ALABAMA COOPERATIVE Extension SYSTEM

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A L A B A M A A & M A N D A U B U R N U N I V E R S I T I E S

Fertilizing Greenhouse Crops in Alabama

Contents

Introduction

Compared to other forms of agriculture, container plants in a greenhouse are grown at luxury fertility levels. This is necessary because the environment in a greenhouse is super-optimal for plant growth, and most potting media have only a moderate level of fertility at planting time. Developing a fertility program and monitoring the progress of that program are critical to a successful greenhouse business. However, many greenhouse growers are confused about what type and rate of fertilizer to use. Many try to follow a simplified “fertilizer recipe” developed by others without monitoring or understanding the impact it may have on plant growth under their growing conditions. Growers should also realize that there is more than one way to supply the fertility needs of a crop. They must account for the different sources and amounts of nutrients to ensure that plants do not receive too much or too little fertilizer.

Of the 17 nutrients required for plant growth, 12 are typically supplied through the fertility program, either preplant as part of the potting media or postplant as water-soluble fertilizer or controlled-release fertilizer. These nutrients can be classified as “macronutrients” (N, P, K, Ca, Mg, and S) or “micronutrients” (Fe, Mn, Zn, Cu, B, and Mo) based on the relative amounts needed for plant growth.

The Beginning

To begin planning the fertility program for a crop, determine what nutrients, if any, will be supplied from the water supply and potting media.

Water Supply

Certain characteristics of the water used for greenhouse crops are important to consider: the nutrient content, the effect on potting media pH, and the amount of soluble salts. Water from some sources, especially from surface water or shallow wells, can be high in one or more dissolved nutrients (typically N, Ca, Mg, S, or B) that should be subtracted from subsequent fertilizer applications. Other dissolved salts, such as sodium bicarbonate or sodium chloride, may be in the water and, together with nutrients, can contribute to high total soluble salt levels that can be detrimental to plant growth. Finally, the water supply may be alkaline and may eventually raise potting media pH resulting in poor growth or plant damage. For a more thorough discussion of water quality issues, see Extension publication ANR-1158, “Water Quality Management for Greenhouse Production.”

Potting Media

In many cases, it is both convenient and cost effective to supply several macronutrients and many micronutrients as additives to the potting media during mixing. Growers who mix their own potting media already know the nutrient content of their mix, but growers who purchase a commercially prepared medium may be less certain. To be sure of the nutrient content, take a sample of a potting medium and send it to a soil testing laboratory for analysis. This is especially important when using a medium that the grower has little experience with. In fact, many potting media and fertilizer suppliers will provide these analyses without additional charge.

Preplant Fertility

Generally, the intent of preplant fertilization is to adjust the media pH and to provide a modest amount of fertilizer in the potting media so that newly planted young seedlings or rooted cuttings have sufficient fertility to begin growth quickly. Rarely do growers try to incorporate sufficient fertilizer in the potting media for the entire duration of the crop. The advantage of this approach is that the grower has the option of adding or withholding liquid fertilization to speed up or slow down crop growth as needed. There are five categories of preplant fertilization:

pH Adjustment

One property of potting media that can have an important impact on the plant roots' ability to acquire and utilize fertilizer nutrients is the soil solution pH. Soil pH is a measure of the hydrogen ion concentration in the soil solution (relative acidity or basicity) and is measured on a logarithmic scale ranging from 0 to 14 with values of 0 to <7 being acid, 7 being neutral, and >7 to 14 being basic. Greenhouse crops vary widely in their pH optimum for growth, and each species can operate within a pH range. Therefore, plants are able to cope, to varying degrees, with changes in soil solution pH, but extremes can have a profoundly negative effect on growth. While many crops will grow well at a 5.5 to 6.5 pH, some crops require higher or lower pH values. Fortunately, greenhouse crops can be placed into pH groups and separate potting media can be designed with pH values appropriate for use with each group of plants (Table 1).

Because many of the media components used in formulating soilless mixes are acidic (mainly peat moss and pine bark), agricultural limestone can be added to raise the pH into a range suitable for plant growth. Dolomitic limestone is preferred to calcitic limestone because it supplies two important plant nutrients: slowly soluble calcium and magnesium. Dolomitic limestone comes in different particle size distributions and grades that can have a big impact on how quickly the media pH rises and how long the pH stays at a desired level. Finer grinds of limestone raise the pH quickly but may also leach from the media quickly. Coarser grinds of limestone may not raise the media pH fast enough initially but will remain active in the media longer. Different limestone grades require from 24 hours to 7 days to raise the pH of potting media to the desired level. Unfortunately, there are no standards for limestone particle sizes. The best approach is to work with one limestone brand to find the rate that provides the desired result. Then be aware that changing brands to one with a different particle size distribution and grade may change the effect on pH. Avoid purchasing "pulverized limestone" that is designed for use in masonry because it is ground very fine and will raise the pH rapidly. Always purchase "ground limestone." If calcitic limestone must be used, Epsom salts (magnesium sulfate) can also be added to the mix to provide magnesium. Because dolomitic limestone takes up to 7 days to act initially, some growers add a small amount (1 to 2 pounds per cubic yard of mix) of hydrated lime (calcium hydroxide) to raise the pH quickly before the dolomitic limestone becomes active. Hydrated lime is highly water-soluble and raises the pH quickly but does not remain active for very long because it leaches from the media.

