

Greenhouse Substrates and Fertilization

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Everyone seems to be searching for the ideal plant mix. The criteria are simple: make a mix with good aeration, that doesn't dry out too quickly, can be used in all cell sizes, contains all the nutrients necessary, can be used for all species of and stores indefinitely. All that is needed is a substrate that is not affected by other forces in the greenhouse; a mix that does not change with cultural practices.

Obviously, trying to make the mix totally responsible for air, water and nutrition will be unsuccessful. A better strategy is to integrate the mix into a production system that addresses substrate aeration and water retention as well as plant nutrition and fertilization requirements.

Aeration and Water Retention

Balancing the air and water contents has been one of the biggest problems facing greenhouse growers, especially plug and bedding plant growers. Just after seeding, plugs are too wet, and many drown. But later on, plugs dry out too quickly, as plants mature and increase in size. To compensate for changing plant demands, growers must change their watering practices as the plugs mature. The same holds true for newly transplanted cuttings (pot mums, poinsettias) and bedding plants.

People tend to think of the mix as the overriding factor that determines air and water content in the root zone. Therefore most mixes made over the last 20 years have been classed according to their air and water values, as if they were fixed properties of the mix. They are not. There are four major factors which affect the air and water status in containers. These factors are like the four corners of a plug or tray cell; each is necessary in supporting the air and water content in that cell (Figure 1). The four corners are: ① the substrate (components and ratios); ② the container (height and shape); ③ substrate handling procedures; and ④ watering practices. Each of these four factors have a profound effect on air and water content.

The Substrate. Indeed, the substrate can greatly influence the air and water content in the root zone. Mixes do differ in porosity, but most mixes used in greenhouses are fairly close in total porosity; usually between 80 and 90% (Figure 2). Keep in mind that the majority of what you purchase when buying or blending a mix is SPACE.

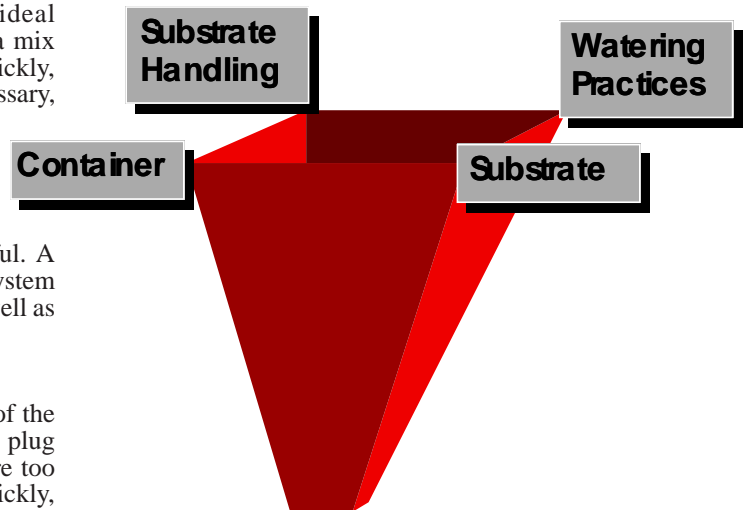


Figure 1. The four major factors which affect the air and water status in containers.

Most mixes used in greenhouse plant production contain 30 to 60% (percentage of the solid fraction) peat moss or 30 to 60% of a peat moss plus composted pine bark combination.

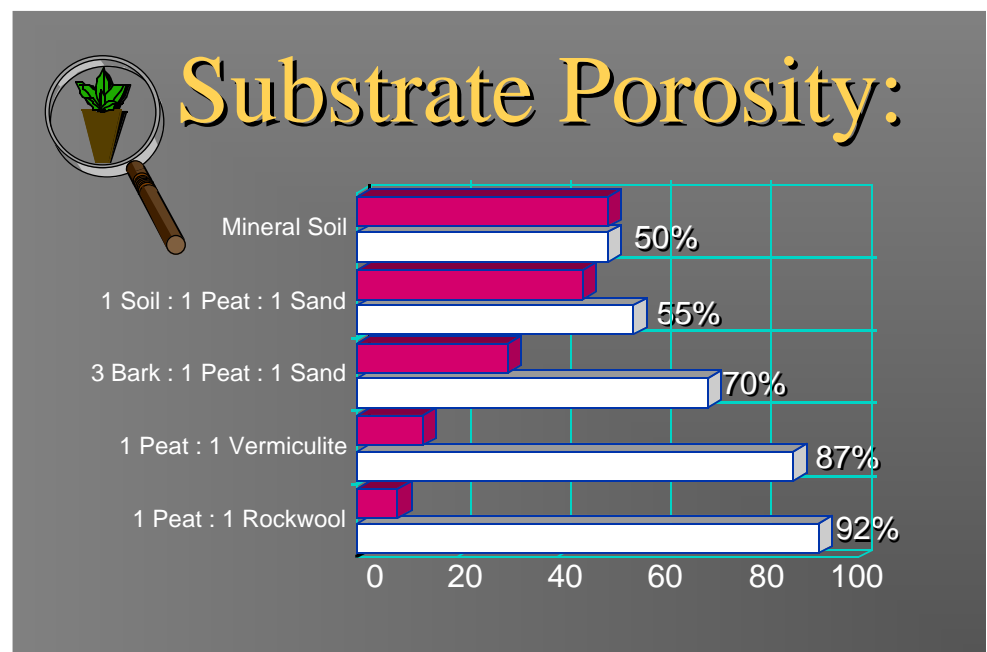


Figure 2. Substrate porosity (indicated by the white bars; dark bars are the percent solid fraction in the mix) can change with substrate components, but most floriculture mixes will have a porosity of 80 to 90%.

These two mix components can vary in quality, and growers should select peatmoss and pine bark based on the following.

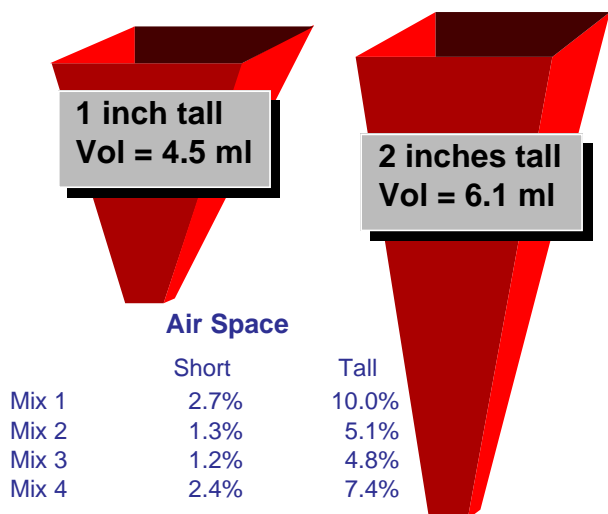


Figure 3. Effect of cell height on air space (reported as percent by volume) in the substrate.

Generally, sphagnum peat is preferred because it has an advantageous fiber structure over hypnum or reed-sedge peats, which allows for good aeration and drainage. A word of caution--simply using a sphagnum peat does not assure you of uniformity. If the peat has been milled too much, fibers can be

crushed and the quality will be reduced. Mix ingredient quality control is essential for repeatable, consistent production results.

If the mix does contain pine bark, the bark should be composted and not "green." Bark that is aged and not composted will result in nutritional imbalances due to microbes decomposing the bark and their ability to absorb nutrients more efficiently than plants.

Aggregates are generally added to peat moss to provide more rapid drainage and increase aeration. Most commonly, vermiculite, perlite and polystyrene beads are added. Vermiculite is the aggregate used most often and in the largest ratio, from 20 to 60% by volume (percentage of the solid fraction). The size of the vermiculite is very important. The size of vermiculite commonly used in general potting mixes and bedding plant flat mixes is #2 (horticultural grade). This does provide larger pores, and is recommended for large-celled flat production and large containers (pots). However, plug mixes generally contain grade #3 (which is finer) to allow the mix to flow more evenly into the trays at filling. Ironically, grade #3 is one of the poorest aggregates for adding air space. It holds less water and much less air. It is also more susceptible to compaction and structural collapse.

What does all of this mean? First, peat plays a much more dominant role in plug and bedding plant flat production than in larger containers (bark is rarely used in plug substrates). Second, aggregates may or may not help improve drainage depending on size and shape of particles. Third, smaller particle sizes do not necessarily improve air and water content and can

