used by various meters ranging from 420 to 1000. See Table 3 for more information on the relationship between EC and TDS.

Q) How do I know how much of each nutrient I am applying?

A) Both EC and TDS measurements are generic measurements, they don't tell you any specifics about the fertilizer solution that you are applying. If you want to know the exact concentration of each of the nutrients that you are applying with the fertilizer, then you need to calculate that from the formula on the bag of fertilizer. See Table 4 for more information on the concentration of individual macronutrient supplied by different fertilizers.

In addition, the irrigation water can supply significant amounts of some nutrients. Unless you are using a pure water source (which contains little if any nutrients), then you should add the concentration of

Table 4. The concentration of specific macronutrients (in ppm) supplied by different fertilizers when applied at a total nitrogen concentration of 100 ppm N

	NH_4-N	Urea-N	NO_3-N	P	K	Ca	Mg	S
			Granular fertilizers					
30-10-10	7	82	11	14	28	0	0	0
21-7-7	43	57	0	14	28	0	0	48
21-5-20	31	9	60	10	79	0	0	0
20-20-20	20	53	28	43	83	0	0	0
20-10-20	40	0	60	22	83	0	0	0
19-4-23-2 Ca	30	0	72	9	100	11	0	0
17-5-17-3 Ca-1 Mg	25	0	75	13	83	18	6	0
15-5-15-5 Ca-2 Mg	8	14	79	14	83	33	13	0
15-3-20-3 Ca-1 Mg	16	0	84	9	111	20	7	0
14-4-14-5 Ca-2 Mg	14	0	86	12	83	36	14	0
13-2-13-6 Ca-3 Mg	6	0	94	7	83	46	23	0
13-3-15-8 Ca-2 Mg	5	0	96	10	96	62	15	0
10-30-20	44	0	56	129	166	0	0	0
9-45-15	100	0	0	215	138	0	0	0
6-30-30	45	0	55	215	415	0	0	0
			Liquid fertilizers					
10-5-5-2 Ca-0.5 Mg	37	0	63	22	42	20	5	0
7-9-5-2 Ca-0.5 Mg	37	0	63	55	59	29	7	1
7-7-7-2 Ca-0.5 Mg	30	0	70	43	83	29	7	1
3-12-6-2 Ca-0.5 Mg	23	0	77	172	166	67	17	3

To calculate the concentration of each nutrient in a fertilizer solution, divide the percentage of desired nutrient in the fertilizer formula by the percentage of total nitrogen in the formula, then multiply by the concentration of total nitrogen in the fertilizer solution. Examples are given below:

How much calcium will I get from 13-3-15 when applied at a concentration of 100 ppm total nitrogen?

% desired nutrient in formula	÷	% total nitrogen	x	Total nitrogen concentration (in ppm) in the fertilizer solution	=	Concentration of desired nutrient
8	÷	13	x	100	=	61.5

When you apply 100 ppm total nitrogen from 13-3-15, the fertilizer is supplying about 62 ppm calcium.

To calculate the values for phosphorus and potassium, and addition step is required. For phosphorus, the calculated value will be for P_2O_5. To calculate the actual concentration of phosphorus you are applying, multiply the P_2O_5 value by 0.43. For potassium, the calculated value will be for K_2O. To calculate the actual concentration of potassium you are applying, multiply the K_2O value by 0.83.

nutrients supplied by the water with those supplied by the fertilizer to get the total nutrient concentration applied to the plant.

Q) Do orchids require high phosphorus fertilizers?

A) Phosphorus is needed by the plant to store and transport chemical and light energy. Although there is no specific research, it appears that applying between 10 and 20 ppm phosphorus with every irrigation will supply enough phosphorus to a plant (any plant, not just orchids) for normal growth and flowering. Once this sufficient level is reached, then there is not any particular benefit to applying any more phosphorus. Thus in this case, there is no benefit to using a high phosphorus fertilizer.

When plants have a phosphorus deficiency, the older leaves tend to turn purple, and the plants show a marked loss of vigor. Unfortunately, with some plants, phosphorus deficiency is hard to see, and all you will notice is a lack of vigor with poor root growth and limited if any flowering. Because orchids are slow growing to begin with, you might not notice the problem at all. Under these circumstances, it is appropriate to apply a fertilizer that is high in phosphorus simply to get the plant growing again. However, because the plant has been stressed, you will likely see a reduction in blooming and growth when compared to plants that never had the deficiency to begin with.