The amount of dolomitic limestone to add to a potting mix depends on the initial pH of the ingredients, the crop grown,

Table 1. Recommended pH Ranges for Greenhouse Crops Grown in Soilless Mixes

pH range	Crop
6.5 to 6.8	Easter Lily
6.0 to 6.8	Celosia, Chrysanthemum, Cyclamen, Dianthus, Fuchsia, Geranium, Lisianthus, Pentas
5.8 to 6.2	Africa Violet, Dahlia, Geranium, Gerbera Daisy, Holiday Cactus, Hydrangea (pink), Impatiens, Kalanchoe, Marigold, Melampodium, Ornamental Cabbage/Kale, Ornamental Pepper, Poinsettia, Portulaca, Primula, Salvia, Sunflower, Zinnia
5.4 to 5.8	Ageratum, Begonia, Calibrachoa, Cosmos, Gloxinia, Ivy Geranium, Lobelia, Pansy, Petunia, Primula, Salvia, Scaevola, Snapdragon, Verbena, Vinca
5.2 to 5.6	Hydrangea (blue)
4.5 to 5.8	Azalea

the water alkalinity, and the liquid fertilization program. Ideally, potting media should be mixed with all ingredients except limestone and then be pH-tested by an institutional or private lab to determine how much limestone to add. Alternatively, several media batches can be mixed in-house with different limestone rates. Fill pots with each batch, water the media with distilled water, and measure the pH after 5 to 7 days. Additional batches with different limestone rates may be needed to find the rate necessary to achieve a target pH. As a rule of thumb, the addition of 1 pound of dolomitic limestone per cubic yard will raise the medium pH 0.1 units. General rates call for 5 to 15 pounds of dolomitic limestone per cubic yard of mix.

If the potting media does not require liming, calcium and magnesium can be added to potting media without changing the pH. Calcium can be added as gypsum (calcium sulfate) at 5 pounds per cubic yard of mix. Magnesium can be supplied using Epsom salts by mixing 0.5 pounds in sufficient water to treat 1 cubic yard. Because Epsom salts leaches quickly, the crop must be monitored closely for reapplication.

Phosphorus and Sulfur

Phosphorus can be added as either superphosphate (0-20-0) or treble superphosphate (0-45-0) when a potting medium is mixed. Superphosphate is a mineral that is mined and ground to particle sizes suitable for incorporation in potting mixes. Superphosphate is preferable because it is available as a fine powder while treble superphosphate is a *coarse,* pellet material that is more slowly available in the mix. Also, superphosphate contains gypsum that supplies additional calcium and sulfur. Superphosphate is usually incorporated at 2.5 to 4.5 pounds per cubic yard depending on the needs of the crop. If treble superphosphate is used, include 2.25 pounds treble superphosphate plus 1.5 pounds gypsum per cubic yard to provide the additional calcium and sulfur found in superphosphate.

Some growers choose not to incorporate phosphorus in the potting mix relying instead on a liquid fertilization program to supply phosphorus. In this case, be sure to choose a liquid fertilizer that will supply adequate phosphorus and add gypsum to the potting mix because few water-soluble fertilizers contain adequate calcium and sulfur. Even if phosphorus, calcium, and sulfur are incorporated in the potting mix, they may still be required in the liquid fertilization program, but in reduced amounts.

Micronutrients

The micronutrients iron, manganese, zinc, copper, boron, and molybdenum are often added to the potting medium using a commercial micronutrient product designed for this purpose. Water-soluble micronutrient products used in liquid fertilization programs are not appropriate for preplant application. Two types of commercial formulations are available for preplant mixing. Both use water-soluble micronutrient salts that are impregnated in clay granules or fine particles of glass ("fritted") to slow leaching and facilitate mixing with media. In most cases, follow the manufacturer's recommendations for a rate of incorporation in potting media. Generally, preplant micronutrient products will supply adequate micronutrients for 3 to 4 months.

There are two alternative methods of supplying micronutrients. The first is the one-time application of a water-soluble micronutrient product at a high rate as a potting media drench applied soon after planting. This method supplies micronutrients for 3 to 4 months. The second method is the use of a commercial N-P-K soluble fertilizer that also contains micronutrients. With this method, micronutrients are applied every time the crop is fertilized but at a much lower rate than the one-time application method. Whichever method is chosen, it is important to avoid duplication. Overapplication of micronutrients can cause micronutrient toxicity.

Nitrogen and Potassium

Some growers add a "starter charge" of soluble nitrogen and potassium to the potting mix so young seedlings or rooted cuttings have sufficient fertility to begin growth quickly. This can be especially useful at times when fertilization with these nutrients cannot begin right away, such as when plants are under mist propagation. Generally, nitrogen and potassium are supplied from calcium nitrate and potassium nitrate at a rate of 1 pound of each per cubic yard of mix. This rate supplies adequate nitrogen and potassium to young plants for the first 10 to 14 days. Incorporating nitrogen and potassium in the potting mix is optional. If a liquid fertilization program can begin soon after potting, it may be unnecessary.

