3. Water, Growing Media and Crop Nutrition

Introduction

Living plants consist of 85–90% water with the remainder composed of organic matter and minerals. The biological process known as photosynthesis occurs in the green leaves, producing carbohydrates and ultimately organic matter. Water and minerals (plant nutrients) are taken up by the roots growing in soil or soilless substrate and transported within the plant through specialized tissue (the veins of the plant) called the xylem. Carbon dioxide from the air and light energy absorbed by chlorophyll are the drivers of the whole photosynthetic process. About 90% of the water taken up is lost through the leaves and into the air in a process called transpiration, primarily because of the vapour pressure difference between the internal leaf environment and the surrounding air. About 1% of the water taken up is used for photosynthesis and about 9% becomes part of plant constituent. Carbohydrates (sugars and starches) are produced by photosynthesis and distributed within the plant by conductive tissue called the phloem, generally in a downward direction.

Water

Water is one of the most important compounds for growing a crop, yet it is often the most neglected. Water serves as a medium in which chemical processes such as nutrient uptake and photosynthesis take place. It acts as a coolant through transpiration for both the crop and its environment. Both quantity and quality of water are critical for a good crop.

Uptake

Water uptake can be divided into active and passive uptake. Active uptake requires energy (from respiration in the roots) by increasing the nutrient concentration within the roots and creating suction on the water outside the roots through osmosis.

Passive uptake of water through the roots of the plant begins with water transpiration from the leaves, through openings called stomata. Water vapour moves from areas of high water vapour pressure in the leaves, through the stomata, to areas of lower pressure outside the plant. Under conditions of high humidity, the plant will lose less water vapour than when the humidity is lower, because there is a higher water vapour pressure outside the plant (resulting in a lower pressure difference between the inside of the leaf and the surrounding air). This process begins a chain reaction whereby water is drawn up through the xylem to replace what is lost through the leaves. Consequently, water in the soil is drawn in through the root hairs following the same gradient. Water uptake into the roots is also dependent on the moisture level and salt concentration in the soil. All three factors – relative humidity in the air, soil moisture and salt concentration in the soil solution – affect water uptake.

Quantity

Water requirements for a crop can vary between 0.1 and 7 L of water per square metre of greenhouse per day, of which 90% is required during daylight hours. This varies according to plant species, plant size, relative humidity, solar radiation, temperature/heating and rate of ventilation. When sizing irrigation equipment (lines, pumps, nozzles), use a minimum of 1 L/m^2/hour as a base requirement for capacity sizing of the irrigation lines and system. The total annual water requirement for a year-round greenhouse operation with a high leaf area index (e.g., vegetables) in a re-circulating system exceeds the Ontario annual precipitation of approximately 75 cm by 25–35%. This means that rainwater collected from the greenhouse roof alone will not fulfil the annual requirements of a crop. Water is particularly critical during the summer. Greenhouse operations using 50,000 L or more on any one day from surface water or groundwater sources must comply with Ministry of the Environment and Climate Change (MOECC) regulations regarding usage by securing a Permit to Take Water.

Permits to Take Water

www.ontario.ca/environment-and-energy/permits-take-water

Permit to Take Water program

The *Ontario Water Resources Act* (OWRA) and the Water Taking and Transfer Regulation (O. Reg. 387/04) govern the taking of water in Ontario.

Section 34 of the OWRA requires anyone taking more than a total of 50,000 L of water in a day, from a lake, stream, river or groundwater source (including spring-fed ponds), to obtain a permit from the MOECC) to take water. All permit holders are required to collect and record the volume of water taken daily and report these data annually to the MOECC.

Water conservation is an important part of the MOECC's Permit to Take Water program.

Conservation measures being proposed or taken must be documented when making an application.

Managing water use

Efficient use of water as a resource should be a key best management objective of every greenhouse operation. Closed or recirculating nutrient systems are inherently the most efficient, but are not suitable or cost-effective for all cropping systems. For growers using open irrigation systems, there are a number of approaches to consider. For example, converting to low-volume drip emitters for potted flowering crops and to low-volume drip tape for soil-grown cut flowers are relatively low-cost measures to reduce the amount of water and fertilizer used, and potentially leached from, the root zone of the crop. Greater integration of the growing environment (light, temperature and humidity) with respect to crop and crop age can also reduce water and fertilizer usage.

Consideration should be given to directing tile drain leachate into an irrigation pond, an artificial wetland or vegetative filter strip before discharging to the environment. Both federal and provincial legislation (Section 53 of OWRA) protect watercourses and aquatic organisms from harmful discharges. Information regarding waste water and storm water management can be found on the Ministry of the Environment and Climate Change website. See Rules for Greenhouse Operators at *www.ontario.ca/environment-and-energy/rules-greenhouse-operators#section-Quality.*

Quality

In addition to having a plentiful and reliable supply of water, the quality must also meet certain criteria, the most important of which are:

- the concentration of suspended particulates, which can affect irrigation equipment or residue on the foliage with overhead watering
- the amount of dissolved chemicals/elements (anions and cations), which can impact plant growth and nutrition

It is the latter (the amount of dissolved chemicals or ions) that causes growers the most concern. The specific requirements for water quality depend on several factors:

- The type of growing/irrigation system to be used. It can be a once-through overhead irrigation using low-volume emitters, overhead booms or hand watering, a recirculating top irrigation system (using soilless substrate), a recirculating sub-irrigation system (potted/container-grown flowering plants), or a nutrient film technique (vegetable crops grown without substrate with root systems constantly being bathed in a nutrient solution).
- Water quality. Standards must be higher for recirculating systems, as ions like sodium, chloride and sulphate, which are only required at very low levels for plant growth, will accumulate in the solution, negatively impacting uptake of essential nutrient ions for plant growth and therefore increase the frequency of refreshing recirculating nutrient solutions. There is an increased potential for spread of root diseases when recirculating irrigation water, but treatment technologies such as ultra-violet light, ozonation and heat can be used where necessary to sanitize recirculating nutrient solutions.
- Good growing media drainage to remove excess water in case the need for leaching arises.
- The type of crops to be grown and their specific needs for, or sensitivities to particular elements such as boron, fluoride, zinc, etc. Biofilm is a common problem (in part due to the increased use of non-chlorinated irrigation water) causing uneven flow due to plugging of small-diameter drip lines and low-volume pressure-compensated emitters. The use of hydrogen peroxide-based products or the use of UV or ozone will prevent the growth of biofilm within the irrigation system.

In situations where crops are being irrigated from the top (overhead) with no recirculation, a basic water analysis on a seasonal basis or when changing water sources to determine water quality will suffice. This analysis includes electrical conductivity (EC), hydrogen ion (pH), sodium (Na^+), chloride (Cl^-), and sulphate (SO_4^{2-}) concentration. For sub-irrigation or in recirculating systems, obtain a complete water analysis including bicarbonates (HCO_3^-) and micronutrients such as iron (Fe^{2+}/Fe^{3+}), boron (B), zinc (Zn^{2+}), manganese (Mn^{2+}) and copper (Cu^{2+}).

Electrical Conductivity (EC)

The electrical conductivity (EC) is a measurement of the total concentration of ions (or total ionic charge of cations and anions) in the solution. The total ionic charge is measured by an EC meter, and is often referred to as the total soluble salts. A high number of ionic charges results in a high EC. The EC measures the conductivity of a solution by means of two electrodes, each 1 cm^2 in size and 1 cm apart. It is expressed in milli-Siemens/cm (mS/cm or dS/m) or older terminology of millimhos/cm (mmho/cm) at the standard temperature of 25°C. Most EC meters today are temperature-compensated to take into account the influence of temperature on the EC reading. Another method of referring to soluble salts is by the ionic concentration in equivalent weight per litre (eq/L or meq/L), which represents the amount of charge provided by all ions in solution. The meq/L of the anions and cations in solution reported in a laboratory test must be equal.

To convert between eq/L and mS/cm*:

- 1 meq/L ≈ 0.055 mS/cm ≈ 55µS/cm
- 1 mS/cm ≈ 1,000 µS/cm ≈18.2 meq/L

* The ‘m’ represents milli (0.001 or 1 part per thousand) and the µ represents micro (0.000001 or 1 part per million).

Remember that an EC meter does not measure the concentration of specific ions but rather the total sum of all ionic charges. As the EC reading of the solution increases, so does the concentration of ions. This makes it more difficult for plants to absorb water from the solution due to the increased osmotic suction. The EC meter should be calibrated on a regular basis with a standard solution that has a known EC. For example, 0.01 M (molar) potassium chloride (KCl), made by dissolving 0.74 g KCl in 1 L water, has an EC of 1.4 mS/cm at 25°C. With repeated use of the meter, the EC reading becomes lower as the electrodes oxidize. Clean the electrodes by placing them in an acid solution (pH 1.0–2.0) overnight. If the EC meter is not temperature-corrected (or compensated) to 25°C, increase the measured values by 2% for each 1°C less than 25°C.

A general quality classification for water is given in Table 3-1. *Classification of Water Quality Based on Electrical Conductivity (EC) and Certain Specifications* on this page. Note that all conditions must be met in order to place a sample in a certain class. Classification of the water source is important to know because of its influence on the greenhouse crop being grown and the irrigation technology being used.

Table 3-1. Classification of Water Quality Based on Electrical Conductivity (EC) and Certain Specifications

Class	EC (mS/cm)	Sodium (Na^+) (ppm)	Chlorides (Cl^-) (ppm)	Sulphates (SO_4^{2-}) (ppm)
1	<0.5	<30	<50	<100
2	0.5–1.0	30–60	50–100	100–200
3	1.0–1.5	60–90	100–150	200–300

Source: The information in this table is based on historical data and has been developed over time by Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) greenhouse specialists.

Water quality of Class 1 is good for all irrigation purposes and irrigation systems. Most water obtained from the Great Lakes falls within this category as well as all rainwater captured in cisterns from greenhouse roofs. Water in Class 2 should only be used in substrate and soil culture where adequate leaching can take place. If being used for recirculating top irrigation systems, more frequent refreshing of the nutrient solution will be required. Disposal of the solution without impacting the environment must be taken into consideration.