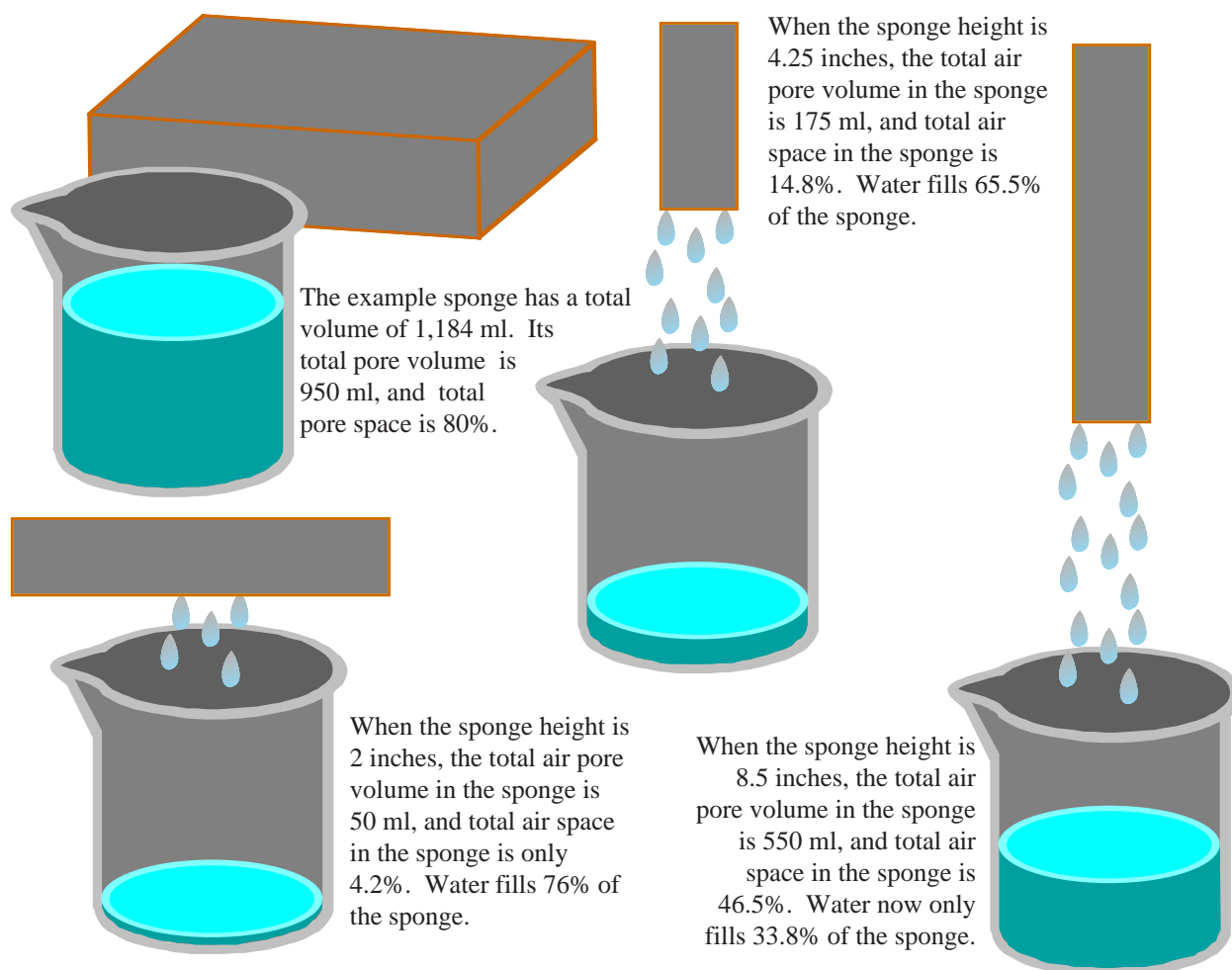


Figure 4. Container height drastically affects air space in a substrate.

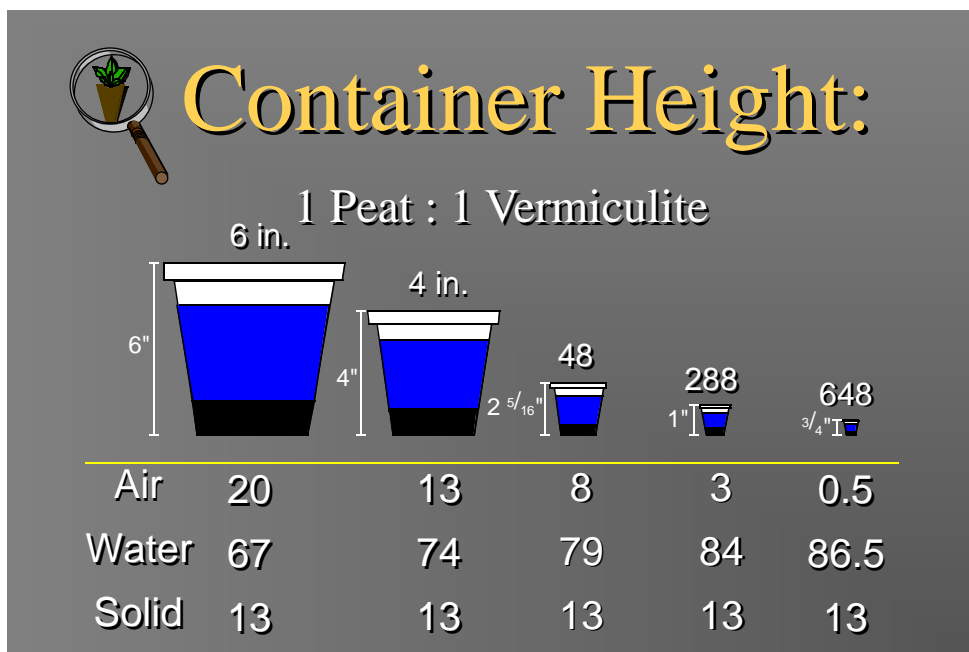


Figure 5. Container height will affect how much pore space will be filled with air and with water after watering. The substrate used was a 1 peat moss : 1 vermiculite (v : v) mix. Notice that total porosity (air + water) does not change with container height.

in fact hurt. When selecting a substrate, examine the contents and particle sizes prior to deciding on what is best for the crop (plugs, bedding plant flats, or larger containers) that are being grown.

The Container. The second “corner” of cell air and water content is container height and shape. For large containers and large cell flats, container effects are not as much of a concern, but the effects of containers are greatly accentuated in plugs.

The main reason why it can be harder to grow a good plug than a good pot mum is the plug cell itself. Plug cells have only two basic problems - they are too short and too small. They are so short that at best they drain very little and at worst (like in the 648 waffles) they do not drain at all. For example, a 1 peat: 1 vermiculite mix has an air space of 2.8% by volume in the 288 cell and only 0.5% in the 648 tray. This same mix has an air space value of 13% in a 4 inch pot (4" tall) and 20% in a 6 inch pot (6" tall).

The importance of height is illustrated well by Figure 3. A normal 273 plug is approximately 1 inch tall. We “manufactured” a tall 273 cell with the same length and width at the top opening, but made it 2 inches tall with the same general taper. The effect on drainage was dramatic. The four mixes in Figure 3 are commercial plug mixes run through our lab for diagnostic purposes and are simply listed as Mix 1, 2, 3, and 4. Notice the difference in air content between the short and tall plugs. Air content went from a range of 1% to 3% in the short plugs to 5% to 10% in the tall. If we could get 10% air space in all of our plugs we could cut our plug production problems in half. Taller cells equals more air space. Obviously, it is possible to grow good plugs in short plug cells. But the smaller the cells, the greater the chance of the plants being over-watered and under-watered.

This phenomenon of changing percent air space based on container height is sometimes called a “perched water table” effect. After watering a container, there will always be a portion of the substrate at the bottom of the container that does not drain, and pores remain saturated with water. This saturation zone is a larger percent of the total volume in shorter containers. A good

demonstration sometimes used to visualize the effect of container height is a sponge (Figure 4). Imagine that the sponge is the substrate in a container. The example sponge in Figure 3 is 2" × 4.25" × 8.5". This is a total volume of 72.25 cubic inches or 1,184 ml. When fully saturated (squeezing out all the air then soaking in water), the sponge holds 950 ml; the total porosity is 80%. Holding the sponge so it has a 2 inch height resulted in about 50 ml water being drained. The sponge had 4.2% air space when two inches tall. Turning the sponge on its side to create a height of 4.25 inches drained another 125 ml; total air space of 14.8%. Holding the sponge so the height is 8.5 inches drained another 375 ml and resulted in a total air space of 46.5%! Notice the difference in the total volume drained from the sponge, depending on the height. This effect holds true for

different height containers filled with the same substrate as well (Figure 5). The height of the container will dictate the total air space of the substrate after drainage of excess water.

Another issue is container shape. Good plugs can be grown in both round or square plug cells. “Round” cells are actually portions of a cone, while “square” cells are sections of pyramids (Figure 6). Of the two designs, the square cells are preferred because they have a larger volume. In Figure 6 we see a round and a square 288 cell. If you calculate the volumes of each you find that the round cells has a volume of 4.66 ml, while the square cell has a volume of 6.18 ml. Although these numbers are small, the square cell is 33% larger than the round one. This extra volume translates to more water being available to the plant and less chance of drying out. This extra volume does not necessarily increase air space percentage. However, as long as the height remains the same, there is no decrease in drainage, so air space is not adversely affected. There is no advantage to growing in round cells. Even if you can get a

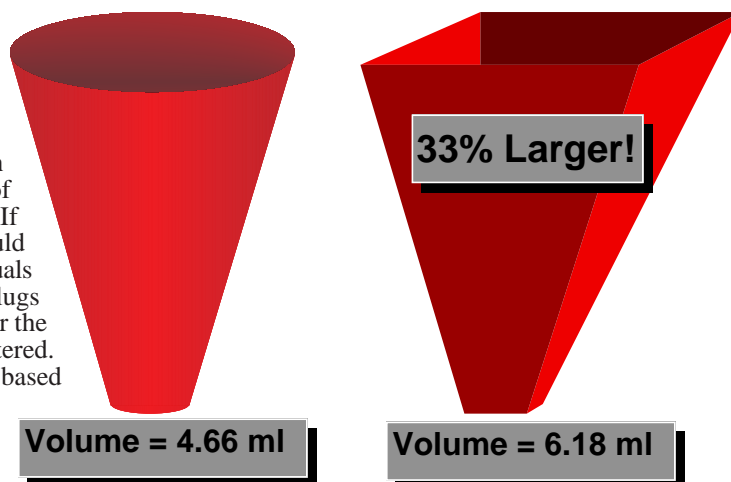


Figure 6. Container shape can affect cell volume, as demonstrated by these two 288 cells.

better price on round trays, the decrease in container and substrate volume is not worth it.

Substrate Handling. The “third corner” for air and water in bedding plant cells is substrate handling. How a mix is handled can greatly affect the air and water content of the mix. All efforts to select the best material, conscientiously blend them and carefully package them and ship them can be undone on the other end by someone who handles the mix improperly.

What should growers be cognizant of? One factor is *compaction*. Pots (containers), cell paks and plug trays should be lightly filled and the excess brushed away. This can be accomplished by hand or machine flat fillers and pot fillers. The substrate should not be packed down, and pots and trays should not be stacked directly over one another. Air space can be cut in half or even completely eliminated by compaction (Table 1).

Table 1. Effects of compaction on air space (AS), unavailable water (UW), and available water (AW) in 48 cell bedding plant flats filled with a 1 peat : 1 vermiculite substrate.

Compaction	AS %	UW %	AW %
light	9	21	58
medium	4	26	56
heavy	2	30	52

The second consideration is the *moisture content* of the mix prior to container filling. When water is added to dry components, such as peat, they hydrate and swell. This swelling helps to create more aeration by reducing the tendency of the particles to nest within one another. This effect is not so dramatic on larger containers, but can be the difference between success and failure of a plug crop. Most plug mixes tend to be

inadequately moistened prior to flat filling. Water should be added to the mix before it is placed into the cells / pots. Ideally, the substrate should be moistened, mixed, and allowed to set overnight prior to use. However, even a 2 hour wait after adding the correct amount of water is beneficial for the hydration process.