Controlled-Release Fertilizers

Controlled-release fertilizers are products manufactured from fertilizer salts designed to release fertility at a controlled rate over time. This is accomplished by coating the fertilizer with materials, such as sulfur, waxes, polyethylene, polyurethane, or acrylic resins. Many growers find that combining controlled-release fertilizer with water-soluble fertilizer in an overall fertility program provides better results than water-soluble fertilizer or controlled-release fertilizer alone. Temperature, moisture, and thickness of the coating determine the release rate of these products. Of these, temperature is the most important. Higher temperatures accelerate fertilizer release while lower temperatures slow fertilizer release.

Controlled-release fertilizer can be either mixed with the potting media or added as a top dressing after planting. Top-dressing involves adding a predetermined amount of the product (based on container size) to the media surface. Fewer nutrients are lost from leaching with top dressing compared to the amount lost with media incorporation because the nutrients must travel down through the soil profile and are retained by the soil or taken up by the plant. Top-dress and media incorporation rates are usually printed on the product container. Do not exceed the manufacturer's recommendations. Problems from overapplication are difficult to correct. If both a controlled-release product and postplant water-soluble fertilizer are to be used in a production system, reduce the rates of both to achieve the total nitrogen rate desired for the crop grown.

Postplant Fertility

The most common type of postplant fertility for greenhouse crops is liquid fertilization using a water-soluble fertilizer. It is important to provide a continuous supply of nitrogen and potassium because these nutrients leach from the media quickly. Small amounts of phosphorus and sulfur are also often included despite being mixed in the media. These nutrients may leach from soilless media quickly, and it is difficult to predict when their levels will fall short of crop needs.

Fertilization Frequency

Two methods are commonly used by growers today: (1) **constant liquid fertilization,** which involves applying a dilute solution of fertilizer at each irrigation; and (2) **scheduled fertilization,** which calls for a more concentrated solution of fertilizer that is applied at periodic intervals, usually once per week. Labor inputs and the availability of delivery equipment determine which method to use. It may be better to use scheduled fertilization in a greenhouse business where access to a fertilizer injector is limited. However, when fertilizer injectors are an integral part of the irrigation system, constant liquid fertilization is easier. Many growers prefer constant liquid fertilization for the following reasons:

- Fertilizer nutrients are constantly available in the soil solution for root uptake with little fluctuation in concentration. With scheduled fertilization, fertilizer concentrations may be very high at the time of application but may be very low a week later, just before the next fertilization.
- The chance of dangerously high fertilizer concentrations in the media is low because a dilute solution is applied every time the plants require water. In practice, many growers make one clear water application every 3 to 4 fertilizations as insurance against fertilizer levels that are too high.
- From a management point of view, two tasks, watering and fertilizing, are combined. In addition, workers don't have to decide whether to fertilize.
- Inherent in this method is that nutrient application adjusts to the needs of the plants. For example, during sunny, warm weather, plants require more nutrients for growth. Under these conditions, the potting media will dry faster, require watering more often, and, therefore, receive fertilizer more often. Conversely, during cool, cloudy weather, plants need fewer nutrients for growth. Under these conditions, the potting media will dry more slowly, require water less frequently, and, therefore, receive fertilizer less often.

Fertilization Rate

Fertilization rates for water-soluble fertilizers in the greenhouse industry are based on parts per million (ppm) of nitrogen in the fertilizer product. It would seem that with all the fertilizer formulations and different types of crops grown in greenhouses, the decision of what rate to apply would be a difficult one. However, a rate of 240 to 720 ppm nitrogen applied weekly or a rate of 90 to 250 ppm nitrogen applied at every watering works well. In practice, crops can be placed in categories (Table 2) based on fertility requirements: seedlings, light, moderate, and heavy. Concentration ranges are provided because growers often reduce the rate (lower end of recommended range) in the winter, during cloudy periods, or when other factors slow growth and raise the rate (higher end of range) in the summer, during sunny periods, or when other factors speed growth. When the category of a particular crop is known, it is easy to assign rates to it.

Growers may also increase or decrease fertilizer rates depending on the stage of growth, the desired rate of growth, or the leaching percentage during irrigation. With respect to stage of growth, young seedlings and newly rooted cuttings are sensitive to high fertility, therefore, lower fertilizer rates are used (Table 2). Plants growing vegetatively require higher fertility while those approaching flower have a decreasing need for fertilizer. Growers also often reduce or eliminate fertilization before shipping plants to customers to increase product shelf life in a retail setting. Despite concerted efforts to schedule crops for market dates, it is sometimes necessary to speed up or slow down growth to meet target shipping dates. This may be accomplished, to a limited degree, by increasing or decreasing fertilizer rate or application frequency. Finally, leaching percentage (the percent of total irrigation applied that drains from the containers) can have a significant impact on crop fertilizer requirements. In general, a higher leaching percentage requires a higher fertilizer rate.