Water in Class 2 is not suitable for a nutrient film technique and salt-sensitive crops grown in sub-irrigation systems, especially if any one of the listed ions, sodium, chlorine or sulphates is within the identified ranges. From a water chemistry perspective, it is very uncommon to observe, for example, high sodium and low chloride levels in Ontario water because the source of the sodium and chloride is typically associated with the solubilisation of sodium chloride. A water source could still be classified as a Class 2 even if the sodium, chloride and sulphate levels are within the Class 1 range because other anions and cations contribute to the overall EC of the water in the same way as sodium, chloride and sulphate. In Ontario, well and surface water sources often have high calcium, magnesium and bicarbonate levels that contribute to the EC of the water. High calcium and magnesium levels are not necessarily problematic for plant growth because these are two key nutrients for plant growth. However, they are problematic in relation to technology such as low-volume irrigation emitters because the calcium and magnesium will precipitate as calcium and magnesium oxides and carbonates within the emitter, causing plugging and leading to a lack of uniform irrigation per plant.

Class 3 is not recommended for salt-sensitive crops (e.g., primula, African violet, gloxinia), or crops grown in a limited root volume or recirculating systems. If the salt level exceeds 1.5 mS/cm, it is considered marginally suitable for any greenhouse irrigation. In some cases crops can be grown, but yields may be reduced as a result. The toxic concentration for sodium (Na^+) is lower than that for chlorides (Cl^-) due to the tendency of sodium to be absorbed in soil or humus particles and accumulate in the soil/substrate. It may interfere with the uptake of potassium, calcium and magnesium. Chloride has fewer tendencies to accumulate in soil/substrate due to its negative charge. Some crops (e.g., Dracaena, cucumber, azalea, lilies) are extremely chloride sensitive. Note that for most areas in Ontario, sodium levels are low in well water, while sulphates can be relatively high due to the presence of gypsum in the aquifers. Most crops do not require more than 100 ppm of sulphates (33 ppm elemental sulphur) to meet their nutritional requirement for sulphur.

Importance of measuring media or media solution EC

Though the EC measurement does not indicate the presence or quantity of specific plant nutrients, it does provide an overall level of the nutrient status of the solution. A high EC indicates there are many dissolved ions in solution, which makes it difficult for the plant roots to take up water. In severe cases of high EC, roots may lose water, which leads to root damage or death, particularly during summer when demand for water is great because of high transpiration rates. This generally occurs when there is insufficient leaching, plants are over-fertilized, or the irrigation water is of poor quality (high EC). Foliage may be dark-green and small, and plants may wilt during the brightest or hottest part of the day even though the media is quite moist. Most importantly, plant roots may be brown in colour with little or no new active white root growth present.

A low EC indicates there are few dissolved ions in solution and it is easier for roots to take up water. The plants will usually be lush with large leaves and may actually be slightly under-fertilized since there may be fewer nutrients available for plant growth. However, root growth will be encouraged. An extended period of low EC often leads to a deficiency of one of the macro-elements (nitrogen, phosphorus, potassium, calcium, magnesium or sulphur) required for plant growth.

How to measure EC of the growing medium

There are four primary ways to determine EC in a substrate sample, and each will provide you with slightly different results. Therefore it is important to be consistent in using one of the following techniques:

- saturated medium extraction (SME) method
- Spurway (1 part soil:2 part water on a volume basis) dilution method
- pour-through method
- squeeze method

The SME and Spurway methods involve removing a sample of substrate from the root zone and taking measurements of the filtrate. With the SME, sufficient water is added to the substrate so it becomes saturated, while the Spurway technique mixes one volume of soil with two volumes of water. These are the most commonly used techniques in an analytical laboratory. Across North America, the SME is the most common greenhouse media extraction procedure used by university and private laboratories. The EC using SME is usually approximately 2.5 times greater than that measured by the 1:2 Spurway technique.

The pour-through method is accomplished by pouring distilled or deionized water into the media from the top of the pot and collecting the first 50 mL of the leachate for EC and pH readings. This method is rapid and very useful for in-house monitoring, but the water has to be poured evenly and consistently over the soil surface. In addition, high values can be found in some older (especially sub-irrigated) pots due to the accumulation of salts at the top of the growing medium, while the root zone may actually have lower EC values. When using this method, the media should be moist to ensure an accurate reading.

Another option for in-house monitoring is the squeeze method where plants are removed from the pot, and the lower half of the root ball is squeezed to extract the root-zone nutrient solution. This gives a fairly good representation of the actual level *in situ* of the soil solution in contact with active roots. This technique is widely used for monitoring media EC in plug seedling trays. Because of the small sample solution extracted, a special EC meter, which uses only 1–2 drops of solution, must be used. Media must be quite moist to be able to extract solution from the media.

Interpretation of EC measurements

The nutrient demand of a crop depends on the crop development and can be divided into three stages: a low demand during seed germination or rooting of cuttings, a high demand during the very active vegetative stage of crop growth, and a lower demand as the plants reach maturity. As a general rule, shelf life is improved by lowering the nutrient levels (and reactivating the root system) towards the end of the crop (e.g., chrysanthemum, hydrangea, poinsettia). However, some crops such as Easter lily benefit from continued fertilization until shipping. Table 3-2. *Relative EC Requirements of Actively Growing Greenhouse Crops Using the Saturated Medium Extraction (SME) and Pour-through Methods* on page 26 provides suggested EC levels for the actively growing stages of various potted crops using two sampling techniques. For the initial and final growth stages, lower the EC by about 1.0 mS/cm. Sample five pots per representative area per week, calculate the average and record the results.

- If the EC is too low, raise it by increasing the rate of fertilization.
- If the EC is too high, lower it by leaching or diluting with fresh water. For top irrigated crops, add a low EC solution from the top. Apply sufficient water to saturate the growing media to increase the solubility of excess salts. Wait 1–2 hours and apply sufficient fresh water to push the high EC solution down and out of the pot. A form of leaching can also be used for sub-irrigated crops, but rather than flushing the salts out of the media, the salts are moved into the upper zone of the media where no active roots exist. It is important to determine if the high salts are only in the upper part of the growing medium (which is normal in sub-irrigated crops and does not affect the root zone), or if they are also high in the active root zone. If the active root zone has a high EC, sub-irrigating with a low EC nutrient solution or clear water is appropriate, as the salts are forced upwards or diluted for easier uptake by the roots. Crops grown during low light conditions in the autumn and winter require a higher EC than during the summer, because reduced transpiration during this time of the year results in less water (and fertilizer) being taken up. In the summer, because of high transpiration and increased water uptake, it is important to compensate by lowering the EC of the nutrient solution (fertilizer solution) being applied to the crop. In the summer, the EC of the fertilizer solution being applied to sub-irrigated crops should be reduced by 30–40% compared to winter.

Table 3-2. Relative EC Requirements of Actively Growing Greenhouse Crops Using the Saturated Medium Extraction (SME) and Pour-through Methods

Nutrient Require-ments	SME (mS/cm)	Pour-through (mS/cm)	Crops
Low	0.75–2.0	1.0–2.6	African violet, azalea, begonia, calceolaria, calla, cineraria, cyclamen, gerbera, gloxinia, impatiens, orchid, primula, streptocarpus
Medium	1.5–3.0	2.0–3.5	Schlumbergera, clerodendrum, dahlia, exacum, zonal geranium, hibiscus, kalanchoe, rose, calibrachoa
High	2.0–3.5	2.6–4.6	Chrysanthemum, poinsettia, lily, geranium

Source: The information in this table has been developed over time by Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) greenhouse specialists.

pH and its Role

pH is the inverse measure (or a negative logarithm) of the concentration of hydrogen ions (H^+) in solution. A high number of H^+ ions results in a low pH, while a low number of H^+ gives a high pH. pH is measured on a scale of 1–14, where a pH less than (<) 7.0 is acidic, more than (>) 7.0 is basic, and 7.0 is considered neutral. The higher or lower the pH, the more strongly basic or acidic the solution. Each unit in the pH scale represents a change in the concentration of H^+ by a factor of 10.

Alkalinity and bicarbonate

Alkalinity is a measure of the concentration of a number of ions and their capacity in water to neutralize acids or hydrogen ions. Alkalinity is connected to pH because it establishes the acid buffering capacity of water. It defines how resistant the water is to a change in pH. Under most Ontario conditions, the ion having the greatest effect on alkalinity is bicarbonate. In Ontario, it is not unusual to have water with more than 200 ppm of bicarbonates, which originate from the underlying limestone (calcium and magnesium carbonate) beneath the soil. In this case, the high concentration of bicarbonates neutralizes the hydrogen ions, resulting in a low concentration of H^+ and therefore a high pH. It is important to note that there is a general correlation between pH and bicarbonate, but this relationship is not specific. Therefore, the amount of bicarbonates present in the water source must be known in order to determine the amount of acid needed to neutralize or lower the pH.

Laboratories throughout North America and Europe providing testing services for greenhouse operators often report alkalinity in different ways. Ontario laboratories report the concentration in parts per million (ppm) of bicarbonate present in the water, while others report it in other ways, with mg/L $CaCO_3$ of alkalinity or millequivalents (meq) alkalinity being most common. The relationship between this terminology is as follows:

- 61 ppm bicarbonate = 50 ppm alkalinity = 1 meq alkalinity

The influence of the bicarbonate level or alkalinity on the growing medium pH

When the bicarbonate concentration or alkalinity is high, pH of the growing medium will rise quickly when water is applied through top irrigation or through sub-irrigation with no leaching potential. Typically the smaller the volume of the container with growing media (e.g., a seedling plug tray), the more quickly the pH will rise. This is because the typical bicarbonate level in Ontario well or surface water has greater buffering capacity than the acidity or basicity of the fertilizers being used to grow the crops. In addition the rise in pH is enhanced based on the composition of the fertilizer used.