How much water should be added to the mix? For peat-based substrates used in large containers and bedding plant cell pak production, use a 1 water : 1 oven dry substrate (w : w) ratio (50% moisture content). Plug mixes should have a 2 water : 1 dry substrate ratio (67% moisture content) prior to filling the plug tray. The rule of thumb is, the smaller the cell, the more water to add prior to planting. This level of moisture will seem much wetter than “normal,” but will actually improve aeration (Table 2). Increasing initial moisture content from 60 to 70% more than tripled the air space of a 273 plug (Table 2).

Table 2. Effect of substrate moisture content on total porosity (TP), unavailable water (UW) and air space (AS) of a 1 peat moss : 1 vermiculite mix in a 273 plug tray. TP, UW, and AS are reported as % of plug volume.

Moisture (% wt)	TP	UW	AS
60%	87	21	2
70%	88	16	7

Figure 7 outlines how to calculate the initial moisture content of a mix and lists how much water is present at different moisture levels. Once you have calculated the initial moisture percentage, add the difference between the target water volume and the initial water volume. For example, if your initial moisture percentage is 20%, there are 5 gallons of water per cubic yard of substrate. If you want a moisture content of 50%, you should add 15 gallons of water per cubic yard. If you want a moisture content of 67%, then 35 gallons should be added per cubic yard.

Note that the table in Figure 7 is based on substrates having a bulk density of 0.1 g/cm³ (168.55 lb/yd³ or 6.2426 lb/ft³). If the substrate you are measuring has a different bulk density, then you must adjust the gallon numbers given in the table in Figure 7 for water additions. To measure the bulk density (BD) of your substrate, weigh 1 cubic foot of oven-dried substrate. Insert the measured BD into the equation below:

$$1 + [(BD - 6.2426) \div 6.2426] = \text{gallon multiplier}$$

Multiply the numbers in the water volume column of the table in Figure 7 to adjust for the bulk density of your substrate. For example, if your measured BD is 5 lb/ft³, then the resulting numbers in the water volume column would be: 0, 1.6, 4.0,

Moisture Content

Best for cells

Percent Moisture Content:

$$[(IW - DW) \div IW] \times 100$$

- IW = initial weight of substrate
- DW = dry weight of substrate
- weigh 3 known volumes (~1 cup each)
- dry in 225 °F oven for 24 hours
- take dry weights
- use averages in above formula
- add difference needed

Best for plugs



Water volumes present in one cubic yard of peat : vermiculite or peat : perlite plug mixes.*

Moisture** (% weight)	Water volume (gal/cubic yard)
0	0
10	2
20	5
33	10
50	20
60	30
67	40
72	50
75	60

*Calculations based on dry bulk density of 0.1 g/cc (6.25 lb/cu ft).

**Actual calculations based on mass wetness values of 0, 0.1, 0.25, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 g/g, respectively.

Figure 7. How to calculate moisture content of a substrate and to reach a targeted moisture content.

8.0, 16.0, 24.0, 32.0, 40.0, and 48.1 gal/cubic yard. If your measured BD is 8 lb/ft³, then the resulting numbers in the water volume column would be: 0, 2.6, 6.4, 12.8, 25.6, 38.4, 51.3, 64.1, and 76.9 gal/cubic yard.

Adding the correct amount of moisture to a plug mix prior to use eliminates the need for heavy watering after seeding. Light misting for germinating the seed is fine but the mix does not need more moisture after filling, if moisture content was adjusted prior to filling flats..

Pre-filling pots, cell paks or plug trays and letting them dry out can be detrimental if they are handled much before they are remoistened. Continuous flow mixers can also cause problems when portions of the mix sit on the conveyor belts overnight. Slight separation of the mix can occur on the belt which can result in a “different mix” in several containers.

Watering Practices. The fourth “corner” for air and water in cells is watering practices. How you water a mix can influence air and water content in the root zone more than the mix itself, especially for plugs. Because plugs do not drain well they are easily over-watered. There is an old saying in the greenhouse business, “the person at the end of the hose controls your profits.” This is certainly true for plug production. Knowing when to water is perhaps the most important skill for a bedding plant grower. It is also the biggest headache.

Watering is the product of frequency of irrigation × volume of water applied. For best aeration and water availability, as cell size decreases, decrease water volume and increase irrigation frequency. Also, the smaller the cell size, the smaller the droplet size should be to avoid “blasting out” the cells and plants.

By understanding the four corners outlined in Figure 1, you can begin to use them as management options. They should be considered together, as a package when trying to optimize the air and water conditions in pots, bedding plant cells, and plug tray cells. Each of the factors are interrelated, and none can be modified without affecting the rest.

Nutrition and Fertilization

Growers are responsible for providing 12 essential plant nutrients--six macronutrients (N, P, K, Ca, Mg, and S) and six micronutrients (Fe, Mn, Zn, Cu, B, and Mo). Fortunately, 10 of the nutrients can be added to the substrate prior to planting in quantities that will last for most bedding plant cropping periods. This makes a postplant liquid fertilization program easy to manage.

Incorporated fertilizers. A minimum base charge is placed in the mix (Table 3) and additional nutrition is applied as liquid feed. This gives the grower added flexibility in speeding up or holding back plants. Also, liquid feeding will provide a more uniform distribution of nutrients from cell to cell, tray to tray and even house to house than incorporation into the mix. Preplant nutrient additions fall into four categories: ① pH adjustment materials; ② phosphorus and sulfur sources; ③ micronutrient sources; and ④ a nitrogen and potassium starter charge.

The most commonly used pH adjustment material is dolomitic limestone. In addition to raising the pH to a desired level, dolomitic limestone also supplies *calcium* and *magnesium*. If a calcitic limestone and / or calcium hydroxide material is used instead of dolomite, growers should incorporate Epsom salts to supply ample Mg. An alternate source of calcium (for substrates not requiring a large lime charge) is gypsum (CaSO₄·2H₂O). Gypsum should

be incorporated in the substrate if the pH adjustment material is not supplying sufficient calcium.

Phosphorus additions are sometimes made during bedding plant substrate blending. Treble (triple) superphosphate (0-45-0) is used to supply phosphorus. Many growers used to use superphosphate (0-20-0), which also contained sulfur. Since triple superphosphate does not contain sulfur, growers should incorporate gypsum as a sulfur source (Table 3).

Some bedding plant growers will not incorporate phosphorus into the substrate, but will rely on the liquid fertilization program to supply P. If there is no P incorporated in your substrate, select a liquid fertilization program that does supply P. Even if phosphorus and sulfur are incorporated into the substrate, additional P and S may be required in the liquid fertilization program. Phosphorus and sulfur are both susceptible to leaching during production, and it is difficult to generalize on the rate of leaching for different growing systems. Monitor crops through substrate and tissue tests to determine if additional applications of P and S are needed in your liquid fertilization program.

Micronutrient programming for bedding plants is pH-dependent (see following section on substrate pH). An initial incorporation of micronutrients is recommended for all bedding plants; the need for subsequent applications in the liquid feed program should be determined by species requirements. For example, species requiring a low substrate pH generally require micronutrients in higher concentrations than species requiring

Table 3. Nutrient sources commonly added into greenhouse substrates during formulation.

Nutrient source	Rate per cubic yard	
	Soil-based substrates	Soiless substrates
<u>For pH regulation and to provide calcium and magnesium</u>		
Dolomitic limestone	0 to 10 lb	10 to 15 lb
<u>To provide phosphorus</u>		
Triple superphosphate	1.5 lb	2.25 lb (≤1 lb)*
<u>To provide sulfur</u>		
Gypsum (calcium sulfate)	1.5 lb	1.5 lb (1 lb)*
<u>To provide micronutrients: iron, manganese, zinc, copper, boron, and molybdenum</u>		
Esmigran®	5 lb	5 lb (2.5 lb)*
OR		
Micromax®	1 to 1.5 lb	1 to 1.5 lb (0.5 to 0.75 lb)*
<u>To provide nitrogen and potassium (optional)</u>		
Calcium nitrate	1 lb	1 lb (≤1 lb)*
Potassium nitrate	1 lb	1 lb (0 lb)*

*Plug substrate recommendations differ from other greenhouse substrates. Plug substrate recommendations (when different from the general rates) are given parenthetically. Soil-based substrates are not generally used or recommended for plugs.

Table 4. Suggested substrate pH ranges for specific greenhouse crops grown in a soilless substrate. For crops not listed, the recommended pH range is 5.4 to 6.2.

Species	pH	Why?
Celosia	6.0 to 6.8	prevent Fe & Mn toxicity
Dianthus	6.0 to 6.8	prevent Fe & Mn toxicity
General Crops	5.4 to 6.8	pH tolerant
Geranium	6.0 to 6.8	prevent Fe & Mn toxicity
Marigold (African)	6.0 to 6.8	prevent Fe & Mn toxicity
Pansy	5.4 to 5.8	prevent B & Fe deficiency; avoid Thielaviopsis
Petunia	5.4 to 5.8	prevent B & Fe deficiency
Petunia	5.4 to 5.8	prevent B & Fe deficiency
Salvia	5.4 to 5.8	prevent B & Fe deficiency
Snapdragon	5.4 to 5.8	prevent B & Fe deficiency
Vinca	5.4 to 5.8	prevent B & Fe deficiency; avoid Thielaviopsis

a high substrate pH (see Table 4 for pH recommendations). If the pH is not kept in the recommended range, micronutrient additions should be adjusted accordingly: increase micronutrient additions to low-pH requiring species if the pH is too high; decrease or avoid micronutrient additions to high-pH requiring species if the pH is too low.

The addition of a *nitrogen* and *potassium* charge in the substrate at mixing is optional. If liquid feed can be started soon after planting then they are not necessary additions to the mix. The decision to incorporate N and K into the substrate is a matter of personal choice based on experience.

Substrate pH. The pH of the substrate, as estimated by measuring the pH of a substrate extract, is very important to plug and bedding plant nutrition. The pH directly affects the availability of many plant nutrients, especially micronutrients (Figure 8).

Too low of a pH can result in increased micronutrient availability that can lead to phytotoxic responses in some plant species. For example, a low pH in conjunction with excessive levels of iron and manganese can result in iron and /or manganese toxicity in celosia, geraniums and marigolds (Table 4). Calcium and magnesium deficiencies can develop when the pH is too low. There is a greater chance of ammonium toxicity problems in low pH conditions; and phosphorus leaching increases at a low pH.

