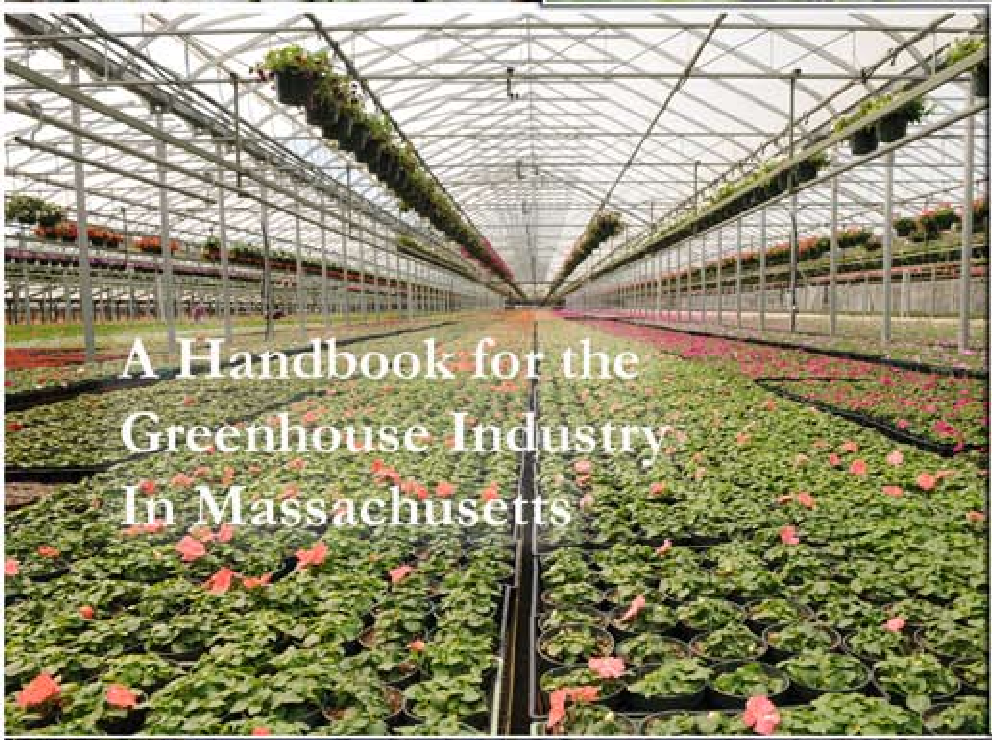
Greenhouse BMPs

A Handbook for the Greenhouse Industry In Massachusetts



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MASSACHUSETTS GREENHOUSE INDUSTRY BEST MANAGEMENT PRACTICES GUIDE

Cover page photos: Tina Smith, UMass Extension

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Prepared June, 2010

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The contributors emphasize the importance of consulting experienced and qualified consultants, advisors, and other business professionals to ensure the best results for producing nursery stock.

OVERVIEW OF BEST MANAGEMENT PRACTICES

A set of production guidelines known as Best Management Practices (BMPs) for the purposes of this manual are voluntary activities undertaken to minimize negative effects on the environment. The manual is not intended for regulations. BMP considerations for greenhouse production include site selection, water management and irrigation, nutrient management, composting, prohibited plants, pesticide use and storage, insect, mite, disease and weed management, animal damage management, organic and inorganic waste management, and alternative energy and energy conservation. BMPs are adaptable for the diversity that exists within the industry. Applying these practices will help Massachusetts greenhouses and nurseries to remain (or become) healthy and profitable.

TYPES OF GREENHOUSES

A greenhouse is a structure with a glass or plastic roof and side walls that is used for the production of ornamentals and food crops and may be used seasonally or year round. The closed environment of a greenhouse has its own unique requirements, compared with outdoor production. Pests and diseases, and extremes of heat and humidity, have to be controlled, and irrigation is necessary to provide water. Significant inputs of heat and light may be required, particularly with winter production of warm-weather crops.

Greenhouses for commercial production can be classified as free-standing or gutter-connected.

A free-standing greenhouse can have a quonset (hoop), gothic or gable roof shape. The quonset is usually the least expensive and is available in widths up to 36'. Gothic designs have higher light transmission and shed snow easier. Gable designs may use trusses to span a width up to 60'.

A gutter-connected greenhouse is a series of trusses connected together at the gutter level. Individual bays vary in width from 12' to 25' and have a clearance of 8' to 16' to the gutter. Bays can be put together to get any width of greenhouse desired.