How to measure pH

There are four main methods of measuring pH in solution:

- Litmus paper, which is the least expensive (but also the least accurate method), involves dipping the paper into the solution and comparing the colour change in the paper to established colour codes for different pH ranges.

- pH pens, which are reasonably priced, quite accurate, and easy to carry. They are simply dipped into the fertilizer solution to provide a digital readout of the pH. However, the lifespan (accuracy) in a greenhouse setting is much less than more rugged, expensive models and the probe is not replaceable.

- Electrode-type pH meters, which are the most accurate for measuring pH, are also the most expensive and require the most maintenance. Placing the pH probe directly into the solution until the reading stabilizes gives a quick reading. Many of the better pH meters have temperature compensation, but the temperature dependence is small (usually within 0.1–0.3 units) in the temperature range of irrigation water used by most growers. Rinse the probe between samples. Calibration is very important. The probes are not as stable as the probes of EC meters. Calibrate probes at least bi-weekly using standard pH solutions of 4.0 and 7.0. Keep probes clean and stored in solution, and replace more frequently than EC probes.
- In-line pH electrode-type meters are now installed as part of computerized fertilizer and acid dosing systems to monitor and adjust pH on a constant basis. Two meters are installed in parallel with computerised dosing systems to detect changes in accuracy. Adequate mixing time is required to ensure steady and accurate pH readings.

Check the pH of the substrate using the paste or slurry or solution by the pour-through method collected for measuring EC. Use distilled water, as many water sources have pH buffering compounds (e.g., bicarbonates) that can affect the pH.

Importance of pH

Although hydrogen ions are not considered one of the nutrient elements, pH does influence the solubility and thus the availability of many other nutrients (especially micronutrients). For instance, in soilless growing media, most positive ions (cations) such as iron, manganese and calcium, as well as phosphate ions, are more soluble (and therefore more available to the plant) at a lower pH. Conversely, at higher pH, such ions are tied up in unavailable forms. Molybdenum on the other hand, is more available at a higher pH. The pH also directly influences the colonization of certain pathogens in the soil that may be harmful to plants.

Different crops have different sensitivities to pH based on their sensitivities to some of these micronutrients (or lack thereof). For example, pH less than 5.5 can result in the accumulation and toxicity of micronutrients such as manganese and iron in marigold, geranium and zygocactus. In other plants, such as azalea and hydrangea, a low pH is required to ensure maximum uptake of iron and aluminum, which is essential for proper leaf and bloom colour if blue inflorescences are desired. A pH of 5.8–6.5 is considered optimal for most crops grown in soilless mixes with more than 50% organic matter. Table 3-3. *Optimal pH Range for Various Crops* on this page lists crops with more specific optimal pH ranges.

Table 3-3. Optimal pH Range for Various Crops

Crop	Optimal Range
Marigold, geranium, celosia, Easter lily	6.0–6.6 (+/− 0.2)
Pansy, petunia, snapdragon, vinca, salvia, blue hydrangea, calibrachoa, petunia, bacopa	5.4–5.8
Azalea	4.8–5.4

Source: The information in this table has been developed over time by Ontario Ministry of Agriculture, Food and Rural Affaris (OMAFRA) greenhouse specialists.

Other factors to consider include the following:

- It is desirable for crops sensitive to low pH, such as geranium and marigold, to have slightly higher pH and to fertilize with fertilizers with a basicity potential.
- Petunia, calibrachoa, bacopa, scaevola are prone to iron deficiency and should be grown at a pH below 5.8 and perform best when fertilized with fertilizers with an acidity potential. If high pH is always a problem, consider applying iron-EDDHA on a constant basis. Consult with a greenhouse floriculture specialist for rates.
- Crops such as potted chrysanthemum, which tend to force the pH to rise over time, should have a lower pH early in the crop.
- The stage of crop growth (age) is important. At flowering, pH is often not as critical as it is earlier in the development of the crop.
- The fertilizers being used also affect the pH of both the nutrient solution and media. It is important to know whether the complete fertilizer being used is basic or acidic in reaction. This is stated on the fertilizer packaging as the potential acidity by the number of kilograms of calcitic limestone required to neutralize one tonne of that specific greenhouse water-soluble fertilizer. Likewise, if the fertilizer is basic in reaction, then it is stated as the potential basicity in terms of equivalent kg of calcium carbonate added to the growing medium by one tonne of fertilizer.

Because of the bicarbonate content of most well and surface waters in Ontario, most growers now adjust the pH of their irrigation water using either phosphoric, nitric or sulphuric acid or a combination thereof to maintain the pH of the crop growing medium at pH 6.2 or lower. Because many growers collect rainwater, blending it with surface water usually enables them to better manage fertilizer solution pH.

From a grower's perspective, managing the pH of irrigation water when using rainwater alone is often challenging because of its total lack of buffering capacity, and therefore blending rainwater and surface water is often easier to manage.

Adjusting the pH

Irrigation water

For many smaller operations, injecting acid through the fertilizer injector is the method of choice. Ensure that the injector is designed to handle acids. For other growers, installation of in-line pH probes controlling an acid pump is the method of choice. Both methods are effective. Required rates of acid are shown in Table 3-4. *Volume of Acid Required to Neutralize 61 ppm* HCO_3^- *(1 mmol/L or 1 meq/L) per 100,000 L of Water* on this page.

Leave about 60 ppm bicarbonates in the irrigation water as a buffer and also to provide a margin of error against small changes in water makeup and dosing rates. Therefore, if the initial level of bicarbonates is 240 ppm, approximately 180 ppm should be neutralized. In this case, three times as much acid as is indicated in the table would be needed.

When 1 mmol/L or meq/L of bicarbonate is neutralized with different acids, the following nutrients are added to the solution:

- if nitric acid is used, 14 ppm nitrogen (in nitrate form)
- if phosphoric acid is used, 31 ppm of phosphorus (as 71 ppm P_2O_5)
- if sulphuric acid is used, 16 ppm sulphur (as 48 ppm sulphates)

Table 3-4. Volume of Acid Required to Neutralize 61 ppm HCO_3^- (1 mmol/L or 1 meq/L) per 100,000 L of Water

Acid	Spec. Gravity (kg/ L)	Volume of Acid (L)
Phosphoric (85%)	1.7	6.8
Nitric (67%)	1.5	6.6
Sulphuric (93%)	1.8	2.8

Media

If the pH is too low, consider one or more of the following steps, but keep in mind that it is difficult to adjust the pH upward.

For soilless mixes

- Discontinue acidifying water supply.
- Shift to a basic-reaction fertilizer (high in nitrate nitrogen).
- Use potassium bicarbonate (100–200 kg/1,000 L) of stock at 1:100 dilution, with an EC in the final solution of approximately 1.5–2.0 mS/cm.
- If limestone is used, the amount to add depends on the type and ratio of the ingredients. Sphagnum peat moss (pH 3.5–4.5) and bark (pH 4.0) are acidic. The amount of limestone needed to neutralize sphagnum moss from a pH 3.5 to a pH 5.5 is approximately 6–7 kg/m³ of loose peat moss. Alkaline materials are often the baked-clay types, such as Haydite and Crackpot or sand. Adding clay additives with a high pH should reduce the amount of limestone needed. Check the pH after preparation but before planting. The pH of newly prepared moist media will continue to rise for about 10 days.

For soil beds

- To increase the pH by 1 unit, use 4.8 kg super-fine dolomitic limestone per 100 m².
- For a soil with higher clay content or a higher organic matter content, increase the amount by approximately 25%.

- Two to three weeks after application, check the soil pH to see if the desired pH level has been attained. Note that the finer the limestone, the quicker its reaction with the soil.
- The rate of pH change is also affected by temperature, moisture and aeration conditions of the soil. Changes will occur most rapidly when soils or soilless media are warm, moist and well-aerated.
- The use of hydrated lime in greenhouses has some severe drawbacks, as it reacts very quickly and thoroughly. Proper distribution of the material throughout the soil mixture is difficult, and consequently the use of this material is very limited. However, it is often used as a portion of the total limestone demand for soilless media in order to achieve a quick change in the pH, so that the media can be used for planting.

A media pH that is too high can be difficult to lower, but one or more of the following steps will help.

- Increase the acidity of the irrigation water. Usually it is harmless to lower the pH of the nutrient solution to 5.2–5.4, while maintaining 30–60 ppm of bicarbonate (see above). The goal is providing an acidic solution around the roots to allow for uptake of micronutrients until the nutrient solution is buffered up in pH.
- Discontinue using basic-reacting fertilizers such as calcium nitrate where possible.
- Use more ammonium-based fertilizers, particularly during the high-light months of the year.
- Drench with iron sulphate at 5 kg/1,000 L of water. Be sure to lightly wash the foliage immediately afterward to avoid burning.
- Use elemental sulphur at 15 kg /1,000 L of water. This treatment requires 3–4 weeks to be effective.

See also Table 3-5. *Adjusting pH for Soil Beds* on this page.

Table 3-5. Adjusting pH for Soil Beds

Materials	kg/100 m² to Lower pH 0.5–1 Unit*	Rate of pH Change
Finely ground sulphur	2.5	Slow
Aluminum sulphate	15	Rapid
Iron sulphate	15	Moderate

* Rates are for light to medium soils. For heavier soils and those with more organic matter, increase rate by one-third. The rates per m³ of potting soils are one-half of the above rates.

Soilless Growing Media

Commercial growers have replaced soil-based potting mixes with soilless potting mixes. Whether the mix is used for plant growing, propagation, container growing, bench crops or even cut flowers, there has been a gradual reduction in the use of actual soil and an increase in the use of alternative ingredients in soilless substrates. Soilless mixes are available ready to use in bags or skyscraper bales, in bulk or as separate ingredients that can be blended together by the grower.

Advantages of soilless mixes

Soilless mixes offer several advantages over a conventional soil mix.