At the other end of the spectrum, pH above 6.2 can lead to problems such as iron deficiency chlorosis in petunias and pansies; and boron deficiency in salvia, petunias, and pansies (Table 4).

Most bedding plant crops (grown in a soilless substrate) can tolerate a pH of 5.4 to 6.8, but there are exceptions that growers must know (Table 4). There are three categories of bedding plants with respect to substrate pH: ❶ species that require a low pH for best growth; ❷ species that require a high pH for best growth; and ❸ species that are relatively pH tolerant. Growers should target substrate pHs based on the species being produced and should treat species

according to their requirements rather than using a blanket production system.

The ideal production situation is one where substrate pH is identical to the requirements of the particular species being produced; and no changes occur. Preventing pH changes will eliminate many of the nutrient problems encountered in bedding plant production. Unfortunately, there are many forces at work that affect substrate pH, and maintaining a constant pH is no easy task.

There are four major forces that affect the substrate solution pH during plant production: ❶ preplant materials such as dolomitic limestone put into the substrate and the substrate components themselves; ❷ the alkalinity of the irrigation water; ❸ the acidity / basicity of the fertilizers used during production; and ❹ the plant species being grown. With so many factors affecting pH, it's no wonder that pH stabilization is easier to write about than to implement!

Preplant materials. As previously mentioned, the starter lime charge should be adjusted based on the substrate components used in the mix and the desired starting pH. Although you know what starting substrate pH is best for the species you intend to grow, it may take from 24 hours to 7 days for the pH to adjust up to the desired level after the mix has been moistened. The length of this "equilibration period" will depend on the ratio of components used in creating the substrate; particle size and grade of lime used; the salts used to make the

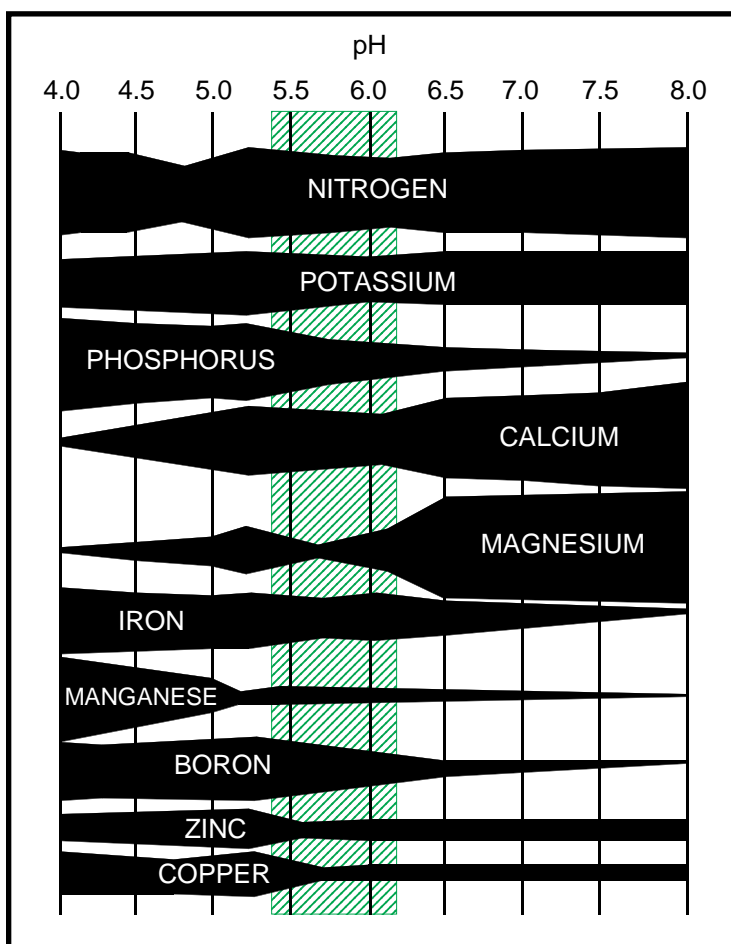


Figure 8. Influence of pH on the availability of essential nutrients in a soilless substrate containing sphagnum peat moss, composted pine bark, vermiculite, and sand. The pH range recommended for most greenhouse crops is indicated by slashed lines.

base nutrient charge, and the pH and alkalinity of your irrigation water.

Prior to using a mix, fill a few pots with it, water them in with distilled water, and set them in the greenhouse for a few days, keeping them moist. After this equilibration period, measure the pH of the substrate; it should be within the range targeted for the species being grown. If it is far off target, you may need to adjust your pH control strategy.

Water alkalinity. The alkalinity of your irrigation water is a key player in the substrate solution pH. The greater the alkalinity, the greater the tendency for substrate pH to rise over time. Research at NCSU that varied the initial lime charge in plug trays and varied the alkalinity of irrigation water used in plug production shows that over time, the effect of the alkalinity in the irrigation water far exceeds that of the initial lime charge (Figure 9). Acidification of high alkalinity water may be required to prevent an undesirable rise in substrate pH.

Cooperative research between Allen Hammer and Brian Whipker at Purdue University and the authors of this article led to the development of an Excel® spreadsheet that allows users to input their water pH and alkalinity then select sulfuric, phosphoric, or nitric acid to use as an acidifying agent to reach a target pH or alkalinity. The spreadsheet modules calculate the nutrient additions from the acid injection and will report your acidification costs, if you input the price per gallon for the acid you wish to use. You can acquire a copy of this spreadsheet to aid in your water acidification needs via the world wide web (http://www2.ncsu.edu/ncsu/cals/hort_sci/floriculture/) or by contacting the authors.

Fertilizer Acidity / Basicity. Most of the fertilizer salts we use have some effect on the substrate pH (Table 5). Some such as 21-7-7 are very acid (high acidity) while others such as 15-0-15 are fairly basic (high basicity). Fertilizer acidity / basicity relates to how the pH of the substrate solution changes after the fertilizer is applied and plants absorb nutrients from the substrate. The ratings given in Table 5 are used by fertilizer manufacturers, but are based on the fate of fertilizer salts in a mineral based soil out in the field as measured by researchers in the 1930s! Further research is needed to better define acidity and basicity of common fertilizers in greenhouse substrates.

We can lower, raise, or hold constant the pH of plugs and bedding plants by fertilizer selection. Unfortunately, most acidic fertilizers also have a correspondingly high proportion of ammoniacal nitrogen and cannot be relied on as the only means of reducing the substrate pH. For example, if too much ammoniacal nitrogen is applied in plug production, the plants will stretch excessively and will develop undesirably succulent growth. We will discuss the effects of ammoniacal and nitrate nitrogen in more depth when we address post-planting fertilization.

Species effect on substrate pH. Research at NCSU has shown that bedding plants will modify the substrate pH during germination and seedling growth (Figure 10). However, many species change the pH to a level that is not best for their growth! For example, celosia and dianthus (both grow best at a higher pH) tend to lower the substrate pH. Vinca raised the substrate pH, though vinca grows best at a lower pH. Growers must be aware of species

effects on substrate pH, especially when monitoring the pH of a plug crop during production. Imagine the nightmare of a plug producer basing their entire pH control program on samples of a single species; or on a combined sample of different species. Do you monitor the substrate pH of species *separately* and adjust pH according to sample results? Our research results indicate you should.

Strategies to control pH. We need to establish pH base lines for all major bedding plant species, similar to those suggested in Table 4. Next, upper and lower "decision points" must be determined for each species. Decision points are limits that determine when action must be taken to correct or prevent an out-of-range pH. We have already described the tools available to us in regulating pH for a given species -- preplant materials, regulation of water alkalinity, and fertilizer selection tailored for each species. The final stage of a pH stabilization strategy is to decide how to control pH in your particular production system, then to monitor frequently to assure that you are within the acceptable pH range for each of your crops.

The example pH plot in Figure 11 is assuming a pH base line of 5.8; an upper decision limit of 6.2; and a lower decision limit of 5.4. For this hypothetical species, a grower would target pH 5.8 when adding the liming components into the substrate prior to seeding. They would want to take corrective measures to lower pH if sampling showed a substrate pH of 6.2 or above. Corrective measures to lower pH include: ① acidifying your water down to pH 5.8 (neutralizing ~80% of the alkalinity in your irrigation water); ② discontinuing the use of basic residue fertilizers, such as calcium nitrate and using acid-residue fertilizers to lower the pH, if plants are capable of tolerating the ammoniacal nitrogen; and ③ in severe cases, drenching with aluminum sulfate or iron sulfate to rapidly lower pH. The substrate pH would need to be raised if it fell below 5.4. Corrective measures to raise pH include: ① discontinuing irrigation water acidification, if any is employed; ② using basic-residue fertilizers to raise the substrate pH; and ③ in severe cases, injecting potassium bicarbonate to increase the alkalinity of your irrigation water to increase the substrate solution pH.

There is still much to learn about pH regulation and how to incorporate it into a nutrition program. We have only begun to outline standards, but we hope to eventually create control

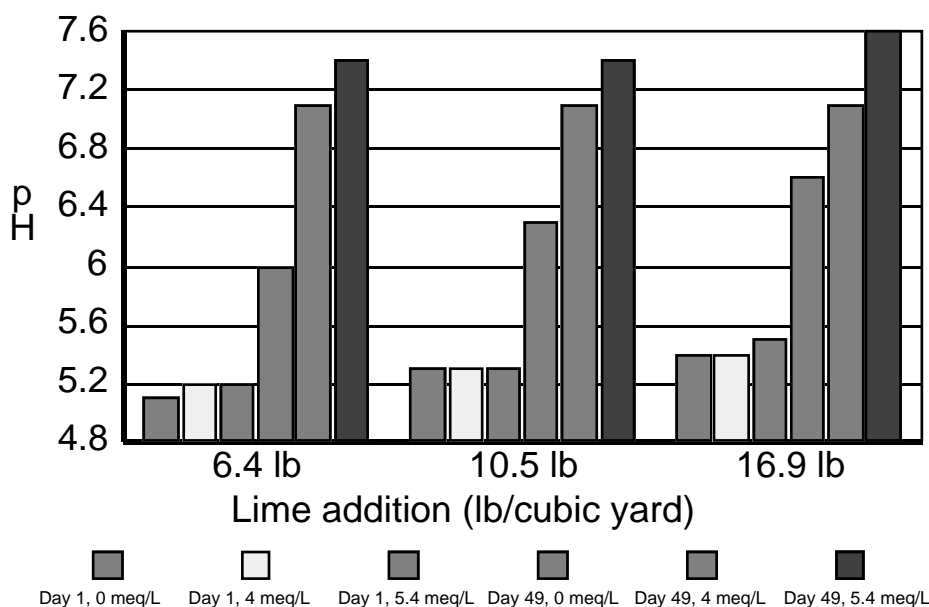


Figure 9. Change in vinca 'Pretty in Rose' substrate pH due to initial substrate liming charge (dolomitic limestone) and irrigation water alkalinity.