Greenhouses can be made any length. Standard lengths that utilize glazing materials to advantage are 96' and 144'. All greenhouses are modular with frame spacing of 4' or 5' for hoophouses and 10' or 12' for gutter-connected designs.

Most greenhouses are built of galvanized steel tubing and are available from many manufacturers throughout the U.S. Steel makes a strong frame to carry snow and wind loads and still allow about 80% of the light to enter.

Most greenhouses are covered with a plastic glazing. Low-cost polyethylene film or covering applied as an air inflated double cover will last 4 years. Anti-drip agents and infra-red inhibitors are added to give better service and reduced heat loss. Semi-rigid structured sheets of polycarbonate or acrylic are more permanent and have a life of at least 15 years. Tempered glass is used for crops requiring high light levels.

The following is a short review of the advantages of the different styles of structures:

Free-standing Greenhouses

- Easier to provide separate environments as each house is controlled by its own heating/cooling system. One house can be run warm for propagation and the next one, cooler for growing.
- Individual houses can be shut down for periods when not in use saving energy.
- Best suited for heavy snow areas as multi-span houses need heat to melt snow from the gutters.
- Good for non-level sites.
- Individual houses are easier to build and maintain.

Gutter-connected Greenhouses

- More cost effective for areas greater than 20,000 sq ft.
- Reduced heating costs as surface area to floor area ratio is less. Heating costs can be as much as 25% less due to reduced glazed area.
- Less land is needed. About 30% more growing space can be placed on the same amount of land area.
- Heat can be centralized.
- Open-roof designs that eliminate fans and reduce electricity use are available.

Production Systems

In addition to the greenhouse style, there are a variety of production systems used inside the greenhouse. Some crops are grown in containers on benches, such as many spring ornamental crops, while others are grown in the soil in the ground such as cut flowers or vegetable crops (ie. tomatoes, lettuce). Some crops are grown in containers or bags of growing media that are placed on the ground (tomatoes). Some greenhouses have soil or gravel floors, some have concrete floors and some have a combination. All of these differences contribute to best management practices that will vary according to the greenhouse and systems used for production.

Reference

Bartok, J.W., Jr. 2005. *Selecting and Building a Commercial Greenhouse*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_building_gh.htm

Tomatoes Grown in Containers in Free Standing Greenhouse
Photo: Paul Lopes, UMass Extension

Heated Bench System for Propagation in Gutter-connected Greenhouse
Photo: Tina Smith, UMass Extension

CHECKLIST
SITE PLANNING: STORMWATER AND WASTEWATER

- ✓ Be aware that agricultural activities are subject to the jurisdiction of the Massachusetts Wetland Protection Act (WPA) when they occur within the resource areas (and their 100-foot buffer zones) defined in the Act. Many normal farming activities are exempt from regulations under the WPA. For information on the Massachusetts Wetland Protection Act, contact Massachusetts Department of Environmental Protection: http://www.mass.gov/dep/water/approvals/wmgforms.htm, phone [617]-292-5706).

- ✓ Growers planning to withdraw water from ground or surface sources in excess of an annual average of 100,000 gallons per day or 9 million gallons in any three month period must apply for a Water Management Act permit. Note that municipalities may also have water withdrawl requirements.

- ✓ Allow time for zoning, wetlands and building permits that may be required. Permits usually take several months to obtain due to infrequent meeting schedules and public hearing requirements.

- ✓ Use BMPs to handle wastewater from greenhouse roofs, driveways, parking areas, indoor growing areas, outdoor growing beds, flood floors and benches.

- ✓ Adopt integrated pest management practices and avoid pesticides which are persistent, have high leaching potentials, or move readily on the surface.

- ✓ Reduce pesticide use by properly timing the pesticide application and subsequent evaluation of the resulting level of pest control.

- ✓ Stormwater and wastewater management systems may require an engineer to design handle maximum runoff conditions. Permits may also be required. USDA Natural Resource Conservation Service (NRCS) may be a resource. See “Resources” for contact information. For new construction, contact Massachusetts Department of Agricultural Resources, Division of Technical Assistance for information on current regulations on stormwater and wastewater management.

- ✓ Consider directing rainwater from greenhouses to a retention pond or constructed wetland to allow most sediment to settle out before it reaches a brook or stream.

- ✓ For gutter-connected greenhouses, consider installing a rainwater harvesting system to store some of the water to use for irrigation.