- Uniformity and consistency of each batch/load is critical to water and fertilizer management practices for the numerous crops being grown.
- Most are considered to be essentially free of diseases and insects, thereby reducing the need for costly pasteurization. They are generally considered free of weed seeds as well.
- There is less likelihood of contamination from herbicide residues, which can occur with mixes containing field soil.
- The ingredients of a soilless mix are readily available and most are much lighter than soil.
- Soilless mixes have greater pore space and higher water-holding capacity than soil-based mixes.

Functions of a good growing medium

A growing medium should:

- provide an anchor system for the plant roots.
- store water for absorption by plant roots between irrigation events.
- provide a buffer for nutrients absorbed by the roots.
- provide oxygen (air space) for root respiration.

Common ingredients

Sphagnum peat moss

This is one of the most widely used materials, due to its physical characteristics and price. Sphagnum moss is a primitive plant that grows in bogs. While the upper part of the plant continues to grow, the bottom part dies, decomposing into peat. The moss leaves consist of living cells that may or may not contain chlorophyll, as well as dead "sphagnum" cells, which contain water and air. The dead sphagnum cells are unique in that they can absorb and conduct water. These cells have lignified walls that prevent their collapse when drying out. Water in these cells is absorbed by capillary action. Because the leaf and stem cells are surface active and are generally negatively charged, they can adsorb nutrients (e.g., positive ions) in a similar way to clay particles. Nutrients can also be absorbed in the sphagnum cells as dissolved ions in water.

A sphagnum peat bog has a top, middle and bottom. Because of the way sphagnum grows, the older mosses will be at the bottom and are the most decomposed. They are also the darkest in colour and finest in particle size. The top layers are more yellowish and coarser in structure. Coarse peat has low bulk density and greater air space than fine peat. The water-holding capacity (by volume) is lower, and as a result, is better quality.

The method of peat moss harvesting plays an important role in particle size distribution. Peat is harvested in two ways. Vacuum harvesting involves loosening the surface, air drying and vacuuming the top surface of the bog. Block harvesting involves digging the peat in chunks and letting them dry over winter. The following spring, the chunks are loosened and packaged. Block-harvested peat is coarser than vacuum-harvested and is usually considered the best quality, but is also more expensive.

Cation exchange capacity (CEC) indicates how many cations can be adsorbed per unit weight and how their supply to plants will be regulated (buffered). With its high CEC, peat moss is well-suited as a nutrient reserve and buffering agent. Pure peat moss, however, contains very few nutrients as determined by the electrical conductivity of the saturated medium (EC<0.5 mS/cm).

Due to its naturally low pH (3.5–4.5), peat moss is considered to be free of active pathogenic diseases, although dormant pathogenic spores or weed seeds may be present.

The low cost on a volume basis makes peat moss one of the more desirable mix ingredients. Normally, commercial and grower-made mixes consist of 50–100% sphagnum peat moss. The sphagnum peat mosses available in Ontario are generally sold in a compressed form and will expand by 40–60%, depending on compression level.

Sphagnum peat, particularly when dry, is hydrophobic in nature. To maintain uniform wetting and rewetting, the addition of a surfactant or non-ionic wetting agent is critical throughout the growing cycle of crops.

Vermiculite

This is a mica-like material that has been expanded under high temperature (900°C). This material can be compared to clay particles, except that it has lost its swelling and shrinkage capabilities. It has a high cation exchange capacity (CEC), similar to peat moss on a weight basis, and contains considerable quantities of potassium and magnesium ions. It improves porosity, provides structure to the medium (less shrinkage) and makes rewetting of a mix easier. Water can also be absorbed internally between the platelets. Acidity is near neutral, and bulk density is 80–100 kg/m^3. Three grades are normally available – coarse, fine and regular. It is mined in South Africa, the United States, China and Brazil.

Perlite

This is an aluminum-silicate of volcanic origin that has been heated to approximately 1,000°C. It is similar to popcorn as it consists of a number of closed, air-filled cells. Water is absorbed primarily on the outer surface and to a lesser degree within the particle. This inert material is primarily added to the mix to improve aeration and drainage, as well as structural stability. The pH is approximately 7.0, and the CEC is negligible. Its bulk density is similar to that of vermiculite or peat moss, at approximately 100 kg/m³.

Coir

Coir is the coarse fibre pith produced as by-product when the long lignin fibres are extracted from the fibrous outer husk of the coconut fruit. These fibres are typically washed with fresh water to remove the excess sodium and chloride ions prior to processing for horticultural uses. It has a high water-holding capacity, 8–9 times its dry weight. It has excellent wetting properties and high cation exchange capacity. The pH is typically 5.7–6.5. Prior to planting, growers should complete an EC sampling of each shipment to ensure that the coir was adequately washed to remove potentially high sodium and chloride levels. Coir is available as 1 L compressed bricks that will expand to 8–9 L of fluffed-up material, as chunks, and as compressed 1 m slabs sleeved with plastic for greenhouse vegetable production. Compressed bricks that fail to expand properly when wetted should be discarded. Currently, coir is being used for the production of long-term cut flower crops, such as gerbera and roses grown in containers or troughs. Coir is also being used to make biodegradable pots for spring bedding plant crops.

Rockwool

This product is manufactured from basalt and limestone by spinning the molten rock. Bonded product and granulated material are the two forms available. The base material is sterile and does not contain any CEC or an appreciable level of soluble salts. The bonded product is cut into slabs 15 or 20 cm wide, 7.5–10 cm thick, and 90–200 cm long. It can be purchased with or without a plastic sleeve. Slabs contain a binder for stability and a wetting agent to facilitate water absorption and distribution. The granulated material comes in three sizes (fine, medium and coarse) and does not contain any binder and/or wetting agent. Granulated rockwool is added to a mix to increase pore space and water-holding capacity, as well as for easier rewetting if the medium is allowed to dry out. Rockwool is currently used for the production of a few long-term cut flower crops, such as roses and gerbera, and greenhouse vegetable crops.

A similar rockwool-like material can also be manufactured from steel slag. This material, often referred to as mineral wool, generally has a relatively high pH (7–8) and higher levels of micronutrients compared to rockwool.

Polystyrene chips

This is a waste product created from polystyrene bead boards. The material is inert, with negligible CEC and near-neutral pH. Its role in a medium is similar to perlite, except that there is no surface absorption of water. Bulk density is 25 kg/m³, and it cannot be pasteurized due to shrinkage. It has a tendency to float to the surface of the pot and can be a nuisance with recirculating sub-irrigation systems. Soil mix uniformity can be a concern because of its tendency to separate from the rest of the mixture. Its use is not recommended because of environmental concerns associated with polystyrene beads blowing in the wind or falling into and floating in watercourses.

Turface®

This is a baked clay with neutral reaction (pH 7.0). Because the bulk density is 750 kg/m³, and the CEC is high for regular grade, the material is used to increase the weight and the buffering capabilities of the mix. The CEC is comparable to vermiculite.

Haydite®

This is a type of shale expanded by heating to 1,200°C. Bulk density is approximately 800 kg/m³, depending on size and grade. It has a high pH (8.5–9.5) and can be obtained in several grades according to particle size. The neutralizing capacity of this material has to be considered when used in appreciable quantities.

Gro-Bark®

Composted barks may suppress toxic substances and plant pathogens. Hardwood barks are generally composted for three months, while softwood barks take approximately one and a half months to compost. Nitrogen is generally added at 1 kg or 0.5 kg/m³ for hardwood and softwood bark, respectively, before composting. Gro-Bark®, a commercially available product, is a blend of aged pine bark and sawdust that has been naturally composted for 10–40 years.

It ranges in pH from 4.5–6.5 and is low in salts. Available in bulk only, it is often used as bedding in walkways, as an amendment for containerized nursery material, or as a substitute for peat moss.

Grow-Rich®

Grow-Rich® is a composted material produced from paper mill sludge and other organic materials (animal manures, sawdust and corncobs). The bulk density is approximately 400 kg/m³, while typical particle size ranges from 3–6 mm. The pH ranges between 5.5–6.5, and soluble salts are near 1.5–2.0 mS/cm, using the SME method. As a consequence, the final potting mix should not contain more than 25% of this material.

Worm castings

Worm castings are a by-product of worm raising. They are high in organic content and stable in structure. The pH is 6.0–7.5, while soluble salts are between 1.0–1.5 mS/cm. Bulk density is approximately 200 kg/m³. It should be used sparingly in a mix (less than 25% of the volume) to provide structural stability and more pore space to the media. It is somewhat hydrophobic in nature, may contain weed seeds and is quite expensive.

Sand

Although technically a type of soil, sand is quite often incorporated into soilless mixes to provide weight. It is about 15 times heavier than the other major components (peat, perlite and vermiculite). Drawbacks with sand include:

- grinding action on the other ingredients if mixed too long, causing a reduction in air space
- potential for containing plant pathogens, therefore requiring pasteurization

However, sand (similar to soil) improves wettability of the mix. Depending on its source in Ontario, sand often has a high pH (approximately 8.5), indicating the presence of free calcium carbonates. Consider its neutralizing capacity when using sand.

Physical characteristics of a soilless mix

A soilless (or soil) mix has three major components – air, solids and water. The air space is needed to provide oxygen for root respiration and to allow nitrification and some microbial activity. The air space in a mix complements the water portion, since air replaces the water absorbed by the plant roots. The air/water ratio in a mix is determined by the particle size of the solids. After a coarse mix is watered, air will enter the mix more quickly than in finer mixes, but may not be distributed uniformly. Therefore, a coarse mix has relatively more air and less water-filled pore space than a fine one. A lack of air space can be a problem when using a fine-textured mix during the lower light periods of the year. Another factor that affects the air/water ratio is the height of the pot – the taller the pot, the greater the air/water ratio, especially in the top of the pot.

After watering, a soilless mix may have up to 75% of the total space filled by water, with the remainder taken up by solids (5–10%) and air (15–20%). In a soil mix, solids compose 50% of the space, with the balance divided between air and water. This basic difference between a soil and a soilless mix therefore necessitates a different crop management approach for each medium. The bulk density of most soilless mixes is approximately 100–200 kg/m³. Shrinkage of the mix is of some concern due to the changing physical properties, but also due to the volume of the medium required for a given pot size. Peat moss and rockwool will both shrink. The addition of structural components such as perlite or vermiculite, or compressing the mix when filling the pots, helps to alleviate medium shrinkage.