Table 2. Categories of Greenhouse Crops Based on Fertility Requirements Using Constant Liquid Fertilization

Category	Rate, ppm nitrogen	Crop
Seedlings	50 to 100	Seedlings in plug flats, Ornamental Pepper
Light	100 to 150	Africa Violet, Ageratum, Azalea, Begonia, Celosia, Coleus, Cosmos, Dianthus, Gloxinia, Impatiens, Lobelia, Marigold, Melampodium, Pansy, Pentas, Petunia, Portulaca, Primula, Salvia, Snapdragon, Verbena, Vinca
Moderate	150 to 200	Begonia, Carnation, Coleus, Cyclamen, Dahlia, Dusty Miller, Easter lily, Fuchsia, Geranium, Gerbera Daisy, Holiday Cactus, Hydrangea, Ivy Geranium, Kalanchoe, Lisianthus, Ornamental Cabbage/Kale, Portulaca, Rose, Sunflower, Verbena, Zinnia
Heavy	200 to 250	Chrysanthemum, Poinsettia

Nitrogen : Potassium Ratio

Most crops develop well when the balance between nitrogen (N) and potassium (K) is approximately equal. There are a few exceptions. Elatior begonias grow faster and develop more side shoots when the fertilizer ratio is 2 N: 1 K. The requirement for azaleas is 3 N: 1 K, while carnations grow best when the ratio is 2 N: 3 K. Excess potassium can reduce the uptake of calcium (Ca), magnesium (Mg), manganese, ammonium, and zinc. A 4 K: 2 Ca: 1 Mg ratio in the potting media will limit antagonism among these nutrients.

Phosphorus : Nitrogen Ratio

Sufficient phosphorus can usually be incorporated in the medium to satisfy a 3- to 4-month crop using superphosphate. However, it is hard to determine when that supply runs out, and phosphorus may leach quickly if the medium pH is allowed to fall adversely low. Traditionally, too much phosphorus has been applied in greenhouse production and the excess ends up in ground water. Excess phosphorus in the potting medium reduces plant growth, reduces flower size, and can induce deficiencies of iron, copper, manganese, and zinc. High phosphorus can also cause stretching (excessive internode elongation), especially in marigolds and pansies. How much is enough or too much? The exact answer is not well known and is crop dependent. However, applying phosphorus at a concentration of one-half the rate of nitrogen is sufficient for most crops even when it has not been incorporated in the medium. Some growers inject phosphoric acid into the water supply to control water alkalinity. Be sure to subtract the amount of phosphorus injected from the fertilization program. A 10 N: 10 K: 10 Ca: 5 Mg: 1-2 P ratio in the potting media will limit antagonism among these nutrients.

Ammonium : Nitrate Nitrogen Ratio

Three different forms of nitrogen are used in formulating fertilizers: nitrate, ammonium, and urea. Plant response to these nitrogen forms varies, though the responses to ammonium and urea are about the same because urea must be converted to ammonium before plants can use it. Generally, high ammonium and urea fertilizers stimulate rapid leaf expansion and internode elongation but may suppress flowering and root growth. High nitrate fertilizers keep plants more compact with less internode elongation (thicker leaves and stems) and improves root growth and flowering.

Under certain conditions, ammonium can become toxic to plants when the ammonium plus urea percentage of a fertilizer is above 40 percent of the total nitrogen. Growers can calculate this percentage with the information on the fertilizer bag by adding the percent ammonium to the percent urea, dividing by the percent total nitrogen, and multiplying by 100. Ammonium toxicity symptoms appear as interveinal V-shaped chlorosis with green veins and downward cupping of younger leaves. Normally, nitrifying bacteria in the soil convert ammonium and urea to nitrate, but the optimum pH for these bacteria is about 7.0. In soilless media where the pH is usually 6.0 and below, these bacteria may be less active. The bacteria are also much less active when the potting media is cool (< 60 degrees F). Therefore, the combination of cloudy, cool weather in winter, lower pH, and nearly saturated media (limiting oxygen) can bring disaster from ammonium toxicity. In addition, high ammonium can contribute to stretching of plants under winter conditions. The availability of nitrate nitrogen to plant roots is not linked as strongly to media temperature or bacterial activity. Generally, the best approach for preventing ammonium toxicity is to use fertilizers with 25 to 40 percent of total nitrogen in the ammonium plus urea forms during winter. It would be a mistake, however, to assume that ammonium and urea are bad and eliminate these from the fertility program. Plants grown on all nitrate nitrogen often have short, thick stems and small, brittle leaves. During warm, bright times of the year, ammonium and urea promote vegetative growth.

Calcium and Magnesium

The importance of calcium and magnesium in greenhouse fertility programs has been given particular emphasis recently. Most of these nutrients can be supplied from the potting media by incorporating dolomitic limestone to adjust pH. Additional amounts may come from the water source. However, dolomitic limestone may not release calcium and magnesium quickly enough for some crops and may run out for long-term crops. It is important to test the water source and potting media to determine how much of these nutrients are present and to know if the water-soluble fertilizer you are using contains these nutrients since many do not. This information is printed on the fertilizer bag label. Generally, acidic, high ammonium fertilizers contain little if any calcium and magnesium while basic, high nitrate fertilizers contain high calcium but may or may not contain magnesium. One postplant fertilization strategy is to alternate between these two types of fertilizers and supplement magnesium with Epsom salts. A 2-5 Ca: 1 Mg ratio in the potting medium will limit antagonism between these nutrients.