SITE PLANNING: STORMWATER AND WASTEWATER

As greenhouse operations add more growing space, support buildings and vehicle access area, stormwater and wastewater management becomes more important. Good management, including site planning, source controls and pollution prevention can help growers reduce environmental impact and keep water resources clean.

Slope

Sites where greenhouses are located should have a gentle slope to the south for good winter light and protection from northerly winds and to provide drainage of rain and runoff. A fairly level site with a 1% to 2% slope reduces site preparation costs. Greenhouses should be placed on a gravel base, 6" to 12" above grade. Swales between greenhouses are necessary to direct the water from the area.

Wetlands Protection Act and Water Management Act

Wetland and water resources are found on many Massachusetts farms. These resource areas include (but are not limited to) streams, ponds, bogs, marshes, swamps, floodplains, isolated land subject to flooding, wet meadows, salt ponds, salt marshes, and fish runs. Agricultural activities are subject to the jurisdiction of the Massachusetts Wetland Protection Act (WPA) when they occur within the resource areas (and their 100-foot buffer zones) defined in the Act.

Many normal farming activities are exempt from regulations under the WPA. Others require a certain level of review by local Conservation Commissions. For information on the WPA, contact the Massachusetts Department of Environmental Protection http://www.mass.gov/dep/water/waterres.htm, phone [617]-292-5500.

The Water Management Act (WMA) authorizes the Massachusetts Department of Environmental Protection to regulate the quantity of water withdrawn from both surface and groundwater supplies. The WMA consists of a registration program and permit program. Persons planning to withdraw water from ground or surface sources for purposes in excess of an annual average of 100,000 gallons per day or 9 million gallons in any three month period must apply for a WMA permit. For information on the WMA, contact the Massachusetts Department of Environmental Protection http://www.mass.gov/dep/water/approvals/wmgforms.htm, phone [617]-292-5706.

Stormwater and Wastewater Management

Best management practices should be used to handle wastewater from greenhouse roofs, driveways, parking areas, indoor growing areas, outdoor growing beds and flood floors and benches. Stormwater and wastewater management systems may require engineering design to handle maximum runoff conditions. Permits may also be required. USDA Natural Resource Conservation Service (NRCS) may be a resource. See “Resources” for contact information. Flow rates and nutrient/pesticide levels of the different sources should be monitored on a regular basis to have data available if questions arise by regulatory agencies. Collecting and reusing some of this water will reduce the environmental impact. For new construction, contact Massachusetts Department of Agricultural Resources, Division of Technical Assistance (under “Resources”) for current regulations on stormwater and wastewater management.

Rainwater

In most operations, the greatest amount of water comes from building roofs. A one-inch rainfall on an acre of impervious surface such as a greenhouse roof or parking area amounts to about 27,000 gallons. This may come as intermittent rain over a day or two or it could come in as little as a few minutes in a heavy downpour. Good drainage design is required to handle this water without degrading the water with sediment, pollutants or debris.

Rainwater from greenhouses can be kept relatively clean with grass or stone lined swales. Directing this waster to a retention pond or constructed wetland will allow most sediment to settle out before it reaches a brook or stream.

For gutter-connected greenhouses, consideration should be given to installing a rainwater harvesting system to store some of the water for use for irrigation. See sections “Water: Supply and Sources” and “Water Quality for Crop Production”.

Driveways and Parking Areas

This space can add up to a significant amount of impervious area if it is paved. There is a greater impact if some of this is sloped. Non-paved driveways and parking areas should have a minimum of 10” of compacted gravel base with 2” of processed gravel on top. This allows for good drainage underneath. Maintaining a cross slope of 3% from the middle of the driveway to the edges will allow water flow off to a swale. A curtain drain with 6” filter fabric pipe on the uphill side will keep water from getting under the driveway. Where the grade is greater than 10%, the driveway should be paved with a minimum 3” of bituminous concrete laid in two courses. This will prevent erosion of the driveway.

Truck turn-arounds, dock and materials handling equipment areas should have a bituminous paving over a 12” minimum granular base. Adequate natural drainage or culverts should be installed to remove runoff. Drainage from paved areas with considerable vehicular traffic or where vehicles are parked should be filtered through a sediment/oil separator to remove sand, silt, oil and growing media before it is discharged to wetland or brook. For large impervious vehicle areas, it may be desirable to have the water directed to a retention pond for further settling.