See also Table 3-6. *Example of a Soilless Mix with Amendments* on page 33.

Preparing a soilless mix

There are several factors to consider when preparing a soilless mix. They include:

- water-holding capacity
- air porosity
- nutrient availability
- buffering capacity
- weight
- price

Table 3-6. Example of a Soilless Mix with Amendments

Ingredients	Percent (by volume)
Sphagnum peat moss	50–60%
Vermiculite, perlite, polystyrene, bark, granulated rockwool	20–40%
Turface®, Haydite®, sand	10–20%
Amendments	**Rate/m³ of mix**
Limestone (fine grade, dolomitic)	3.5 kg
Superphosphate	1.5 kg
Potassium nitrate (12-0-44) or ammonium nitrate (34-0-0)	1.0/0.4 kg
Trace element mix OR Media Premix (2-3-6 + micronutrients)	0.25–0.5 kg Discuss with supplier
Wetting agent	100 mL

Due to its excellent growing properties, the major component in most soilless mixes is sphagnum peat moss. The quality of the peat moss is important as it is the principal ingredient. A coarse peat provides more natural air space and can be used at a higher percentage in the mix. A finer mix, with less air space, should constitute less of the final mix. For aeration purposes and to give structure to the mix (with less shrinkage), use one or a combination of the following ingredients: vermiculite, perlite, granulated rockwool or coir. Vermiculite and rockwool are excellent materials, as they increase water-holding capacity and have good rewetting characteristics. The third ingredient (Turface®, Haydite® or sand) is added for weight, buffering capacity and/or pore space.

Add limestone (3.5 kg/m³ of mix) to bring the pH of the mixture to an acceptable level (based on a mix containing 50% peat moss). The amount of limestone indicated does not take into account any neutralizing effects from the other ingredients (e.g., Haydite®, sand) or the acidifying effect of some fertilizers (e.g., ammonium nitrate). It may take one week after mix preparation and initial wetting before the pH is stabilized.

When using calcitic limestone, supply magnesium in the form of Epsom salts (0.5 kg/m³). Add superphosphate for phosphorus, sulphur and calcium. If nitrogen and/or potassium are also added, use potassium nitrate (12-0-44) at 0.5–1.0 kg/m³, or ammonium nitrate (34-0-0) at 0.3–0.5 kg/m³. The nitrogen addition will amount to approximately 0.25–0.50 g nitrogen per 15 cm pot. In some instances, calcium nitrate may be used as the nitrogen source at 0.5 kg/m³. Use Nutritrace or a similar micro-element mix to add the following trace elements; iron (Fe), copper (Cu), boron (B), zinc (Zn) and manganese (Mn). As a wetting agent, a non-ionic surfactant such as Aqua-Grow® or Agral-90 is suitable. Add to water and spray over the mix for uniform distribution. Sometimes a combination of trace elements and wetting agent is available in granular form. For the purpose of convenience, many growers have the amendments premixed by their fertilizer supplier. Most ingredients can be mixed when dry. Screw-turn and tumbler-type mechanical mixers can be used, but prevent pulverization of components by minimizing mixing time. Add water when the ingredients are being mixed to prevent dust and promote stable particles. Most growers rely on custom-blended soilless media to individual grower specifications prepared and delivered by the sphagnum peat moss suppliers.

Chemical characteristics of mixes

After preparing a mix, always check the total soluble salts (EC) and pH. The EC gives an indication of the nutrient status by measuring the conductivity of the solution, while the pH plays a major role in determining the nutrient availability (see *Electrical Conductivity (EC)* on page 23). The optimal pH for organic soilless mixes is approximately 5.5 (±0.5). This contrasts with the target of pH 6.5 for soil mixes. In the peat-like mixes, a high pH (over 6.5) can cause deficiencies in iron (Fe), manganese (Mn), boron (B), copper (Cu), zinc (Zn) and phosphorus (P), while a pH of 5.0–5.5 can cause molybdenum deficiency (especially in poinsettia). Adding ammonium nitrate (34-0-0) at 400 g/m³ may reduce the pH by approximately 0.5 of a unit.

Ready-made mixes

Most commercially prepared mixes have been tested and will perform well when managed properly. When comparing prices between commercial mixes and custom mixing (your own), consider the costs of materials, mixing, equipment, storage space and labour. Smaller operations often use ready-made mixes. Some manufacturers will blend and deliver mixes to growers' specifications. The ready-made mixes usually follow the above outline of ingredients, although the third major ingredient (Turface® or sand) is usually omitted. Most ready-made mixes have a pH of 5.5–6.0 and an EC of 1.2–1.8 mS/cm using the SME method, while the water-holding capacity is approximately 70% on a volume basis after a 15-cm pot is totally saturated and allowed to drain.

Composts

Some growers may choose to use composted material as part of their soilless mix, particularly for field-grown potted crops in larger containers such as perennials. Composts may contain antagonistic fungi and bacteria (to suppress plant diseases) as well as other beneficial microorganisms (such as nitrifying bacteria). Composts made from assortments of organic by-products are available in bulk from various suppliers at relatively low costs. These may be used successfully as amendments, but it is advisable to check pH and soluble salts before use.

Common problems with soilless mixes

- Mixing the ingredients of a soilless mix for too long grinds the particles together, breaking them down and thereby destroying medium structure. A general guideline is 3–5 minutes at 12–14 rpm.
- Rewetting a soilless mix after it has dried out is difficult, but not impossible. Use several light applications of water or mist applications. Alternatively, add a wetting agent to the water at approximately 1 mL/L of warm water. Normally, a wetting agent is added when mixing the ingredients because of the hydrophobic nature of peat moss.
- During production of crops with a cropping period longer than 6–8 weeks, the addition of a wetting agent or surfactant is necessary to ensure uniform rewetting throughout individual containers but also of the crop in general. This is a problem commonly observed in crops grown using sub-irrigation. Wetting agents break down over time. Apply additional wetting agent through the irrigation system following manufacturer's recommended rates. Two wetting agents available include Aqua-Grow 2000 L and Deluge.
- Excessive levels of wetting agent incorporated into the medium (e.g., 2–3 times the usual rate) can result in the development of only a few long stringy roots or a failure of the roots to penetrate the medium. This may cause overall stunting of sensitive species, including impatiens, begonia and cucumber.
- Algal growth on the surface may restrict seedling emergence, reduce water penetration and/or serve as a food source for fungus gnats. Some fungicides may reduce algal growth. As the plants grow, reduced light levels on the surface will also restrict development of algae. Hydrogen peroxide-based products such as ZeroTol are commonly used. Algae-free irrigation water also reduces this problem.
- Optimal nutrient levels are usually higher than in soil-based mixes, and therefore the crop should be kept well-fertilized. Soluble salts readings can safely be about twice as high as those in a soil mix.
- Symptoms of magnesium deficiency show up quickly on crops such as tomato and chrysanthemum. This is because most conventional water-soluble "complete" fertilizers do not contain magnesium. Pre-plant incorporation or separate feedings of Epsom salts (magnesium sulphate) or magnesium nitrate will help prevent this situation.

Nutrients Necessary for Plant Growth

Plant nutrients can be divided (depending on the quantity of each required by the plant) into macro- and micronutrients. Table 3-7. *Macro- and Micronutrients in Plants* on page 35 also indicates the form in which the element is taken up by the plant and its remobilization within the plant.

Table 3-7. Macro- and Micronutrients in Plants

Elements	Form	Mobility in Plants*
Macronutrients – Primary		
Nitrogen (N)	Ammonium (NH_4^+), Nitrate (NO_3^-)	High
Phosphorus (P)	Dihydrogen phosphate ($H_2PO_4^-$)	High
Potassium (K)	Potassium (K^+)	High
Macronutrients – Secondary		
Calcium (Ca)	Calcium (Ca^{2+})	Low
Magnesium (Mg)	Magnesium (Mg^{2+})	High
Sulphur (S)	Sulphate (SO_4^{2-}), Sulphur dioxide (SO_2)	Low – Medium
Micronutrients		
Iron (Fe)	Ferrous (Fe^{2+}), Ferric (Fe^{3+})	Low
Manganese (Mn)	Manganese (Mn^{2+})	Low
Copper (Cu)	Copper (Cu^{2+})	Low
Zinc (Zn)	Zinc (Zn^{2+})	Low
Molybdenum (Mo)	Molybdate (MoO_4^{2-})	Medium – High
Boron (B)	Boric acid (H_3BO_3)	Low – Medium
Chlorine (Cl)	Chloride (Cl^-)	High
Beneficial Elements of Interest to Specific Greenhouse Crops**		
Silicon (Si)	H_4SiO_4	Low
Aluminum (Al)	Aluminum (Al^{3+})	Medium – High

* Nutrients are typically categorized by their ability to re-translocate or remobilize throughout the plant. Mobile nutrients move out of older tissue or leaves (the source) into developing flowers or leaves (the sink) when the levels are deficient in the root substrate. Nutrients capable of remobilization move to the strongest sink, the area of the plant with the greatest demand. In descending order, the strongest sinks in the plant are fruit, flowers, new leaves, older leaves, then roots.

**Silicon and aluminum have been included as beneficial elements of interest to specific greenhouse crops. Silicon has been shown to improve yields of certain greenhouse crops including cucumbers, and reduce the incidence of powdery mildew. The timing and application of aluminum (in association with low pH) to hydrangeas during forcing is critical to development of blue inflorescences.

Nutrients considered immobile, from a whole plant perspective, generally do not move out of the plant organ once at their “final destination,” resulting in deficiency symptoms becoming evident on new growth as levels present in the root substrate become insufficient.

There are two main factors affecting the mineral content of a plant. The first is genetically determined and accounts for the fact that nitrogen and potassium content of many plants (4–6%) is about 10 times higher than that of phosphorus and magnesium, which are in turn 100–1,000 times higher than most micronutrients.