Commercial Fertilizer Formulations

Commercially available, water-soluble fertilizers are combinations of fertilizer salts called *fertilizer carriers.* A portion of fertilizer carriers contains essential nutrients for plant growth while the rest is nonnutritive. Commercial fertilizers used in greenhouse production come in a variety of formulations. Complete fertilizers contain three macronutrients: nitrogen, phosphorus, and potassium, in various proportions (for example, 20-10-20). Fertilizer packages are labeled with these three percentages. The first indicates the percent of actual nitrogen (N); the second, the oxide form of phosphorus (P_2O_5); and the third, the oxide form of potassium (K_2O). Other commercial fertilizer formulations may lack one of the three macronutrients, most commonly phosphorus (for example, 15-0-15).

The most common commercial formulation of water-soluble fertilizer used for many years by the greenhouse industry was a 20-20-20. However, 20-20-20 contains about 70 percent of the nitrogen in the form of ammonium and urea that can cause plants to stretch, may cause ammonium toxicity during cloudy, cool times of the year, and is too high in phosphorus. A 20-10-20 formulation is more often used today. Several companies manufacture this formulation of fertilizer either with or without micronutrients. If preplant phosphorus is added to the potting medium, the 10 percent phosphorus is superfluous. In this case, use a low or no phosphorus fertilizer.

Low-light conditions tend to favor plant stretching, especially in seedlings. In low light, fertilize less often or at a lower rate and use a fertilizer with less ammonium, urea, and phosphorus and more calcium and nitrate. High light conditions favor rapid growth and plants use nutrients more quickly, particularly when plants are grown in a retractable-roof greenhouse or outdoors. Under these conditions, fertilize more often or at a higher rate and use a fertilizer with more ammonium, urea, and phosphorus.

If preplant micronutrients are added to the potting medium, fertilizers containing micronutrients may be unnecessary or harmful to some crops. In general, crop species with low media pH requirements need higher micronutrient concentrations than species with a high media pH requirement need. A media pH that is too low for high pH-requiring crop species can increase micronutrient availability and lead to toxicity symptoms, especially of iron and manganese. Symptoms of micronutrient toxicity are bronze speckles on older leaves followed by necrotic pitting along the margins. Lisianthus, celosia, marigold, New Guinea impatiens, and seed and zonal geraniums are susceptible. Irrigation water in some localities may contain high iron levels. Be sure to test your irrigation water for iron. Levels greater than 0.5 ppm can be a problem for sensitive species. Calcium and magnesium deficiencies can also develop at low pH levels increasing the chance of ammonium toxicity. Conversely, a media pH that is too high can lead to micronutrient deficiencies, in particular, iron deficiency in petunias and pansies and boron deficiency in salvia, petunias, and pansies.

Fertilizer Acidity/Basicity

Most water-soluble fertilizers will change the potting media pH to some extent. Some are very acid, such as 20-20-20 (potential acidity 583), while others are mildly basic, such as 15-0-15 (potential basicity 420). Potential acidity, or basicity, is printed on the fertilizer label based on calcium carbonate as a benchmark. This number provides some indication of how acid or basic a particular formulation is. See Table 3 for some common acid and basic fertilizer formulations. Note that acid fertilizers tend to contain greater amounts of ammonium nitrogen while basic fertilizers contain much less ammonium nitrogen. One consequence of fertilizer chemistry is that basic fertilizers also tend to be low in phosphorus. Potting media pH can be somewhat controlled through fertilizer selection. Fertilizers with potential acidity will lower pH while fertilizers with potential basicity will raise pH. However, large changes in media pH cannot be accomplished by changing fertilizer formulation.

Fertility Monitoring

Diagnosing nutritional problems in greenhouse crops requires a combination of experience, methodical process, and information on the nutrient status of the crops. A lot of the uncertainty in identifying nutritional problems can be reduced by keeping accurate, up-to-date records on the day-to-day events in the production process and, specifically, the details of the fertility program. Despite these efforts, nutritional problems arise even in the most carefully thought-out fertility programs. Several tools are available that allow growers not only to identify and correct nutritional problems when they arise but also to forecast problems. These include visual diagnosis, tracking soluble salts and pH, water testing, soil testing, and foliar analysis.

Visual Diagnosis

Visual diagnosis is probably the least reliable method of fertility monitoring because it requires considerable experience and can vary by crop species, cultivar, and the conditions under which the crop is grown. While information is available depicting visual symptoms of deficiencies or toxicities of individual nutrients in greenhouse crops, in actual practice, visual diagnosis is often problematic because several nutritional problems can occur at the same time. When this occurs, it is almost impossible to sort out the problems with visual symptoms. Other causal agents, such as too much light, incorrect temperature, air pollution, plant pathogens, spray injury, and even dripping cold water can also complicate diagnosis. Another drawback to visual diagnosis is that it can only be employed after crop damage and reduction in crop quality have occurred. Often, nutritional problems are at least partially reversible, but crop quality may be reduced and crop timing may be delayed. If this occurs late in the production cycle, the crop may never reach its full potential even if the problem is corrected.