Outdoor Growing Areas

If uncovered, the leaching of irrigation water and rainfall from containers can add significant nutrients and pesticides to the runoff. In areas with heavy rains, placing a vinyl liner with drain tile buried in a few inches of gravel will allow runoff to be collected and treated before it reaches a wetland. A holding tank, detention basin or retention pond makes a good storage. Water can be treated for reuse or sent through a constructed wetland.

Constructed Wetlands

The use of constructed wetlands has increased in recent years as an effective method of removing pollutants from wastewater. It is fairly simple consisting of a sediment trap, filter bed, wetland and retention pond.

The sediment trap removes the solid matter (growing media, sand, leave, etc). A tank or pond can act as a sediment trap. This has to be cleaned when the solids build up in the bottom and are disposed of by spreading on agricultural land or by disposing in a landfill.

The wastewater is then distributed over a filter bed. This is an area of soil, grass and a vinyl liner. The fine sediment which contains phosphates and nitrogen is removed. The grass is mowed occasionally and the clippings which contain nutrients are taken out of the system. They could be used for compost.

The constructed wetland is a vinyl lined area with a gravel growing media that supports water plants. These need to be selected for your zone but frequently include water lilies, sedges, cattails and wild rice. This removes the remaining nutrients leaving water that is 99% clean.

A retention pond can be added to hold the clean liquid for several days to complete the process. Water from this pond can be released to a stream or drainage area.

Constructed ponds and wetlands can eventually obtain all the regulatory protection that a natural wetland possesses.

Pesticides and Fertilizers

Pesticides and fertilizers used in the normal course of growing plants are potential environmental hazards if they enter groundwater or surface water by runoff or leaching. Gasoline and fuel oil, leachate and other materials are also serious threats, but regulations and methods of reducing their threat are largely in place.

Pesticides having high leaching potentials, high surface loss potentials, or which are persistent in soil are of greatest concern. Method of application, pesticide formulation, soil type, and microbial activity in the soil are other factors which affect how much chemical may reach the groundwater. Adopt integrated pest management practices and avoid pesticides which are persistent, have high leaching potentials, or move readily on the surface. Proper timing of application and subsequent evaluation of the resulting level of pest control are important steps in reducing pesticide use. See sections on “Pesticides and Groundwater Protection” and “Integrated Pest Management”.

Nitrates and phosphates from fertilizer are potential environmental hazards if they enter groundwater or surface water by runoff or leaching. Careful selection of fertilizer and application that meets the nutrient needs as the plant grows can help to reduce environmental impact. If the floor is concrete, drains can be installed to collect and treat this runoff. Recirculating flood floor and bench systems eliminate runoff as irrigation water is returned to holding tanks. See sections on “Nutrient Management” and “Irrigation” for information. Provision has to be made to dispose of the water from cleaning the holding tanks several times a year.

References

Bartok, J.W., Jr. 2010. *Stormwater and Wastewater Management for Greenhouses.* Fact Sheet

Cox, D.A 1993. *Groundwater and Your Greenhouse*.
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/water.html

CHECKLIST
WATER: SUPPLY AND SOURCES

- ✓ Determine the amount of water needed based on crops grown, weather conditions, time of year and the environment control system.
- ✓ Adapt low usage irrigation systems to extend a limited water supply such as zoning and low flow wells.
- ✓ Samples of a potential water supply should be sent to an irrigation water testing laboratory for analysis.

Water Sources

- ✓ **Drilled wells –** Deep wells are best. Location may require local and state regulations and permits.
- ✓ **Surface water –** Filters may be needed. High sodium and chloride levels may be a problem.
- ✓ **Drainage ponds** – Commonly contain fertilizers or chemicals. Algae growth may be a concern.
- ✓ **Rain water –** Can be collected from greenhouses or roofs without contacting the ground. It is a clean source of water except for any debris that gets into the system.
- ✓ **Municipal water –** The cost and quality are typically high. May contain additives such as fluoride, chlorine or sodium.

WATER: SUPPLY AND SOURCES

Water Supply

Water is a major factor in successful production of greenhouse plants. An adequate water supply is needed for irrigation, pesticide application, evaporative cooling (if applicable), growing media preparation and clean-up.