The second is the availability of nutrients in the growing medium and the ability of the plant to absorb them. In practice, this is the only factor growers can influence. Up to a certain level, the nutrient content of a given plant increases with a higher content of nutrients in the growing medium. Beyond this optimum level, no benefit can be expected from further increase in availability.

Uptake and Translocation of Essential Nutrients for Plant Growth

Non-Fertilizer

Carbon is taken up primarily in the form of CO_2 through the stomata in the leaves. It is then transformed into organic material through the process of photosynthesis. To a lesser extent it may also be taken up in the bicarbonate form (HCO_3^-) from the nutrient solution. Water is the major supplier of hydrogen ions through absorption by the root hairs. Oxygen is taken up as CO_2 during daylight, and as oxygen dissolved in water through the roots. Collectively these three elements represent approximately 90% of typical plant content on a % of dry weight basis.

Macronutrients

In general, all macronutrients except calcium are mobile within the plant. Mobile nutrients can move in both the xylem and phloem and will be translocated to where they are most needed, usually developing shoots, flowers or bracts.

Macronutrients

Primary

Nitrogen in both its ammonium (NH_4^+) and nitrate (NH_3^-) forms can be absorbed by the roots and metabolized by the plants. The rate of NO_3^- uptake is usually greater than that of NH_4^+. However, this depends strongly on pH. NH_4^+ uptake occurs best in a neutral medium and decreases with a lower pH. The reverse is true for NO_3^-. High carbohydrate levels in the plant (e.g., during summer) favour uptake of NH_4^+. Within the xylem, nitrogen is transported as nitrate and amino acids. Nitrogen typically represents 3.5–5.0% on dry weight basis.

The majority of **Phosphorus** is actively taken up (from very low concentrations in the soil to higher levels in the xylem) as $H_2PO_4^-$. Phosphorus represents 0.3–0.6% on dry weight basis.

Potassium is taken up as K^+, often actively, and is mobile within the plant and represents approximately 4.0–5.5% on dry weight basis depending on species.

Secondary

Calcium is absorbed passively (from higher concentrations in the soil to lower concentrations in the plant) as Ca^{2+}. Calcium in the xylem sap is translocated in an upward direction within the transpiration stream, and thus depends on transpiration rate and humidity (or vapour pressure deficit). Uptake is also favoured by NO_3^-. Within the plant, calcium is not mobile. Calcium typically represents 1.0–1.5% on dry weight basis.

The rate of **Magnesium** uptake is determined by the competitive effects of other cations (e.g., potassium and ammonium). It is taken up passively by the transpiration stream but its movement in the roots can be strongly affected by the level of potassium present. It is mobile in the xylem when levels are low, resulting in breakdown of the chlorophyll molecules (where it is the central ion) in the lower leaves and its movement both in the xylem and phloem to active growing points. Magnesium typically represents 0.5–1.0% on dry weight basis.

Sulphur is primarily absorbed mainly in the form of sulphate (SO_4^{2-}), which may be taken up actively. Sulphur typically represents 0.5% on dry weight basis.

Micronutrients

All micronutrients are essentially immobile. They can be absorbed by the roots, moved through the plant in the transpiration stream and distributed to various plant parts. However, they cannot be moved out of the various plant tissues and redistributed to other plant parts if needed.

Iron uptake is influenced by rate of plant metabolism, as well as by the presence of other cations such as manganese (Mn^{2+}) and copper (Cu^{2+}). Iron uptake is depressed by high pH, root damage, and high levels of phosphate, manganese, boron and calcium. It is enhanced by high ammonium (NH_4^+). Iron (Fe^{3+}) is not mobile between plant parts.

Manganese uptake is influenced by plant metabolism (similar to iron). Low soil temperature causes low metabolic activity and therefore reduces uptake (e.g., roses in soil beds in winter). Manganese is relatively immobile in the plant. Young plant tissue is usually rich in Mn^{2+}. Manganese availability is enhanced by low pH.

Copper uptake is similar to iron and manganese. Copper (Cu^{2+}) is not very mobile within the plant, but can be translocated from older to younger leaves under certain conditions. There are generally very low levels in the plant compared to other micronutrients.

For **zinc**, there is some disagreement as to whether its uptake is passive or active, although most researchers consider it active. It has a strong interaction with copper. Zinc is not very mobile within plants.

There is not a great deal known about **molybdenum** (MoO_4^{2-}), but it is required in the smallest quantity by plants. In floriculture, poinsettia is one of a few plant species known to be sensitive to low levels. Deficiency is often associated with low pH and high ammonium levels in the growing media. Molybdenum is important in the function of a major enzyme in plant metabolism.

Boron is likely taken up as undisassociated boric acid (H_3BO_3) and follows water flow through the roots. It is immobile within the plant and is concentrated more in older rather than younger leaves. Deficiency is found in the plant tip and toxicity in the older leaves.

Chlorine is easily taken up by plants as chloride (Cl^-), is readily soluble and highly mobile. Chloride plays a role in stomatal regulation and photosynthesis. Most greenhouse crops are very sensitive to high chloride levels particularly in the seedling stage, while fern, Dracaena and lily are very sensitive at all growth stages.

Nutrient Analysis

Testing of water, growing media and tissue for nutrient analysis can be done through laboratories in Ontario (see Appendix C. *Greenhouse Media, Nutrient Solutions and Tissue Testing Laboratories in Ontario* on page 154).

Water

The raw water used for irrigation purposes may contain all the major elements needed for plant nutrition, however, the quantity of each element required can only be adjusted based on a nutrient analysis. A water analysis will indicate whether the water source is suitable for irrigation purposes or whether the concentration of specific ions such as sodium, fluoride (F^-) or boron (B) may be too high. In addition to knowing the pH, the bicarbonate level (ppm or meq/L) is required so the amount of acid can be calculated to obtain the desired pH. Table 3-8. *Maximum Desirable Concentrations of Specific Ions in Raw Water Used for Irrigation Purposes in a Greenhouse Using Soilless Substrates (Rockwool, Oasis, Peat or Coir)* on this page lists the most common elements involved in plant nutrition and desirable levels in raw water to be used for irrigation.

Table 3-8. Maximum Desirable Concentrations of Specific Ions in Raw Water Used for Irrigation Purposes in a Greenhouse Using Soilless Substrates (Rockwool, Oasis, Peat or Coir)

Element	Maximum Desirable (ppm)
Nitrogen (NO_3^-)	5
Phosphorus ($H_2PO_4^-$)	5
Potassium (K^+)	5
Calcium (Ca^{2+})	120
Magnesium (Mg^{2+})	25
Chloride (Cl^-)	100
Sulphate (SO_4^{2-})	200
Bicarbonate (HCO_3^-)	30–60
Sodium (Na^+)	60
Iron (Fe^{3+} or Fe^{2+})	5
Boron (B)	0.5
Zinc (Zn^{2+})	0.5
Manganese (Mn^{2+})	1.0
Copper (Cu^{2+})	0.2
Aluminum (Al^{3+})	5
Molybdenum (Mo)	0.02
Fluoride (F^-)	1
pH (H^+)	5.0–7.0

Source: The information in this table has been developed and adapted over time by Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and University of Guelph greenhouse specialists.

Comments regarding the various elements:

N, P, K, although they are used for fertilization purposes, high levels of these elements (nitrogen, phosphorus and potassium) in the raw water indicates contamination.

Ca^{2+} (calcium) and **Mg^{2+}** (magnesium) at the maximum desirable levels described above provide adequate levels of nutrition for most crops. Higher values do not necessarily mean toxicity, but can contribute to the hardness of the water and the formation of insoluble compounds at the tips of irrigation emitters.

HCO_3^- (biocarbonates) is present in most water sources in southern Ontario in excess of the given range. Bicarbonates are not very toxic, but levels of 250 ppm or higher may create problems for plant growth. High levels provide a high alkalinity (pH), which over time may increase pH levels in the growing medium. The precipitation of calcium and/or magnesium carbonates causing leaf residues and the plugging of emitters is another disadvantage of high bicarbonate levels. Neutralize high bicarbonate levels by using nitric, phosphoric or sulphuric acid (see *Adjusting the pH,* on page 28).

Fe^{3+} (iron) in its oxidized form, has a low solubility and can therefore easily precipitate as amorphous iron hydroxide, which plugs emitters. For drip irrigation systems, levels higher than 0.25 ppm are undesirable.

Boron (B) can be quite toxic to plants and should be carefully controlled in substrate culture (less than 0.5 ppm) or for a recirculating system (less than 0.25 ppm).

Zn^{2+} (zinc) can be found in water sources that have been in contact with uncoated galvanized metal (e.g., the rainwater from a greenhouse roof using untreated galvanized gutters). The ions may accumulate in recirculating systems.

Mn^{2+} (manganese) is not often a problem except under specific circumstances (e.g., steam pasteurization), however, it is toxic at high levels when it accumulates in older plant tissues.

Cu^{2+} (copper) levels may be higher (up to 0.5 ppm) than the 0.2 ppm listed in Table 3-8 on page 37 if organic-based media are used rather than inert media.

Al^{3+} (aluminum), **Mo** (molybdenum) and **F^-** (fluoride) are not commonly found at high levels in the water source. However, **Cl^-** (chloride) can be and both chloride and fluoride can cause serious damage to monocotyledon crops (lily, Dracaena, spider plant) as well as other salt-sensitive floral crops. Cleaning compounds for greenhouse roofs (to remove whitewash), which often contain fluoride, should not be allowed to drain into surface water, cisterns or ponds.

pH is a measure of the concentration of hydrogen ions, which, although they are not considered a nutrient element, are important since the availability of most nutrients is pH-dependent. For instance, most positively charged ions such as iron (Fe), manganese (Mn) and calcium (Ca), as well as phosphates, are more soluble (and therefore more available to the plant) at a low pH, while molybdenum is more available at a higher pH. Most water sources in Ontario have a pH of approximately 7.5 due to high levels of bicarbonates. Acidification may be required (see *Adjusting the pH,* on page 28). A pH lower than 5.0 is detrimental to the structure of rockwool slabs and can cause roots to be stubby.