Tracking Soluble Salts and pH

Soluble salts consist of all the organic and inorganic components in the soil solution that conduct electricity. These include salts from preplant amendments, water-soluble fertilizers, controlled-release fertilizers, irrigation water, residual fertilizer, media components, and compounds resulting from microbial decomposition of organic matter. Some fungicide products applied as a media drench also contribute to soluble salts. Excessive soluble salts in the potting medium can be first identified by plant wilting in the bright and warm middle-of-the-day conditions. These plants can fully or partially recover in the evening as temperature and light levels decrease. However, overall growth is reduced and

Table 3. Potential Acidity or Basicity of Common Water-Soluble Fertilizers

Formulation	Potential Acidity	Formulation	Potential Basicity
21-7-7	1560	17-5-17	0
9-45-15	940	17-0-17	75
20-20-20	583	15-5-15	135
20-10-20	422	13-2-13	200
15-15-15	261	14-0-14	220
15-16-17	165	15-0-15	420

plant stunting can occur. Roots may die at the tips and root hairs are damaged, particularly if the medium is allowed to dry out. In severe cases, leaf margins and tips become necrotic, especially on lower leaves. High soluble salts have also been linked with an increased incidence of root rot diseases.

Water-soluble fertilizers vary in how much they affect soluble-salts levels in the potting media. Consider the salts index of fertilizers when selecting a fertilizer product. Salts index refers to the relative drought-inducing effect produced by a fertilizer compared to an equal weight of sodium nitrate. This information can usually be found on the fertilizer bag label. Select a fertilizer formulation with a low salts index, but also consider the nutritive content of the formulation.

Soluble salts are a fairly reliable measure of the fertility status of a crop as long as the major source of salts is from the fertility program and not other sources, such as the water supply. Remember that measuring soluble salts does not determine the concentration of individual fertilizer nutrients. A laboratory soil analysis is required to quantify nutrients. A measure of soluble salts is often referred to as electrical conductivity, abbreviated E.C. in trade literature. E.C. and pH of a sample solution are measured using an E.C. and pH meter available at greenhouse supply businesses. A good meter can be purchased for less than $200. It should last for years, if well maintained. However, the pH probe is not very durable and may need replacing every few years. Be sure to purchase E.C. and pH standard solutions for calibrating the meter and follow the manufacturer's instructions.

Even though the meters used to measure E.C. and pH are simple to use, the units of measure for E.C. can be confusing. The traditional unit that most growers recognize is "mmhos/cm" (mmhos/centimeter). Yet, university laboratories and researchers use "S/cm" (siemen/centimeter). These units are synonymous. Electrical conductivity reported as "mmhos/cm" (millimhos/centimeter) or "mS/cm" (millissiemen/centimeter) are both E.C. $\times 10^{-3}$. Occasionally, E.C. may be reported in "μmhos/cm" (micromhos/centimeter), which is E.C. $\times 10^{-6}$. Conversion to mmhos/cm is simply a matter of moving the decimal three places to the left (for example, 2,500 μmhos/cm = 2.5 mmhos/cm).

Several sample extraction methods are used for E.C. and pH testing, including the 2:1 method, the saturated media extract method, and the pour-through method. Private and institutional laboratories use the saturated media extract method for soil testing. It is accurate, but most growers do not have or wish to purchase the equipment needed for this method. The 2:1 method is still used by some growers but is quickly being replaced by the pour-through method, which has several advantages:

- Results closely reflect the actual soil solution to which roots are exposed.
- The method requires less time and equipment than other sample methods require.
- Extracts can be sent to a soil testing laboratory for nutrient analysis.
- Roots are not disturbed and the method is not destructive.
- Controlled-release fertilizer prills are not ruptured in the sampling process or included in the sample, a situation that can occur with other methods.

The pour-through method of nutrient extraction for container media involves pouring distilled water into the media and collecting the extract (leachate). Purchase distilled water at grocery stores or mass-market outlets. The basic procedure for the pour-through method is as follows:

1. The moisture level of the container media should be at or near container capacity. Water (fertilize on constant liquid fertilization) the pots 1 hour before using the pour-through method.
2. Place the pot in a container suitable for collecting all leachate (a plastic saucer) from the pot drainage holes. If the bottom of the saucer does not have raised ridges, place a 1-inch section of PVC pipe under the pots so that water drains from the pots unobstructed. Sample 10 pots and calculate an average pH and E.C.
3. Slowly pour sufficient distilled water on the medium surface to collect about 50 ml (1.7 ounces) of leachate from the pot. Leachate amounts more than 70 ml will overdilute the sample and give misleading results. For a 6-inch pot, start with ¾ cup (6 ounces) distilled water.
4. Test the leachate for pH and E.C. using a meter(s). Refrigerate samples if the "analysis" cannot be performed quickly. Freezing is recommended for extended storage. Allow samples to reach room temperature before testing. General, recommended sufficiency ranges are provided in Table 4 with comparison values using other methods.

The leachate obtained from this method results from displacement of soil solution by water poured onto the soil surface. Although a little dilution

Table 4. Electrical Conductivity Sufficiency Ranges for Several Extraction Methods

2:1	SME*	Pour-Through	Indication
0 to 0.3	0 to 0.8	0 to 1.0	Very low
0.3 to 0.8	0.8 to 2.0	1.0 to 2.6	Low
0.8 to 1.3	2.0 to 3.5	2.6 to 4.6	Normal
1.3 to 1.8	3.5 to 5.0	4.6 to 6.5	High
1.8 to 2.3	5.0 to 6.0	6.5 to 7.8	Very high
< 2.3	> 6.0	> 7.8	Extreme

* Saturated media extract

occurs, resulting readings should be very close to the soil solution and, when constant liquid fertilization is used, be close to the E.C. of the fertilizer solution.