Table 5. Potential acidity or basicity, percent of total nitrogen in the ammonium plus urea form, and Ca, Mg, and S components (when these are $\geq 0.2\%$) for several commercial fertilizers.

Fertilizer*	Potential acidity or basicity**	NH ₄ (%)***	Ca (%)	Mg (%)	S (%)
21-7-7	1,700 A	90	—	—	10.0
21-7-7	1,560 A	100	—	—	—
20-2-20	800 A	69	—	—	—
20-18-18	710 A	73	—	—	1.4
24-7-15	612 A	58	—	1.0	1.3
20-18-20	610 A	69	—	—	1.0
20-20-20	583 A	69	—	—	—
20-9-20	510 A	42	—	—	1.4
20-20-20	474 A	69	—	—	—
16-17-17	440 A	44	—	0.9	1.3
20-10-20	422 A	40	—	—	—
21-5-20	418 A	40	—	—	—
20-10-20	393 A	38	—	—	—
21-7-7	369 A	100	—	—	—
15-15-15	261 A	52	—	—	—
17-17-17	218 A	51	—	—	—
15-16-17	215 A	47	—	—	—
15-16-17	165 A	30	—	—	—
20-5-30	153 A	56	—	—	—
17-5-24	125 A	31	—	2.0	2.6
20-5-30	118 A	54	—	0.5	—
20-5-30	100 A	54	—	—	—
15-11-29	91 A	43	—	—	—
15-5-25	76 A	28	—	1.3	—
15-10-30	76 A	39	—	—	—
20-0-20	40 A	25	5.0	—	—
21-0-20	15 A	48	6.0	—	—
20-0-20	0	69	6.7	0.2	—
16-4-12	73 B	38	—	—	—
17-0-17	75 B	20	4.0	2.0	—
15-5-15	135 B	28	—	—	—
13-2-13	200 B	11	6.0	3.0	—
14-0-14	220 B	8	6.0	3.0	—
15-0-15	319 B	13	10.5	0.3	—
15.5-0-0	400 B	6	22.0	—	—
15-0-15	420 B	13	11.0	—	—
13-0-44	460 B	0	—	—	—

*Notice that identical analyses can have different acidities, basicities, and percent NH₄, depending on the manufacturer.

**A = pounds of calcium carbonate limestone required to neutralize the acidity caused by using one ton of the specified fertilizer. B = equivalent pounds of calcium carbonate limestone added by using one ton of the fertilizer.

***Refers to the percentage of total nitrogen that is in the ammonium plus urea forms; the remaining nitrogen is nitrate-N.

graphs similar to Figure 11 for most bedding plant species produced. Through careful monitoring and precise production management, pH-related nutrition problems can be avoided.

Postplant fertilization. There are three aspects of postplant fertilization to be covered in this article: ① rate and frequency of fertilization; ② pH effects of fertilizers; and ③ ammonium versus nitrate nitrogen in a fertilization program.

The exact fertilizer concentration to use depends on stage of growth, plant species, desired rate of growth, leaching

Species Effect on pH

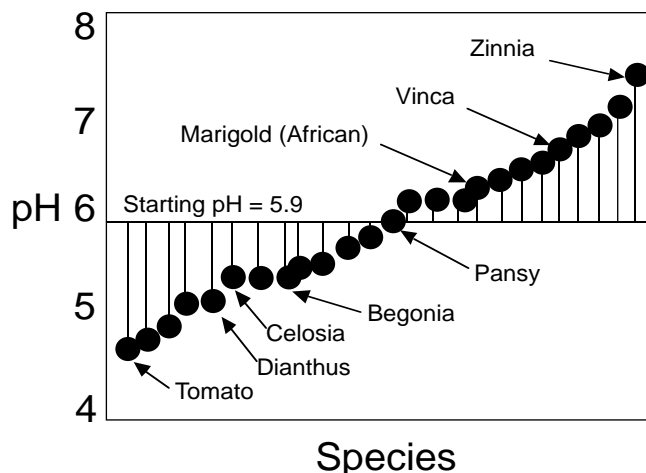


Figure 10. Effects of 25 bedding plant species on substrate pH.

percentage during irrigation, and frequency of fertilizer application. As frequency of fertilization increases, fertilizer concentration should be decreased. For bedding plant flat systems, common choices are fertilization at each watering, each week, or every two weeks (Table 6); while for plugs, choices are fertilization at each irrigation, every other irrigation, or every 3rd irrigation (Figure 12).

Young seedlings and plugs are sensitive to fertilizer salts and have a very low fertilizer requirement, thus the lower rates. Recommendations more specific to plug production are given in Figure 12.

Growers must vary the fertilizer concentration or the application frequency for bedding plant species because species have very different nutrient requirements. Crops with light needs include broccoli, cabbage, cauliflower, impatiens, and pansy. They should be fertilized at or below the lowest concentrations listed in Table 6 and Figure 12. Crops requiring heavy fertilization include begonia, dusty miller, portulaca, verbena, and vinca. These should be fertilized at the high end of the ranges given. Other species not listed should be fertilized using mid-range values.

Required rate of growth is difficult to predict. During a dark, rainy period, fertilization should be reduced to prevent excessive plant stretch. When the market does not open up as rapidly as anticipated, growers may need to hold back bedding plants, and again fertilization should be reduced. There will also be cases where the market may open earlier than anticipated and crops will need to be "pushed" (increase fertilization).

Leaching percentage during irrigation (the percentage of irrigation solution that drains out of the container after irrigation) is a large factor in fertilization requirements of plants. The greater the percent of leachate, the greater chance for loss of fertilizer salts. In general, a greater percent of leaching requires a greater fertilization rate.

The importance of substrate pH control was outlined previously. Fertilizers applied to bedding plants may either raise or lower the pH. Postplant pH can be controlled to a certain degree through fertilizer selection (Table 5). Fertilizers with potential acidity will lower substrate pH while fertilizers with potential basicity will raise the substrate pH. One factor in selecting a fertilizer should be pH regulation.

Another factor in selecting a fertilizer should be the ammonium and nitrate content. Ammoniacal nitrogen stimulated greater leaf expansion and internode elongation than



Substrate pH Regulation

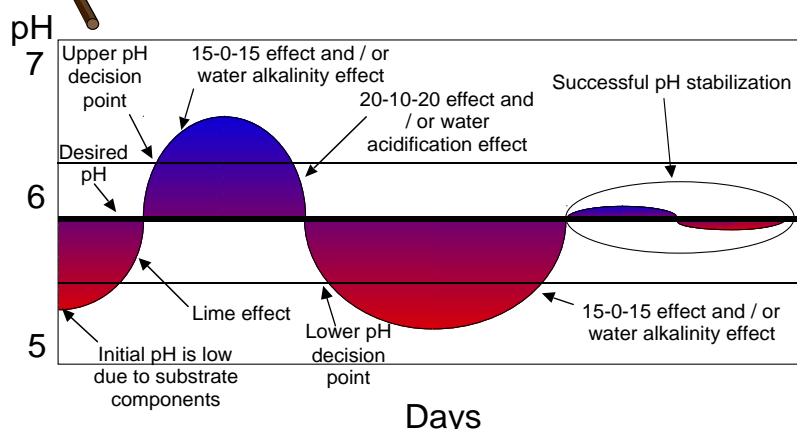


Figure 11. An example pH regulation strategy based on a desired pH of 5.9.

nitrate nitrogen. However, too high a percentage of ammoniacal nitrogen (greater than 40%) can lead to ammonium toxicity problems and should be avoided.

Use fertilizers that contain 15 to 40% of the nitrogen in the ammoniacal or urea form (Table 5) to stimulate rapid growth. Use fertilizers containing less than 15% ammoniacal or urea nitrogen (Table 5) to help keep plants compact and keep growth "hard".

Acid fertilizers tend to contain higher amounts of ammoniacal nitrogen while alkaline fertilizers contain a high proportion of nitrate nitrogen (Table 5). This means that if you wish to use a high nitrate fertilizer for compact growth, the substrate pH may rise over time and if you use a high proportion ammoniacal nitrogen fertilizer, the substrate pH will drop. Close monitoring of substrate pH is important to prevent undesirable fluctuations due to fertilization programs.

Fertilizer formulations. As mentioned above, fertilizer selection for postplant fertilization should be based on desired pH, desired growth habit (rapid versus compact), species being grown, calcium and magnesium supplied via irrigation water source, and preplant incorporation programs (how much phosphorus is needed). Table 7 lists some common fertilizers and amounts to add to make various ppm solutions. It has the sources categorized by pH effect--acid-residue and basic-residue.

Nutritional Monitoring. Types of testing required. Growers should establish a routine monitoring program to avoid nutritional disorders during bedding plant production. These tests fall into three categories: general operations, preplant, and post-plant tests.

General operations testing includes water quality and injector calibration. Preplant tests are substrate pH, soluble salts, and moisture content (testing moisture content was covered earlier). Post-plant tests involve checking fertilizer delivery (rechecking injectors); and monitoring nutrients, pH, alkalinity, and soluble salts during the crop. All of these tests should be simple, and performed frequently to be useful to the grower.

Every greenhouse should be submitting water samples for complete chemical analysis at least annually as part of their general operations testing. If your greenhouse has a history of alkalinity problems in the irrigation water, you should have an on-site test kit and should be testing your water source at regular intervals (we will discuss alkalinity testing in more detail later).

Fertilizer and acid injectors should be *calibrated monthly*;

more often when you suspect a problem. Remember, these devices are only as accurate as their last calibration, so frequent calibration is essential.