See Appendix C. *Greenhouse Media, Nutrient Solutions and Tissue Testing Laboratories in Ontario* on page 154 for laboratories in Ontario that are able to analyze water, nutrient solutions and media.

Soilless media testing

Media testing for nutrient content was for many years done by mixing water with the growing media at a ratio of 1:2 (air-dried/growing media:water), a technique called the Spurway test. Now the Saturated Media Extraction (SME) method using distilled water is the most widely used in North America. It measures the soluble nutrients directly in the extract. This procedure provides an estimate of what is readily available to the plant in the root zone.

Sampling the growing medium for testing

Soil/ground beds should be sampled using a soil probe. Take approximately 20 samples of the area (ground beds) at a depth of 10–25 cm and bulk the samples. Mix the bulked sample well, take a representative sample (approximately 600 g), put in a plastic bag and send for SME analysis (see *How to measure EC of the growing medium* on page 24, and Appendix C. *Greenhouse Media, Nutrient Solutions* *and Tissue Testing Laboratories in Ontario* on page 154). Analysis is conducted on a fee-for-service basis. For seasonal crops, have the soil tested well before the crop is planted. Allow enough time (at least 10 days) between sending the samples and planting the crop to make nutrient or pH adjustments.

Potting media should be sampled only from the bottom two-thirds of the potting substrate. Do not include the top layer, particularly when the crop is being sub-irrigated. Bulk together 8–10 samples and from that take a representative sample of approximately 600 g, place in a plastic bag and send to the laboratory. Growers should conduct their own EC and pH tests (between regular sampling for laboratory analysis) by using the Pour-Through Method (see *How to measure EC of the growing medium* on page 24) on a number of pots with distilled water and measuring the leachate or doing their own SEM. These results should compare fairly closely to the SME used by the laboratory (see *Interpretation of EC measurements* on page 25) and give an accurate indication of the total nutrient status, but not that of the individual elements. To accurately track nutrient levels in the media, collect biweekly samples.

For interpretation of results and adjustments to the growing medium, consult a greenhouse floriculture specialist.

Foliar

In floriculture, leaf tissue analysis is primarily used as a diagnostic tool to verify deficiency or toxicity symptoms, but can also be used to monitor nutrient levels during the cropping period. Different plant parts contain different levels of nutrients, but analysis of leaf tissue is most commonly used for diagnosing nutrient availability (uptake) in the soil. The mineral content of plants is usually expressed as a percentage on a dry weight basis for the macro-elements (nitrogen, phosphorus, potassium, etc.). For micro-elements (iron, manganese, copper, zinc, boron, molybdenum), mineral content may be expressed as milligram per gram (mg/g) or parts per million (ppm) of plant dry matter. The age of the plant parts is important as well. Young plant tissue tends to have higher contents of nitrogen, phosphorus and potassium compared to older tissue, which generally has higher levels of calcium, manganese, iron and boron. Therefore, select the most recently matured/fully expanded leaves of a plant for tissue analysis, if testing regularly to monitor the nutrient status.

Foliar analysis is often a more accurate method of assessing the micronutrient status of the crop or fertility program, rather than analyzing the media micronutrient levels. Sample the most recently matured leaves from several plants unless otherwise indicated. Usually 30–50 leaves are sufficient. Avoid leaves with disorders unless they are to be diagnosed, in which case treat them as a separate sample. Ensure that samples are not contaminated with pesticides or foliar applications of fertilizer. If in doubt, rinse the leaves in distilled water and let them dry before packaging and sending them to the laboratory. Ship leaf samples in paper bags to prevent rotting of the leaves during transport.

Table 3-9. *Tissue Analysis Guidelines* on page 40 provides an overview of the desirable ranges of nutrients. Factors that can affect nutrient content include plant age, position on plant (upper versus lower leaves), cultivar, season, fertilizer regime, number of days after fertilization, media pH, growth regulator application, presence of disease and temperature. These values are a guide only to the appropriate nutritional status for these plants.

Appropriate portion of plant to sample:

- chrysanthemum – uppermost leaves from mature flowering shoots
- exacum – shoot tips with one pair of mature leaves and all immature leaves
- rose – uppermost five-leaflet leaf on flowering stems
- other crops – the most recently mature/fully expanded leaf

Table 3-9. Tissue Analysis Guidelines

Plant	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Iron (ppm)	Manganese (ppm)	Zinc (ppm)	Copper (ppm)	Boron (ppm)
African Violet	2.2–2.7	0.2–0.9	1.5–6.0	0.6–1.7	0.7–1.1	70–320	35–490	20–80	5–30	30–200
Alstroemeria	3.8–7.6	0.3–0.7	3.7–4.8	0.6–1.4	0.2–0.4	175–275	60–90	35–70	5–15	10–50
Azalea	2.2–2.8	0.2–0.5	0.7–1.6	0.2–1.6	0.1–0.6	50–150	30–300	5–60	5–15	15–100
Begonia (Reiger)	3.4–4.6	0.4–0.8	2.0–3.5	0.7–2.4	0.3–0.8	80–390	35–190	20–30	5–10	35–130
Begonia (Wax)	4.4–5.2	0.3–0.4	3.4–4.2	1.3–2.1	0.6–1.0	100–260	90–355	50–65	10–15	30–40
Caladium	3.6–4.9	0.4–0.7	2.3–4.1	1.1–1.6	0.1–0.3	65–90	110–135	125–135	5–10	95–145
Calla	2.9–3.0	0.3–0.4	3.9–4.4	0.9–1.1	0.3–0.4	95–130	635–690	30–45	5–10	30–40
Carnation	3.0–5.0	0.1–0.5	2.0–6.0	0.6–2.0	0.2–0.6	30–150	30–445	15–75	5–30	20–400
Chrysanthemum	4.0–6.0	0.2–1.2	1.0–10.0	0.5–4.6	0.1–1.5	20–750	25–375	5–35	5–50	20–200
Dieffenbachia	3.0–4.0	0.7–1.0	6.4–8.2	1.9–2.4	0.4–0.8	50–300	50–300	40–200	3.5–30	10–30
Easter Lily	2.4–4.0	0.1–0.7	2.0–5.0	0.2–4.0	0.3–2.0	100–250	50–250	30–70	5–25	20–50
Exacum	3.8–5.3	0.3–0.7	2.3–3.4	0.5–0.8	0.4–0.7	55–155	70–165	25–85	5–75	25–60
Ficus benjamina	2.0–2.5	0.2–0.4	2.1–2.5	1.7–2.5	0.3–0.4	50–200	25–100	20–75	5–10	20–40
Freesia	2.7–5.6	0.4–1.2	3.1–5.9	0.4–1.0	0.3–1.8	80–115	30–540	40–110	5–130	30–100
Fuchsia	2.8–4.6	0.4–0.6	2.2–2.5	1.6–2.4	0.4–0.7	95–335	75–220	30–45	5–10	25–35
Geranium (Ivy)	3.4–4.4	0.4–0.7	2.8–4.7	0.9–1.4	0.2–0.6	115–270	40–175	10–45	5–15	30–280
Geranium (Regal)	3.0–3.2	0.3–0.6	1.1–3.1	1.2–2.6	0.3–0.9	120–225	115–475	35–50	5–10	15–45
Geranium (Seed)	3.7–4.8	0.3–0.6	3.3–3.9	1.2–2.1	0.2–0.4	120–340	110–285	35–60	5–15	35–60
Geranium (Zonal)	3.8–4.4	0.3–0.5	2.6–3.5	1.4–2.0	0.2–0.4	110–580	270–325	50–55	5–15	40–50
Gerbera	3.3–4.1	0.3–0.7	3.1–3.9	0.9–4.2	0.3–2.8	80–130	65–260	30–80	5–10	25–50
Gloxinia	3.3–3.8	0.3–0.5	4.5–5.0	1.5–2.2	0.4–0.5	70–150	95–170	20–35	5–20	30–35
Hibiscus	3.5–4.5	0.2–0.6	2.0–2.9	1.9–2.3	0.5–0.7	60–75	135–180	35–50	5–10	20–25
Hydrangea	2.0–3.8	0.3–2.5	2.5–6.3	0.8–1.5	0.2–0.4	85–115	100–345	50–105	5–10	35–50
Impatiens (Common)	4.3–5.3	0.6–0.8	1.8–2.8	2.9–3.3	0.6–0.8	405–685	205–490	65–70	10–15	45–95
Impatiens (New Guinea)	3.3–4.9	0.3–0.8	1.9–2.7	1.9–2.7	0.3–0.8	160–890	140–245	40–85	5–10	50–60
Kalanchoe	2.5–5.0	0.2–0.5	2.0–4.8	1.1–4.5	0.4–1.0	75–200	60–250	25–80	5–20	30–60
Nephrolepis	1.7–2.5	0.3–0.6	2.5–3.9	0.9–1.3	0.6–0.7	30–300	49–181	52–149	10–15	20–40
Petunia	2.8–5.8	0.5–1.2	3.5–5.5	0.6–4.8	0.3–1.4	40–700	90–185	30–90	5–45	20–50
Poinsettia	4.0–6.0	0.2–1.0	1.5–5.0	0.4–2.0	0.2–1.0	100–300	45–300	25–150	5–15	20–200
Primula	2.5–3.3	0.4–0.8	2.1–4.2	0.6–1.0	0.2–0.4	75–155	50–80	40–45	5–10	30–35
Rose	3.0–5.0	0.2–0.3	1.8–3.0	1.0–1.9	0.2–0.4	50–150	30–900	15–50	5–25	20–60
Snapdragon	4.0–5.3	0.2–0.6	2.2–4.1	0.5–1.4	0.5–1.0	70–135	60–185	30–55	5–15	15–40
Streptocarpus	2.0–3.5	0.1–0.7	4.8–5.5	1.2–1.9	0.3–0.5	90–260	130–300	85–130	15–20	55–65
Vinca	4.9–5.4	0.4–0.6	2.9–3.6	1.4–1.6	0.4–0.5	95–150	165–300	40–45	5–10	25–40
Zygocactus (Schlumbergera)	2.7–3.7	0.5–0.9	6.2–7.1	0.7–0.9	1.6–2.2	105–110	35–130	50–65	10–15	65–70

Source: Compiled by R.E. Widmer, June 1985. Expanded and updated by J.M. Dole and H.F. Wilkins, University of Minnesota, October 1988, Department of Horticultural Science and Landscape Architecture, University of Minnesota and values from *Guide Values for Nutrient Element Contents of Vegetables and Flowers under Glass,* Glasshouse Crops Research Stations, Aalsmeer and Naaldwijk, 1987.