Plants require an adequate supply of moisture for optimum growth which is affected by many variables. The amount of water needed depends on the area to be watered, crops grown, weather conditions time of year and the environment control system. The design for the water supply needs to be made for the peak use time of the year. A rule of thumb is to have available 0.3 to 0.4 gallons/square foot of growing area per day as a peak use rate for the warmest day. For example a 30' x 100' greenhouse with 2400 square feet of benches would require a peak use rate of 720 to 960 gallons/day. The following factors can increase or decrease the amount of water needed:

- **Solar radiation.** The level of radiation that reaches the plants is reduced by 10% to 40% due to the glazing and the structural members in the greenhouse. This reduces the transpiration.
- **Shading.** The use of shading outside or inside will reduce the radiation level on the plants. Depending on the level of shade, this will reduce evapotranspiration and therefore water needs.
- **Air movement**. Fan ventilation and HAF systems increase the rate of evapotranspiration. Depending on location and nearby greenhouses or other buildings, sidewall vents and open-roof designs can also have an influence. A 5 miles/hour breeze can increase evapotranspiration by 20%.
- **Type and size of the plants.** Seedlings or small potted plants require less water than a full-grown tomato or cucumber crop. A large root mass or heavy leaf canopy will increase water needs.
- **Type of irrigation system**. Only 20% of the irrigation water applied with an overhead sprinkler system may reach the soil in a potted plant crop with a large foliar canopy. In-pot drips systems are much more efficient as all the water applied with an in-pot drip system gets to the soil. Subirrigation systems such as ebb and flood systems, flooded floors and hydroponics conserve water by recycling and reusing the excess water.
- **Leaching**. Traditionally, the recommendation that at least 10% of the water applied be allowed to leach out to remove excess fertilizer salts increases water usage. Often leaching accounts for a much higher percentage and can increase water needs significantly. The type of growing mix used also affects the amount of water holding capacity and therefore the frequency of watering.

Extending a limited water supply

Water supplies can be extended by several methods. Most common is adapting low usage irrigation systems. Zoning, applying the water to one area or section of plants at a time, will allow a low flow water source to irrigate a larger number of plants. Zones can be sized to utilize the flow from a well or municipal source so that irrigation takes place all day long.

Low flow wells can be set up to be pumped to a storage tank over a many hours. Water from the tank is then used to irrigate plants during the daylight hours.

Collection of rainwater to supplement a well or surface system is also possible. This works best with a gutter-connected greenhouse where the water from the downspouts is piped to an above ground or below ground storage tank. See section on rainwater.

From a conservation standpoint, keeping the piping system in good repair is important. A leak of one drop per second wastes over 113 gallons of water per month.

Water Sources

Characteristics of irrigation water that define its quality vary with the source of the water. There are regional differences in water characteristics, based mainly on geology and climate. There may also be great differences in the quality of water available on a local level depending on whether the source is from above ground (rivers and ponds) or from groundwater aquifers with varying geology, and whether the water has been chemically treated. Municipal system water and deep wells generally provide the best water source for greenhouse operations. Chemical treatment of water may be required when pollutants such as iron, sodium, dissolved calcium and magnesium or bicarbonates are present. Surface water such as ponds and streams may have more particulate matter such as suspended soil particles, leaves algae or weeds that needs to be filtered out.

A sample of a potential water supply should be sent to an irrigation water testing laboratory for analysis.

The main sources for irrigation water are groundwater from wells, surface water, drainage ponds, rain and municipal water.

Drilled wells are a clean source of water for many greenhouse operations however, the water yield from drilled wells is usually limited.

Groundwater is found in aquifers that are located below the earth surface. As rainfall occurs, some of it evaporates, some of it is removed by plant transpiration and the remaining water filters down through the topsoil and flows into sand, gravel and fractured rock. It reaches a depth where all the pore spaces are filled. This saturated zone is call the aquifer.

The flow of water from a well depends on the permeability and size of the aquifer, its recharge area and the amount of rainfall. A well in one location may provide a very low yield, while another area, may provide a high water yield. In most areas, well drillers keep an accurate record of the depth and yield of wells they drill. Groundwater quality varies due to the parent material. For example, in the Berkshires of western Massachusetts groundwater is often drawn from limestone aquifers. Even for one site, the location and depth of the well can have an important effect on water quality. Elemental content and bicarbonate levels can also change with the seasons of the year, and the amount of pumping from the wells.

Since 1974, well drillers have been required to file a Water Well Completion Report with the local board of health, the well owner and the Massachusetts Department of Environmental Management (DEM). This report provides data on the well’s location and depth, the drilling method used, the material it draws water from, and results of water quality and pump tests. The well driller should be registered with the DEM and install the well according to local board of health regulations. There is usually a minimum distance from a septic system or sewer and there may be a minimum distance to a property line.