A third possibility has to do with the over-application of nitrogen rather than the under-application of phosphorus. It is well know that over-applying nitrogen will cause plants to remain vegetative. For example, tomatoes, peppers, squash, new guinea impatiens, or azaleas will not produce fruit (or flowers) if too much nitrogen is applied. Rather, they will produce excess foliage growth. Reducing the nitrogen level in the soil reduces the vegetative growth, and the plants produce flowers or fruit.

Orchid fertilizers like 30-10-10 lend themselves to the over-application of nitrogen because they have a

Figure 1. How much phosphorus is necessary for flowering? Henry Mast Greenhouses from Grand Rapids, MI uses a fertilizer containing 12 ppm phosphorus applied with every watering and reports getting between 60% and 70% of their plants with double flower stalks.

lot of nitrogen per unit weight and they have a low EC or TDS measurement per ppm nitrogen. In comparison, a bloom formula like 6-30-30 has a low concentration of nitrogen per unit weight and a high EC or TDS measurement per ppm nitrogen. If you are using the same amount (or the same EC or TDS measurement) for both fertilizers, then you are over-applying nitrogen with the 30-10-10. When you switch to the 6-30-30, you are effectively reducing the nitrogen level, which in turn induces the plant to bloom.

The paradigm of using high phosphorus fertilizer to get plant to bloom has largely died out in the commercial greenhouse industry. Commercial greenhouses apply fertilizer based on the concentration of nitrogen or they will correct the EC they are applying based on the relationship between the EC and ppm total nitrogen for that specific fertilizer. By maintaining an equal nitrogen concentration and supplying a sufficient amount of phosphorus with both formulas, you probably wouldn't see much difference in growth or flowering between high nitrogen or high phosphorus formulas.

Q) What is the ideal orchid fertilizer?

A) First, the ideal fertilizer for any crop, not just orchids, is one that balances you water quality. Probably the most important aspect of this comes with the management of the substrate pH. Orchids appear to perform the best when the substrate pH is around 6.0 (similar to most other plants). However, since most substrates used for orchid production have little if any buffering, managing the balance between the alkalinity of your water and the acidity of your fertilizer is very important.

That means that the amount of acidic nitrogen should be balanced by the alkalinity of your irrigation water. If you are using a very pure water source, like rain water or reverse osmosis purified water, then your fertilizer should have no more than 10% of the total nitrogen in the ammoniacal or urea form, or you may be driving you substrate pH down to levels that may cause micronutrient toxicity problems. However, the reverse is also true. If you have a large amount of alkalinity in your water, then you should not be using fertilizers that are low in ammoniacal nitrogen or else the pH of your substrate will increase to unacceptable levels causing nutrient deficiencies.

In addition, an ideal fertilizer should supply a sufficient amount of each nutrient for growth. That means that the nutrients contained in the fertilizer should complement those supplied by the irrigation water. If the water does not contain a specific nutrient, like calcium or magnesium, then it needs to be supplied by the fertilizer. It also needs to be supplied at a concentration high enough that it influences plant growth. For example, some 20-10-20 fertilizer contain magnesium, but the amount supplied is so low that it really doesn't influence the nutrition of the plant.

Q) What is MSU "Magic" fertilizer?

A) There is nothing "magic" about the fertilizer being used by Jan Szyren at Michigan State University. Dr. John Biernbaum (from MSU), Larry Metcoff (from GreenCare fertilizers), and I designed two fertilizer formulas to be used with the two types of irrigation water found at MSU research and teaching greenhouses. The formula for pure water (13-3-15) was designed to be used with reverse osmosis purified water. Specifically, the 13-3-15 contains very low ammoniacal nitrogen (acidic nitrogen) to match the very low alkalinity of the RO water. In addition, the 13-3-15 supplies calcium and magnesium because these nutrients are not supplied by the RO water. The formula for well water (19-4-23) was designed with higher levels of ammoniacal nitrogen to compensate for the higher alkalinity levels of the well water. In addition, the formula contains a small amount of calcium and no magnesium because these two nutrients are found at high concentrations in the MSU well water. Both formulas were designed to be used at 125 ppm total nitrogen with every irrigation. At this nitrogen rate, both formulas also supplied about 12 ppm phosphorus.

It is important to note that these formulas were not designed with orchids in mind. In fact, they were not designed with any specific crop in mind. The reason that they have worked well for orchids is the same reason that they have worked well for a huge variety of plant species grown in the research and teaching greenhouses, the formulas complement their specific water qualities both in pH reaction and nutrition.