Symptoms of Nutrient Deficiency

(Source: *Diagnosing Nutrient Disorders in Greenhouse Crops,* C. Rosen and J. Erwin, University of Minnesota).

Nutritional interactions

Nutritional problems in greenhouse crops can be common because of the high rate of growth, the different specific requirements of each crop, the limited rooting volume of the container, and the limited nutrient reserve of the medium in which the crop is grown. Both the amount of nutrients being supplied and their balance play important roles in producing high-quality crops. Changing the level of one nutrient in a solution can affect the uptake or transport through the plant of another. Although interactions between nutrients can be either positive or negative, it is usually the negative interactions that are most well-documented.

Nutrient interactions become a factor in two situations:

- when the levels of two elements are near the deficiency range
- when one element is supplied in excessive amounts while another is at levels that are marginally sufficient.

The precise nature of the interaction depends on the nutrients involved and the plant species. It may be the result of precipitation reactions occurring in the soil solution, or the result of competition during ion uptake, translocation or metabolic function (see Table 3-10. *Some Common Interactions Between Nutrients* on this page). In many cases, the mechanism for the interaction may not be completely understood. These antagonistic effects become important when the level of one nutrient is low relative to the nutrient or element that may trigger the interaction.

Table 3-10. Some Common Interactions Between Nutrients

If excessive in media or tissue:	May cause deficiency of:
Ammonium	Calcium, molybdenum
Nitrate	Potassium
Phosphorus	Iron, zinc, copper
Potassium	Magnesium, calcium
Calcium	Magnesium, boron
Magnesium	Potassium, calcium
Manganese	Iron
Iron	Manganese
Zinc	Manganese, iron
Copper	Manganese, iron, zinc

Nutrient interactions or antagonisms and the proper balance of various nutrients in relation to their supply must be considered when diagnosing nutrient deficiency based on foliar analysis. Following plant uptake and translocation, nutrients may interact to suppress the activity of other elements in lesser tissue concentrations. The same is true during uptake from the nutrient solution, especially when levels of lesser elements are near the low end of the acceptable range while another is in the high range. Nutrient supply is important because optimal nutrient ratios in the plant tissue can only be achieved even when both elements are present in the nutrient solution.

Diagnosing Nutrient Disorders

Once visual symptoms are present on the foliage, marketability of the plants may have already been reduced. Follow rigorous soil-testing programs to detect potential problems before they result in crop losses.

In most cases, symptoms of nutritional disorders occur in defined patterns and are specific for each nutrient. Elements that are mobile within the plant generally induce deficiencies on the older (lower) leaves first, while immobile elements induce deficiencies on the younger (upper) leaves. In some cases, pesticide toxicity or disease symptoms may resemble nutrient deficiencies or toxicities.

The upper portion of the plant consists of three key regions from the top of the plant down. Region 1 is the growing tip and young expanding leaves. Region 2 is the newly/recently expanded leaves. Region 3 is the oldest, most mature leaves of the plant from which most lateral branches develop.

In addition, symptoms of nutritional disorders are often species or cultivar dependent. Use soil and tissue analysis to help confirm whether the symptoms are nutritional.

The following symptoms of nutrient deficiency and/or toxicity for nitrogen, phosphorus, potassium, magnesium and sulphur generally affect lower leaves first and may progress to younger leaves as the problem becomes more severe.

Nitrogen

Deficiency

- Leaves turn pale green to yellow.
- Oldest leaves are affected first, but in severe cases, the whole plant may be yellow. Growth is usually stunted. Symptoms are very similar to sulphur deficiency.

Excess ammonium

- Plant growth is restricted.
- Leaves are yellow.
- Marginal necrosis occurs.
- The growing point dies.
- High ammonium (generally during the winter months) will interfere with uptake and/or translocation of potassium, magnesium and calcium, thereby inducing calcium deficiency and reduced potassium and magnesium content of plant tissue.

Excess nitrate

- Most plants tolerate high nitrate levels without any symptoms.
- Nitrate enhances phosphorus and potassium uptake.
- Excessive nitrate will stimulate vegetative growth and may delay flowering.

Phosphorus

Deficiency

- Leaves appear reddish-purple. Lower leaves are yellowish.
- Oldest leaves are affected first. Necrosis and leaf drop can occur if the deficiency is severe.
- Plant growth is stunted.
- Phosphorus deficiency may be induced under high pH (>7.4) or low pH (<5.0) conditions in soilless media.

Excess

- Excess phosphorus may induce micronutrient deficiency symptoms by inhibiting iron, zinc and copper uptake and/or translocation, possibly due to precipitation of phosphates.

Potassium

Deficiency

- Leaves develop grey or tan areas near the margins.
- Oldest leaves are affected first with characteristic scorching of the leaf tips and around the margins.
- In some plants, spotting or chlorosis between the veins may occur.
- Growth may be bushy.

Excess

- Excess potassium may cause salt burn expressed as a marginal leaf burn at very high rates.
- If magnesium levels are marginal, will induce magnesium deficiency.

Magnesium

Deficiency

- Older leaves turn yellow between the veins (interveinal chlorosis).
- In severe cases, younger leaves may be affected and older leaves may develop necrotic spots and then drop off.
- Deficiency can be induced by high potassium levels.

Excess

- Plants can tolerate high levels of magnesium without adverse effects.
- High levels of magnesium can cause deficiencies of potassium and calcium in plant tissue.

Sulphur

Deficiency

- There is a general yellowing of the plant. Leaf veins are often yellow.
- Symptoms are similar to nitrogen deficiency.

Excess

- Plants can tolerate high levels of sulphur. However, uptake of molybdenum will be reduced.

The following symptoms of nutrient deficiency and/or toxicity for calcium, boron, copper, iron, manganese, molybdenum and zinc generally affect younger or upper leaves first.

Calcium

Deficiency

- Growing points of plants may die.
- Youngest leaves are affected first.
- Root tips die. Root growth is slow.
- In some plants, leaf edges or tips are yellow or scorched (often termed leaf-edge or leaf-tip burn).
- Deficiency can be induced by high levels of ammonium and excessively wet or dry conditions.

Excess

- Plants can tolerate high levels of calcium without adverse effects.
- High levels of calcium can cause lower levels of potassium and magnesium in plant tissue.

Boron

Deficiency

- Usually occurs on younger plant tissue (Region 1).
- Young leaves are often dark green, thick and brittle.
- Growing points die, and leaves appear small and distorted, with multiple shoot development. "Witch's broom" on rose is common.

Excess

- Boron can be highly toxic to some plants.
- Toxicity usually occurs on the oldest leaves (Region 3), usually as a chlorosis followed by necrosis or scorching of the margins between the leaf veins.

Copper

Deficiency

- Yellowing or dieback of youngest leaves occurs (Region 1).
- Yellowing between the veins may appear.
- There is a distortion of the leaves with stunted, strap-like growth.
- High levels of phosphorus may induce copper deficiency.

Excess

- Excess copper may induce iron deficiency and cause stunted root systems.

Iron

Deficiency

- There may be yellowing between the veins on the youngest leaves (Region 1), although veins remain green (interveinal chlorosis). They also may turn totally yellow to white with necrosis.
- High levels of phosphorus may induce iron deficiency.
- Oxygen deprivation due to over-watering will trigger iron chlorosis.
- High pH conditions as well as low soil temperatures will cause iron deficiency. When high pH is the cause, iron chelate in the EDDHA (strongest over the widest pH) can be used to correct iron-related symptoms.

Excess

- Most plants can tolerate high levels of iron without adverse effects.
- Chlorotic spots eventually become reddish-brown to black with eventual collapse of affected tissue (Region 3).
- High levels may induce magnesium deficiency in some plants.

Manganese

Deficiency

- Manganese deficiency appears similar to iron deficiency.
- Yellowing between the veins of the youngest leaves occurs. Usually leaves do not turn white and necrotic.

- Usually only the main veins remain green, causing a fishbone-like appearance.
- Occurs under high pH conditions and/or low soil temperatures.

Excess

- Reddish-brown to black spots appear on lower leaves (Region 3) between veins. The leaves are yellow.
- Occurs under low-pH conditions.

Molybdenum

Deficiency

- Young mature leaves appear pale, distorted and narrow with a whiptail appearance.
- Young mature leaves may show interveinal chlorosis and in-rolling of leaf margins. Ultimately, yellowing tissue becomes necrotic (Region 2).
- In some plants, leaf margins may be scorched.
- Deficiencies occur most frequently under low-pH conditions.
- Phosphorus and magnesium will enhance uptake, while high sulphur will decrease uptake.

Excess

- Plants can tolerate high levels of molybdenum without adverse effects.

Zinc

Deficiency

- Younger leaves are affected first and may show signs of yellowing between the veins.
- Other symptoms may include short internodes and rosetting of leaves.
- High levels of phosphorus may induce zinc deficiency.
- Deficiencies occur under high-pH conditions.

Excess

- Excess zinc may depress uptake of phosphorus and iron in some plants.
- Excess zinc occurs under low-pH conditions.
- Symptoms include reduced root growth and leaf expansion.

Figure 3-1. Key to Determining Nutrient Disorders in Greenhouse Crops