Many growers only check soluble salts and pH when a problem is perceived. **However, scheduled sampling and measurement of soluble salts and pH allow the grower to track trends in these factors and make corrections before problems arise.** Sample 5 to 10 plants weekly from a crop and average the results for soluble salts and pH. Mark these results over time on a chart that indicates the target ranges for these two parameters. Figure 1 shows an example chart for E.C. generated in a computer spreadsheet. Target ranges for E.C. and pH for individual crops can be found in trade literature or on the World Wide Web. Values outside the target range should be a concern and require the grower to take corrective action. Tracking soluble salts and pH is probably the simplest and least expensive way to monitor crop fertility. However, generating this information requires a commitment by management to purchase the equipment and, perhaps more importantly, allocate the labor to monitor media fertility weekly. This resource allocation should be considered against the consequences of crop damage or loss caused by an improperly managed fertility program.

Water Testing

See Extension publication ANR-1158, "Water Quality Management for Greenhouse Production," for information on water testing.

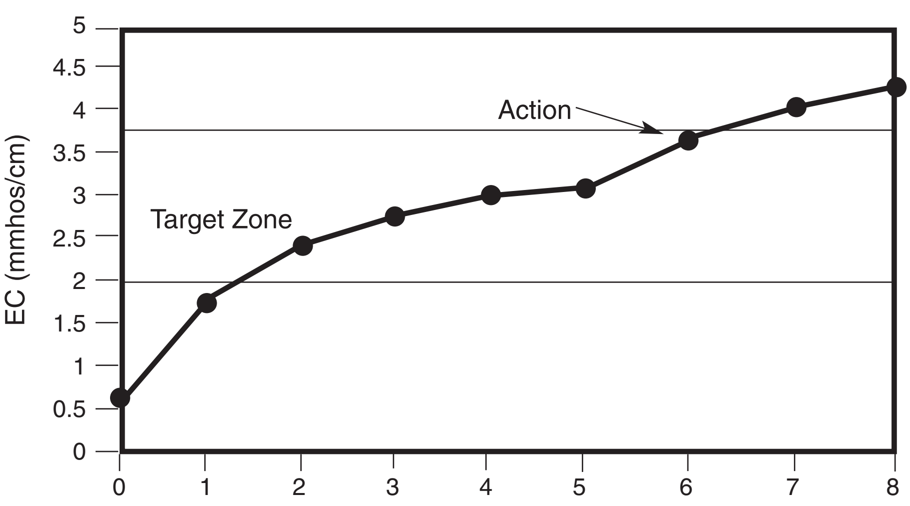

Figure 1. Electrical conductivity chart created on a computer spreadsheet

Soil Testing

Potting media testing at periodic intervals during the production cycle is one of the best ways to track the fertility status of a crop. Samples are taken and sent to a commercial or university lab for analysis of the media nutrient content. Many commercial potting media and fertilizer suppliers provide free media and plant analysis. Consult your suppliers to find out if these services are provided. Often growers utilize these services only when a problem becomes apparent. However, once visual symptoms appear, crop quality may have already suffered. Some growers object to media testing because of the cost and time required to collect samples. However, this must be compared with potential crop loss. Usually a compromise can be found between the cost of processing a large number of samples and gaining the information needed to track a crop's fertility status. See Extension publication ANR-1190, "Submitting Greenhouse Samples for Laboratory Analysis," for details.

Plant Analysis

Plant analysis is an analysis of representative plant parts, usually leaves, to determine the concentration of nutrients as well as potentially toxic elements that a plant has taken up. (See Extension publication ANR-1190, "Submitting Greenhouse Samples for Laboratory Analysis," for sampling details.) Plant analysis works very well because a strong relationship exists between leaf composition and growth. Plant analysis should be combined with soil testing because each provides some information that the other does not. Soil testing provides information about nutrients currently available in the soil solution and those held in reserve in the potting media, while plant analysis provides information about nutrients that have been accumulated in plant tissues. Both are useful because cases often arise in which nutrients may be present in the media but are not present in plant tissues in sufficient quantities due to secondary factors such as pH. Data for interpreting plant analysis results can be found in "Plant Analysis Handbook II" by H.A. Mills and J.B. Jones Jr., 1996, MicroMacro Publishing, Inc.

Corrective Procedures

Conducting potting media testing in-house on a regular basis and periodically through a commercial or institutional laboratory will help keep the fertility program for a greenhouse crop on track. The following are corrective procedures for several common fertility problems.

Low pH

A potting media pH that is too low for a particular crop may be caused by insufficient limestone incorporation into the potting media, use of a limestone with a grind too coarse, the limestone's running out toward the end of a long term crop, or the consistent use of an acid fertilizer. Small increases in pH, 0.5 to 1.0 units, can be accomplished over time by changing to a basic fertilizer. Larger or more rapid pH increases can be accomplished in several ways: (1) Mix 1 pound of hydrated lime with 100 gallons of water and allow the solution to settle overnight. Then drench the plants with the clear solution, not the residue in the bottom. (2) Mix 1 pound of hydrated lime with 3 to 5 gallons of water and allow the solution to settle overnight. Utilize the clear solution by applying it using a 1: 100 or 1: 128 injector. Hydrated lime is fairly corrosive so avoid contact with skin or metal and rinse the foliage of plants after application.
(3) Apply a potassium bicarbonate drench at a rate of 13.4 ounces per 1,000 gallons. Keep in mind that this also supplies 39 ppm potassium that affects subsequent fertilizer selection.
(4) Apply a flowable limestone product according to the manufacturer's directions. These products are more expensive than hydrated lime but are less corrosive and less likely to damage plants.