Preplant testing of substrate pH and soluble salts should be done prior to tray filling. Be sure to moisten the substrate several days, preferably one week, prior to testing it to give the limestone time to react. Limestone may take two days to two weeks to fully adjust the pH. If you make your mix just before you fill the trays, the pH will be different than if you mix the substrate a few days ahead. This difference can affect the rate of germination and establishment of your plugs. You should know the rate of reaction time necessary for your mix to reach its final pH. The best way to do this is to establish a *liming curve* for your mix. The rate of reaction will change with changes in peat source and quality / type / particle size of the limestone used.

A complete post-plant testing program should include visual monitoring of the crop's appearance; routine substrate monitoring checking for pH, soluble salts, and substrate nutrient concentrations (Tables 4, 8, 9, & 10); fertilizer solution analysis including pH and soluble salts; irrigation water analysis including pH, soluble salts, and alkalinity; and plant tissue analysis.

During plug production, weekly substrate and tissue analysis should be conducted. For finishing flats, every two weeks may be sufficient. Separate substrate and tissue tests should be conducted for different bedding plant species, as individual species differ in pH and fertility requirements. Fertilizer delivery should be checked daily, or at least at every fertilization if done every second or third irrigation. This can be accomplished by simply capturing some of the fertilizer water in a glass, jar, or beaker and measuring the EC (it is also a good idea to check pH while you are at it).

Frequency of water analysis depends on the alkalinity content and stability of the water quality. If your water quality (especially alkalinity) changes frequently, then weekly testing of these parameters may be needed, especially for plug

Table 6. Postplant fertilizer rate and frequency.^z

N conc. (ppm) ^y	Frequency	Production stage
50 to 75	as needed	plug—late Stage 2 through mid-Stage 3
100 to 150	as needed	plug—remainder of Stage 3
100 to 200 ^x	each watering	finish flats or pots
200 to 300 ^x	weekly	finish flats or pots
450 to 500 ^x	every 2 weeks	finish flats or pots

^zFertilizer concentrations to use for various bedding plant production stages. Concentrations given are for nitrogen. The phosphorus and potassium concentrations depend on the selected fertilizer's ratio.

^yExact fertilizer application concentration and frequency depends on the plant species, the desired growth rate, and the leaching percentage.

^xThese are three alternative fertilization programs. Use only one.

Plug Fertilizer Concentrations

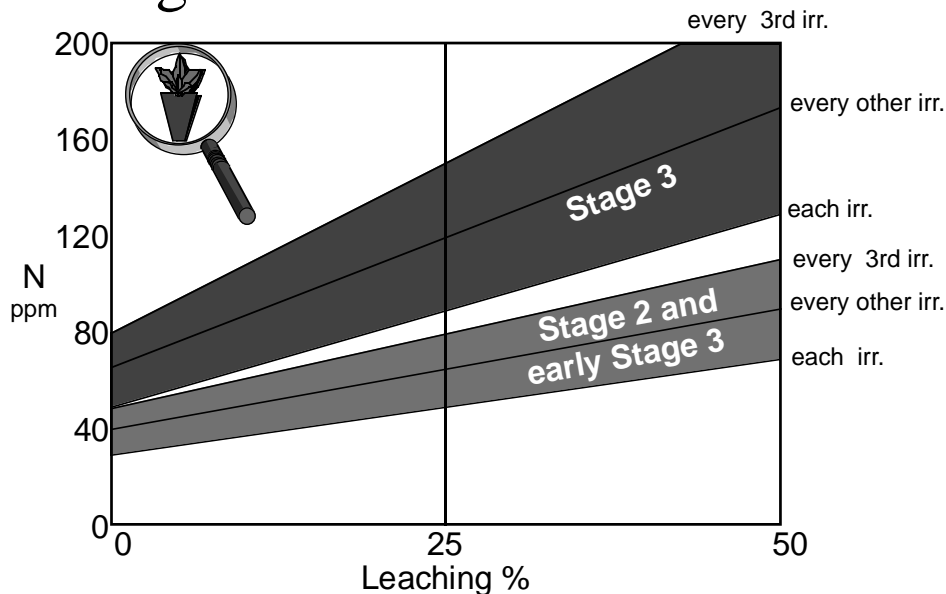


Figure 12. Recommended nitrogen (N) fertilization rates based on plug stage of development, frequency of fertilizer application, and degree of leaching during irrigation.

production. The alkalinity of a water source can change drastically with weather conditions and pumping fluctuations. We have measured alkalinity ranging from 2.8 meq/L to 5.4 meq/L in well water drawn from the same well in North Carolina during the course of one year! Municipal water in many locations is derived from different sources. Although municipalities try to maintain consistent output from water plants, it is possible to encounter alkalinity fluctuations from a municipal water source also.

Regular monitoring of alkalinity is essential if your water quality changes over time. For a plug producer, *weekly measurements* may be needed due to the rapid effects alkalinity can have on a plug substrate system, because of the small volume of substrate in each plug. Alkalinity effects on larger sized containers (larger substrate volumes) occur more slowly, and monthly testing may be sufficient to give growers enough knowledge to adjust for alkalinity fluctuations in the water source.

Testing procedures. Every greenhouse range should have the capability to measure pH and electrical conductivity (EC). These parameters can change too rapidly to rely solely on lab test results, and the cost of the testing equipment is no longer prohibitory for growers.

When selecting a pH meter, look for an accuracy of ± 0.1 pH unit and a range of 1 to 14. To be useful for fertilizer injector calibration as well as substrate and solution testing, EC meters should have a range of 0 to 1,990 mhos $\times 10^{-5}/\text{cm}$ and have an accuracy of ± 10 mhos $\times 10^{-5}/\text{cm}$. Many EC meters report EC in units of $\mu\text{S}/\text{cm}$ (microSiemens per centimeter). The conversion between S/cm and mhos/cm is simple: 1 S/cm = 1 mhos/cm. Both pH and EC meters are available from many sources including the following: Cole-Parmer Instruments, 745 North Oak Park Ave., Chicago, IL 60648, (800)323-4340; Extech Instruments Corp., 150 Bear Hill Road, Waltham, MA 02154, (617) 890-7440; Myron L Co., 6231 C. Yarrow Drive, Carlsbad, CA 92009, (619) 438-2021.

Whether you are collecting a sample for in-house testing (of substrate pH and EC for example) or for laboratory analysis

(of substrate nutrient concentrations or nutrient analysis of plant tissue), take a "representative sample". In problem free, routine sampling situations, a sample should consist of material from several locations. This will provide a sample of the entire crop / greenhouse. When the cause of a problem is being investigated, such as why plants look chlorotic, then a representative sample should consist only of the material from problem areas, plants, or water sources. For best results, a comparative sample from non-affected areas should be taken and submitted at the same time to serve as a standard comparison for problem samples.

To complete the many analyses of a single sample, laboratories require a prescribed amount of material, whether it is plant tissue for foliar analysis, a water sample, or a substrate sample. Submitting less than the amount required results in incomplete testing and / or a delay until additional material is sent. Always be aware of and send the requested sample size for laboratory analysis, and use sample containers

provided by the laboratory you utilize, if provided.

Collecting a substrate sample for laboratory analysis.

Table 7. Quantities (ounces) of fertilizer or fertilizer salts to dissolve in 100 gallons of water to make solutions containing 50 to 250 ppm each of nitrogen (N) and potassium (K_2O).

Fertilizer or salts	Concentration of N and K_2O (ppm)			
	50	75	100	250
Acid-residue sources oz/100 gallons				
20-10-20*	3.34	5.0	6.7	16.7
20-9-20*	3.34	5.0	6.7	16.7
ammonium nitrate +	1.23	1.85	2.5	6.15
potassium nitrate +	1.50	2.25	3.0	7.5
monoammonium phosphate (20-10-20)*	0.54	0.81	1.1	2.7
Basic-residue sources oz/100 gallons				
13-2-13 (-6Ca-3Mg)*	5.13	7.7	10.3	25.65
14-0-14 (-6Ca-3Mg)	4.76	7.14	9.5	23.8
15-0-15 (-9.5Ca-1Mg)	4.45	6.68	8.9	22.25
15-5-15 (-5Ca-2Mg)*	4.45	6.68	8.9	22.25
17-0-17 (-4Ca-2Mg)	3.92	5.88	7.83	19.6
potassium nitrate	1.51	2.28	3.03	7.58
+ calcium nitrate	1.76	2.64	3.52	8.8
+ magnesium nitrate	1.8	2.7	3.6	9.0
(13-0-13-6.6Ca-3.3Mg)				

*These formulations also contain phosphorus (P_2O_5).

Table 8. Interpretive values for essential macronutrients in the substrate solution of a soilless substrate using the saturated paste extraction method.

Interpretation	Concentration in extract solution (ppm)				
	Nitrates	Phosphorus	Potassium	Calcium	Magnesium
Michigan State University					
Low	0 to 39	0 to 2	0 to 59	0 to 79	0 to 29
Acceptable	40 to 99	3 to 5	60 to 149	80 to 199	30 to 69
Optimum	100 to 199	6 to 10	150 to 249	200+	70+
High	200 to 299	11 to 18	250 to 349	—	—
Very high	300+	19+	350+	—	—
The Ohio State University					
Extremely low	0 to 29	0 to 3.9	0 to 74	0 to 99	0 to 29
Very low	30 to 39	4.0 to 4.9	75 to 99	100 to 149	30 to 49
Low	40 to 59	5.0 to 5.9	100 to 149	150 to 199	50 to 69
Slightly low	60 to 99	6.0 to 7.9	150 to 174	200 to 249	70 to 79
Optimum	100 to 174	8.0 to 13.9	175 to 224	250 to 324	80 to 124
Slightly high	175 to 199	14.0 to 15.9	225 to 249	325 to 349	—
High	200 to 249	16.0 to 19.9	250 to 299	350 to 399	125 to 134
Very high	250 to 274	20.0 to 40.0	300 to 349	400 to 499	135 to 174
Excessively high	275 to 299	40.0+	350+	500+	175+

When collecting a substrate sample, always sample more than one container and collect the sample from all levels in the pot. Draw at least 10 cores of substrate, each from a different location within the crop such that many different benches and locations within a bench are included. When drawing a problem sample, make sure to only sample from affected areas. Exclude the top 1/2 inch of substrate (top 1/8 inch for plug samples), since it is not representative of where plant roots are located and could contain high salt levels, especially in a subirrigation delivery system. If the substrate contains a slow release fertilizer such as Osmocote®, it will be necessary to remove all the fertilizer particles prior to testing to avoid skewing nutrient readings. Samples should be refrigerated until sent to the lab or dried for 24 hours at 125 °F. Do not heat to greater than 125 °F as nutrient loss from the sample may occur. One cup (8 fl oz.) of substrate is usually sufficient for most laboratories; always send the volume requested by the laboratory.

Recently, affordable meters for NO₃-N and K (Cardy® meters) became available. These meters allow growers to conduct in-house measurements for both NO₃-N and K. However, for use with substrate solutions, this means that growers must conduct saturated paste

extraction for meaningful interpretation of meter readings.

Preparing a substrate extract for in-house measurement of pH and EC. Routine on-site analysis of substrate pH and EC allows growers to catch fertilization errors early and to prevent major problems from developing. One of the major obstacles to successful testing is the lack of uniformity when many workers do substrate sampling and testing; from location to location within in greenhouse range and from different times. The best remedy is to assign the task of sampling and testing to one worker for consistency in testing.

Probably the easiest method for growers to measure pH and EC of a substrate is a 2 water : 1 substrate mixture (volume :

Table 9. Recommended ranges for essential nutrients in the substrate solution of a soilless substrate using the saturated paste extraction or the pour through exfiltrate method.

Element	Extraction Method				
	Saturated paste			Pour through exfiltrate	
	Cornell University	Michigan State University	Fafard Analytical Services	Cornell University	Virginia Tech University*
NO ₃ -N	23 to 68	75 to 150	40 to 200	23	50 to 100
NH ₄ -N	<12	2 to 10	0 to 20	---	50
P	5 to 20	10 to 20	5 to 30	15	3 to 15
K	150 to 350	75 to 150	40 to 200	50	<100
Ca	200 to 400	125 to 175	40 to 200	15	40 to 200
Mg	70 to 200	40 to 60	28 to 80	15	10 to 50
S	---	75 to 125	---	---	75 to 125
Fe	---	1 to 2	0.3 to 3.0	---	0.3 to 3.0
Mn	---	1 to 2	0.1 to 3.0	---	0.02 to 3.0
Zn	---	1 to 2	0.1 to 0.3	---	0.3 to 3.0
Cu	---	0.1 to 0.5	0.01 to 0.3	---	0.01 to 0.5
B	---	0.1 to 0.5	0.05 to 0.5	---	0.5 to 3.0
Mo	---	0.1 to 0.5	0.01 to 0.1	---	0.0 to 1.0
Al	---	---	---	---	0.0 to 3.0
Fl	---	---	---	---	<1
Na	---	<25	---	---	<69
Cl	---	<25	---	---	<71

*The Virginia Tech University (VTEM) pour through standards are for outdoor nursery production, not indoor greenhouse production. They are included as a comparison of greenhouse to outdoor culture recommendations.

Table 10. Electrical conductivity guidelines from various laboratories using the saturated paste, 1 : 2, and pour through extraction techniques.*

Extraction method												
Saturated paste**				1 substrate : 2 water (v : v)**					Pour through exfiltrate**			
Soil-based		Soilless			Soil-based		Soilless			Soil-based		Soilless
CU	NCSU	CU	MSU	FAS	NCSU	UC	NCSU	MSU	NCSU	CU	CU	VTU***
	≤0.75		≤0.74	≤0.75	≤0.75	<50	≤25	≤24	0 to ?			
	0.75 to 2.0		0.75 to 2.0		0.75 to 2.0	50 to 70	26 to 50		? to 100			<0.5
2.5	2.0	3.5	1.99		2.0	100 to 120	100	75		0.6 to 1.0	1.5	
<3.5	2 to 4		2.0 to 3.5	0.76 to 2.5 (no bark) OR 1.5 to 3.5 (with bark)	2 to 4	<150	51 to 125	75 to 125	100 to 175			0.75 to 1.5
<3.5		<5.0	2.0 to 3.5			<200	126 to 175	125 to 175	176 to 225	1.0 to 2.0	≤2.0	2.0
>3.5	4 to 8		5.0 to 6.0	>3.5	4.0 to 8.0	>200	176 to 200	175 to 225	225 to 350			
	>8.0		>6.0	>5.0	>8.0		>200	>225	>350			
	0.75 to 1.0				0.75 to 1.0		25 to 100		50 to 150			
	1.0 to 1.5				1.0 to 1.5		25 to 125		50 to 175			
	1.5 to 2.0				1.5 to 2.0							
	1.5 to 4.0				1.5 to 4.0		50 to 175		100 to 225			

*Laboratory abbreviations are CU = Cornell University, NCSU = North Carolina State University, MSU = Michigan State University, FAS = Fafard Analytical Services, UC = University of Connecticut, and VTU = Virginia Tech University.

**Saturated paste and pour through exfiltrate ECs are given in mmhos/cm (mhos × 10⁻³/cm). The 1 substrate : 2 water ECs are given in mhos × 10⁻⁵/cm.

***The Virginia Tech University (VTEM) pour through standards are for outdoor nursery production, not indoor greenhouse production. They are included as a comparison of greenhouse to outdoor culture recommendations.

volume). When collecting a substrate sample for in-house testing, follow the collection procedures outlined previously taking care to collect a representative sample and removing any slow release fertilizer, if present. Collect an 8 fl oz. volume of substrate. To this volume of substrate, add twice the volume (16 fl oz.) of distilled or deionized water, readily available at most grocery stores. Stir the mixture, then allow it to stand for approximately 15 minutes prior to measuring pH and EC. During this time, calibrate both the pH and the EC meter against standard solutions to assure accuracy of sample measurements. Consult the instructions that came with your meters to know whether you must filter out particulate matter with a coffee filter or cheese cloth prior to reading the pH and EC. Use Tables 4 and 10 as guidelines for interpreting the EC and pH readings of your samples. Out-of-range readings warrant submission of a substrate sample for laboratory analysis. Adjust your fertilization and / or pH control program accordingly.

Alternative in-house substrate testing procedures include pour through exfiltrate (VTEM method) and the NCSU "squeeze" method. The pour through exfiltrate method offers the advantage of nondestructive sample collection and the potential for submitting the sample to a lab for nutrient analysis after measuring pH and EC or using in-house meters (Cardy meters) for measuring $\text{NO}_3\text{-N}$ and K. However, guidelines for interpreting the pour through exfiltrate results are not as complete as for saturated paste and 2 : 1 (Tables 8, 9, & 10). The squeeze method also allows the grower the option of in-house $\text{NO}_3\text{-N}$ and K analysis or submitting the solution for nutrient analysis, but it is a destructive sampling method and some crop must be harvested during sampling. Also, as with the VTEM method, interpretive tables are still in the formulation stage of development.

Collecting a plant tissue sample for foliar analysis. Analysis of leaves is the most precise method of measuring micronutrient and macronutrient status of a crop. Routine sampling should be conducted in order to establish a "base line" of nutrition readings for reference in case of a future problem. For problem solving, remember to collect material only from problem areas, and to send a second sample representing a problem-free site concomitant with the problem sample for comparison. Table 11 lists nutritional guidelines for various bedding plants. For those not listed, use the last column, general, as a guide.

Leaf samples should be collected in the morning (before noon), when plants are not under water stress. Collect the appropriate number of leaves / volume of leaves indicated on the instruction sheet included in the tissue analysis kit from the laboratory you utilize. Leaves that best represent the crop nutrient status are those that have most recently matured; collect new, fully expanded leaves. If no instructions are given for your crop species, collect at least one cup (8 fl oz.) of leaves with the petioles attached. Collected leaves should be rinsed in distilled or deionized water. Do not use tap water, as the water nutrient content may contaminate the foliar sample. Allow leaves to dry prior to packing for shipment. Leaf samples often rot if enclosed in plastic bags; package in paper bags for best results. Keep samples refrigerated until shipping. Shipping via overnight or next day delivery is helpful in assuring that samples arrive at the lab in good shape.

The Cardy meters mentioned previous can be used for on site testing of plant $\text{NO}_3\text{-N}$ and K concentrations, usually petiole sap concentrations. This technique has been used for many years to test the nitrogen status of tomato, pepper, and other food crops. In the future, standards for floricultural crops may allow for meaningful in-house testing of crop $\text{NO}_3\text{-N}$ and K concentrations.

Collecting a water or fertilizer solution sample for laboratory analysis. When collecting a solution sample, allow

the water to run long enough to flush all piping prior to collecting the sample. Sample containers should be clean and must not be metallic or have an exposed metal cap; plastic bottles are ideal. A 16 fl oz. sample should be more than sufficient for solution analysis. Keep the sample refrigerated until it is submitted to the lab. Transfer samples to the laboratory as expediently as possible, and avoid prolonged exposure to air. Table 12 outlines irrigation water standards.

In-house analysis of water and fertilizer solution pH and EC. Both EC and pH can be measured in-house on a solution sample. However, accurate measurement of water pH is difficult and may require a longer measuring time than for a fertilizer solution or a substrate extract. This is due to the relatively low buffering capacity of tap water.

In-house analysis of water alkalinity. Water alkalinity is caused by the presence of carbonates, bicarbonates, hydroxides, and other dissolved salts. It is measured by titrating a water sample with an acid (usually dilute sulfuric acid) to an endpoint pH of about 4.6 (varies from 5.1 to 4.5 depending on the indicator dye used and the initial alkalinity). A pH indicator dye (usually bromocresol green plus methyl red) is added to a known volume of water (indicated in the test kit instructions; usually about 8 fl oz.), and acid is added until the solution changes color. With the bromocresol green plus methyl red dye system, the color will change from green to pink.

Most water sources acceptable for greenhouse use will have alkalinity in the range of 0 to 8 meq/L (0 to 400 ppm alkalinity expressed as CaCO_3). When looking for a test kit, this is the range that is needed. The level of accuracy does vary from kit to kit; ± 0.4 meq/L (20 ppm alkalinity expressed as CaCO_3) is accurate enough for most situations, but more precise kits are available. We have used Hach alkalinity kits #24443-01 (about \$30 for 100 tests) and #20637-00 (about \$155 for 100 tests, but includes versatile digital titrator) and are satisfied by both (Hach Company, P.O. Box 389 Loveland, Co 80539; phone (800) 227-4224). Although the second model is more expensive, it does have twice the accuracy (± 0.2 meq/L) and also comes with a digital titrator that can be used to measure other solution parameters (using different titrants and indicators) such as water hardness, chlorine, iron, nitrite, and sulfite concentrations.