High pH

A potting media pH that is too high for a particular crop may be caused by excessive incorporation of limestone into the potting media, use of a limestone with a grind too fine, high water alkalinity, or consistent use of a basic fertilizer. Small decreases in pH, 0.5 to 1.0 units over time, can be attained by changing to an acidic fertilizer. Larger or more rapid pH decreases can be accomplished in several ways. Acidify the water to a 5.8 pH by neutralizing about 80 percent of the alkalinity with acid injection (see Extension publication ANR-1158, "Water Quality Management for Greenhouse Production"). To rapidly lower pH, drench the crop with 1.0 to 2.5 pounds of iron sulfate or aluminum sulfate per 100 gallons of water. Rinse the foliage with water after application to prevent foliar damage. These chemicals will raise media soluble salts and may release toxic levels of micronutrients.

Low Soluble Salts

Low soluble salts may result from excessive leaching during irrigation or applying fertilizer at a rate that is too low or too infrequent for the crop species being grown. Low soluble salts can be remedied by increasing the fertilizer rate or frequency, by reducing the leaching fraction during irrigation, or by combining these procedures.

High Soluble Salts

The first step in reducing soluble salts is to leach the potting media twice with clear water at about a 1-hour interval then let the media dry to a normal level. Test the soluble salts and reapply the double leaching again if necessary. If the plant roots have been visibly damaged, do not resume fertilization until new root growth is evident. Next, re-examine irrigation practices and fertilization rate and frequency and have the water supply tested.

Calcium Deficiency

Calcium deficiency symptoms initially appear as stunted plant growth, necrotic leaf margins on young leaves, and eventual death of terminal buds and root tips. Plant damage is difficult to reverse, so take corrective action immediately. Make supplemental applications of calcium nitrate at 200 ppm nitrogen. Test and correct the pH if necessary because calcium deficiency is often associated with low pH.

Magnesium Deficiency

Magnesium deficiency symptoms appear initially as marginal, interveinal chlorosis of older, lower leaves. These symptoms will advance inward on the leaves followed by marginal necrosis. The chlorosis can be corrected, to some extent, but the marginal necrosis cannot. Make a supplemental application of magnesium sulfate (Epsom salts) at a rate of 1 to 2 pounds per 100 gallons of water. Do not mix Epsom salts with other fertilizers.

Iron Deficiency

Iron deficiency symptoms appear as interveinal chlorosis on young leaves that can progress throughout the shoot and result in a shot tip death in severe cases. Deficiency can occur when the potting media pH exceeds 6.5, when roots are damaged, when the potting media is overwatered or poorly drained, or when excess amounts of phosphorus, manganese, copper, or limestone are applied. These problems must be addressed to achieve long-term correction. Symptoms can be alleviated by applying a foliar spray of iron sulfate at a rate of 4 ounces per 100 gallons of water. Alternatively, apply a foliar spray or media drench of a commercial iron chelate product, for example, Sprint 330 or Sequestrene 330. Sprays act more quickly but create a greater chance of foliar damage, and they may leave an unsightly residue. Follow the manufacturer's recommendations. Early morning application is preferable because foliar uptake is enhanced by slower spray drying time.

Manganese Deficiency

Manganese deficiency symptoms appear as mottled, interveinal chlorosis on young leaves that progresses to necrosis. Plant damage is difficult to reverse so take corrective action immediately. Excess levels of iron, calcium or magnesium can induce manganese deficiency symptoms. Alleviate symptoms by applying a foliar spray of manganese sulfate at a rate of 2 ounces per 100 gallons of water. Early morning application is preferable because foliar uptake is enhanced by slower drying time. Manganese uptake is also greater during the light period than it is in the evening. Alternatively, manganese sulfate can be applied as a media drench at a rate of 0.5 ounces per 100 gallons of water, but the results are slower. A 2 Fe: 1 Mn ratio in the potting media will limit antagonism among these nutrients.

Boron Deficiency

Boron deficiency symptoms appear as distorted and clubby young leaves and stems followed by death of the shoot tip and precocious lateral shoot development. Plant damage is difficult to reverse so take corrective action immediately. Excess levels of potassium and calcium and high pH (>6.5) can induce boron deficiency symptoms. Recommended levels are 0.25 to 0.6 ppm boron in the potting media and 60 to 80 ppm in plant tissues. Petunias and pansies may need higher levels. Alleviate symptoms by applying a potting media drench of 0.5 to 0.75 ounces of borax or 0.25 to 0.43 ounces of Solubor per 100 gallons of water.

Additional Reading

D. Wm. Reed (ed). 1996. Water, media, and nutrition for greenhouse crops. Ball Publishing, Batavia, Illinois.

P.V. Nelson. 1998. Greenhouse operation and management. Prentice Hall, Upper Saddle River, New Jersey.

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For more information, call your county Extension office. Look in your telephone directory under your county's name to find the number.

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