Interpretation of test results. Most commercial laboratories will send an interpretation along with sample results. However, since laboratories differ in procedures (say saturated paste extraction compared to a 1 : 2 extraction), it may not be possible to use interpretative guidelines from one lab for analyses conducted in another, especially with substrate samples. When interpreting results of substrate analyses, use the interpretations that correspond with the extraction method employed by the lab (Tables 8 & 9).

The biggest confusion for growers usually arises when trying to interpret soluble salts (EC). Interpretation of EC requires knowledge of the testing procedure employed. The two major extraction methods, saturated paste and the 1 : 2 (substrate : water) method are both reported in mhos/cm, but at differing decimal places. Saturated paste EC is usually reported as mmhos/cm, which is $\text{mhos} \times 10^{-3}/\text{cm}$, while 1 : 2 EC is usually reported as mhos $\times 10^{-5}/\text{cm}$ (Table 10). As previously mentioned, some EC meters read in $\mu\text{S}/\text{cm}$; remember that $1 \mu\text{S}/\text{cm} = 1 \mu\text{mhos}/\text{cm}$ ($1 \text{ mhos} \times 10^{-6}/\text{cm}$). Make sure to use the correct decimal placement when using interpretative tables. For example:

$$1.7 \text{ mmhos} (1.7 \text{ mhos} \times 10^{-3}) = 170 \text{ mhos} \times 10^{-5}$$

and

$$170 \text{ mhos} \times 10^{-5} = 1,700 \mu\text{mhos} (1,700 \text{ mhos} \times 10^{-6})$$

Table 11. Suggested nutritional guidelines for foliar analysis results of various bedding plant species.

Element	<u>Begonia, wax leaf^{Z,Y}</u>			<u>Geraniums, seed^{Z,Y}</u>			<u>Geraniums, zonal^X</u>			<u>Impatiens^Y</u>
	Low	Normal	Excess	Low	Normal	Excess	Low	Normal	Excess	Normal
N (%)	3.5 to 3.9	4.0 to 6.0	>6.0	3.0 to 3.49	3.5 to 4.8	>4.8	2.4 to 3.2	3.3 to 4.8	---	4.3 to 5.3
P (%)	0.2 to 0.29	0.3 to 0.75	>0.75	0.3 to 0.39	0.4 to 0.7	>0.7	0.25 to 0.39	0.4 to 0.7	>1.0	0.6 to 0.8
K (%)	2.0 to 2.4	2.5 to 6.0	>6.0	1.0 to 2.49	2.5 to 4.3	>4.3	0.6 to 2.4	2.5 to 4.5	---	2.8 to ?
Ca (%)	0.6 to 0.9	1.0 to 2.5	>2.5	0.6 to 0.79	0.8 to 1.2	>1.2	0.7 to 0.9	1.0 to 2.0	---	2.9 to 3.3
Mg (%)	0.25 to 0.29	0.5 to 0.8	>1.0	0.15 to 0.19	0.2 to 0.5	>0.6	0.14 to 0.19	0.2 to 0.7	---	0.6 to 0.8
S (%)	0.25 to 0.29	0.3 to 0.7	>0.8	0.2 to 0.24	0.25 to 0.7	>0.8	0.12 to 0.24	0.25 to 0.6	---	---
Na (%)	---	---	---	---	---	---	---	0.1 to 0.5	>1.0	---
B (ppm)	15 to 19	20 to 75	>75	18 to 29	30 to 200	>200	18 to 29	30 to 100	>200	45 to 95
Cu (ppm)	4 to 6	7 to 30	>30	5 to 6	7 to 25	>25	5 to 6	7 to 16	---	10 to 15
Fe (ppm)	40 to 49	50 to 200	>200	60 to 99	100 to 290	>300	50 to 99	100 to 300	---	400 to 600
Mn (ppm)	30 to 49	50 to 200	>200	25 to 39	40 to 200	>200	9 to 39	40 to 150	>400	200 to 450
Mo (ppm)	---	---	---	---	---	---	0.5 to 0.9	1.0 to 5.0	---	---
Zn (ppm)	20 to 24	25 to 80	>200	12 to 17	18 to 80	>200	6 to 9	10 to 50	---	65 to 70
Element	<u>Pansy^{X,W}</u>			<u>Salvia^Z</u>			<u>Marigold^X</u>	<u>Snapdragon^X</u>	<u>Vinca^{Y,X}</u>	<u>General</u>
	Low	Normal	Excess	Low	Normal	Excess	Normal	Normal	Normal	Normal
N (%)	1.5 to 2.4	2.5 to 4.5	>4.6	2.5 to 2.99	3.0 to 4.5	>4.5	3.5 to 5.0	4.0 to 5.5	3.0 to 5.0	variable
P (%)	0.11 to 0.24	0.25 to 0.7	>0.7	0.22 to 0.29	0.3 to 0.7	>0.7	0.3 to 0.45	0.2 to 0.4	0.3 to 0.6	0.25 to 1.0
K (%)	1.0 to 2.4	2.5 to 5.0	>8.0	3.0 to 3.49	3.5 to 5.0	>5.0	3.5 to 5.5	2.5 to 4.0	1.3 to 3.0	variable
Ca (%)	0.3 to 0.59	0.6 to 2.6	>3.0	1.0 to 1.49	1.5 to 2.5	>2.5	2.0 to 3.0	0.8 to 1.5	1.0 to 2.0	1.0 to 2.0
Mg (%)	0.11 to 0.4	0.4 to 0.75	>1.5	0.2 to 0.24	0.25 to 0.6	>0.6	0.3 to 0.5	0.5 to 0.8	0.4 to 0.6	0.25 to 1.0
S (%)	<0.2	0.2 to 0.7	---	---	---	---	0.25 to 0.35	---	---	0.2 to ?
Na (%)	---	0 to 0.5	>1.2	---	---	---	<0.5	<0.2	<0.2	---
B (ppm)	14 to 19	20 to 80	>175	20 to 24	25 to 75	>75	30 to 100	25 to 40	25 to 100	25 to ?
Cu (ppm)	<5	5 to 40	>40	5 to 6	7 to 50	>50	10 to 20	10 to 30	5 to 12	5 to ?
Fe (ppm)	30 to 90	100 to 250	>250	50 to 59	60 to 300	>300	100 to 300	100 to 200	100 to 300	50 to ?
Mn (ppm)	<25	25 to 250	>300	25 to 29	30 to 200	>200	80 to 300	60 to 160	100 to 250	30 to ?
Mo (ppm)	<0.2	0.2 to 5.0	>5.0	<2	2 to 4	>4	---	---	---	0.2 to ?
Zn (ppm)	<20	20 to 100	>100	20 to 24	25 to 200	>200	35 to 60	30 to 60	20 to 60	20 to ?

^ZAdapted from: Jones, J.B. Jr., W. Wolf, and H.A. Mills. 1991. Plant analysis handbook. Micro-Macro Pub., Inc. 185 Paradise Blvd., Suite 108, Athens, GA 30607.

^YAdapted from: Dole, J.M. and H.F. Wilkins. 1988. Tissue testing of selected floricultural pot crops. Minn. State Florists Bul. 37(5):13-15.

^XAdapted from: Anonymous, Soil and Plant Lab, P.O. Box 6566, Orange, CA 92613-6566.

^WAdapted from: Anonymous, Masterblend Fertilizer Company, 4425 S. Western Blvd., Chicago, IL 60609.

Table 12. Water quality guidelines for use in greenhouse production of plants.

Type of problem	Upper acceptable limit
Salinity	
EC (mmhos/cm)	
for plug production	0.75 (480 ppm)
for general production	2.0 (1,280 ppm)
sodium (ppm Na)	69 (3 meq/L)
(evaluated by SAR)	4.0
chloride (ppm Cl)	71 (2 meq/L)
Micro Elements (ppm of each)	
boron (B)	0.5
copper (Cu)	0.2
fluoride (F)	1.0*
iron (Fe)	4.0
manganese (Mn)	1.0
zinc (Zn)	0.3
Alkalinity - pH - Hardness	
alkalinity (meq/L)**	1.5
pH	5.8 is ideal for most greenhouse crops; 5.4 to 6.8 is usually acceptable
hardness (meq/L)***	2 to 4
Organisms to Test For:	
iron fixing bacteria	
plant pathogens	

*Safe for most crops but toxic for many members of the lily family.

**Water with high levels of alkalinity can be used safely if it is treated with acid.

***Hardness is the combined number of milliequivalents of calcium and magnesium in a liter of water expressed as if it were all calcium carbonate. Acceptable limits depend upon the balance of Ca and Mg (should be no greater than 3 meq Ca to 1 meq Mg) and on the balancing ions associated with the Ca and Mg, i.e. chloride vs bicarbonate.

Make sure to use the numbers and interpretations that correspond to the extraction method employed.

Foliar analysis interpretation (Table 11) varies from lab to lab and from crop to crop, especially for macronutrients. Consult the interpretation accompanying the sample analysis report for recommendations, or use Table 11 as a general guideline for interpreting test results.

Use Table 12 as a guide for interpreting water sample results along with laboratory interpretations. If micronutrient and / or sodium and chloride levels are out of range, then these ions could potentially lead to toxicity problems if the water source is used for irrigation. If alkalinity is too high, then you may need to acidify to neutralize the excess bicarbonates in the water for pH control. Table 13 gives general guidelines for water acidification. For exact acidification recommendations to any endpoint pH or alkalinity concentration, you should contact your state's floriculture extension specialist or acquire a copy of the acidification calculator (in Excel spreadsheet format) located on the world wide web at:

http://www2.ncsu.edu/ncsu/cals/hort_sci/floriculture/

Table 13. Amount of acid to inject to drop water pH to approximately 5.8 and the resulting concentrations of nutrients provided by injecting 1 fl oz. per 1,000 gallons water of each acid.

Acid	Amount of acid to add for each meq of alkalinity (fl oz/1,000 gals)*	Concentration of nutrient provided by one fl oz. of acid per 1,000 of water
Nitric (76%)	6.6	1.64 ppm
Phosphoric (75%)	8.1	2.88 ppm
Sulfuric (35%)	11.0	1.13 ppm

*Add this amount for each meq of alkalinity present. For example, if your water report indicates an alkalinity of 3 meq/L and you choose to use sulfuric acid, you would add 33 fl oz. of 35% sulfuric acid per 1,000 gallons of water.