Surface water includes streams, rivers, lakes and ponds which are dependent on runoff from adjacent land or from ground water springs. These are dependent on rainfall rates that vary from year to year.

Surface water is subject to contamination from sources such as sediment, chemicals and plant growth. High levels of particles can reduce the life of pumps and clog irrigation systems and multiple filters may be required. It is also possible that surface waters can become contaminated with road salt, industrial, agricultural chemicals, algae and plant pathogens.

Drainage ponds are usually a combination of rain water and run-off. Drainage ponds commonly contain fertilizers or other agricultural chemicals. Because of the size and lack of aeration, biological conditions such as algal growth may be a concern.

Rain water can be collected from greenhouses or building roofs without contacting the ground and held in a concrete cistern, fiberglass or polyethylene tank, water silo or other holding tank. It is clean except for any debris that gets into the system. Rain water will be very low in elemental or chemical contamination unless there is industrial air pollution or fallout on the roofs. The pH of collected rain may be low (4.0 – 5.0) but is not considered detrimental to crops because it is not buffered (does not resist change in pH) and changes readily. Rain water is an excellent and underutilized source of irrigation water.

A 1" rainfall on an acre of greenhouse amounts to 27,100 gallons. A common yield is about 65% with losses due to evaporation, wind, leakage of piping system and diversion of the first few minutes of the rainfall to remove debris. To calculate the quantity in gallons that can be collected, multiply the square feet of greenhouse building floor (footprint) by 0.4.

A basic system consists of a storage tank, roof washer, inflow pipes, overflow pipes and a diverter to redirect the excess water when the tank is full. Concrete or plastic tanks can be used but are usually limited to about 15,000 gallons. Corrugated steel tanks can be built to almost any capacity as they are delivered in preformed panels and assembled on site. Before the water is collected for irrigation, a device called a roof washer is normally used to divert the first flush of water that is collected to remove debris from the water. Also an overflow is needed to handle excess water. The excess water is diverted to a drainage area where it will not flood neighboring property.

Once rainwater is collected, it can be distributed to the greenhouses through the normal irrigation system.

Municipal water includes water supplied by city, county or municipality. Either, ground, rain, and/or surface water may be used. The cost and quality are typically high since much of the water is for residential use and drinking water and is treated. The key concerns are whether supply is guaranteed in times of shortages and what water treatment procedures are used that may influence plant growth. Municipal water may have fluoride and/or chlorine added at rates which is not a problem for most crops. Occasionally, sodium compounds are added to treat hard water.

References

Bartok, J.W., Jr. 2009. *Sizing the Greenhouse Water System*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_sizing_greenhouseirrigation.pdf

Bartok, J.W., Jr. 2009. *Rainwater Harvesting*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_rainwater_harvesting.pdf

Biernbaum, J.A. 1995. *Water Quality. Tips on Growing Bedding Plants*. The Ohio Florists' Association.

Lopes, M. and G. Walker. 1990. *You and Your Well: How to be responsible for your private water supply*. Issues in Water Quality. Fact Sheet, University of Massachusetts.

Cut flowers growing in crates with drip tape, being irrigated with water from a private well.
Photo: Tina Smith, UMass Extension

CHECKLIST
PROTECTING GROUNDWATER FROM CONTAMINATION

- ✓ Mix and store pesticides and fertilizers away from the wellhead to reduce the chance of contamination. This is particularly important for shallow wells and those in sandy soils.

- ✓ Protect all potable water against backflow to ensure that contaminated water is not mixed with that used for human consumption. Install back flow preventers when chemicals are injected into the irrigation water regardless of source.

- ✓ If water is supplied by a municipal water system, check local regulations prior to installation, as some companies require a complete break in the water system.

- ✓ Water lines or hoses used to fill tanks during mixing should never be immersed in the solution because back-siphoning may occur.

- ✓ Test backflow prevention devices annually. Record and save the date and results of the tests.

- ✓ Select the correct fertilizer for your cropping situation, apply the correct amount and monitor fertilizer injection system to ensure maximum efficiency.

PROTECTING GROUNDWATER FROM CONTAMINATION

Protect Your Water Supply: One of the areas most sensitive to contamination is the immediate source of water which enters your operation. This may be the private wellhead or the water line(s) which carry public water. Wells provide a direct entry point for pollutants to the groundwater. Pesticide and fertilizer mixing and storage should take place away from the wellhead to reduce the chance of contamination. This is particularly important for shallow wells and those in sandy soils. Most liquid pesticide labels now contain a chemigation provision that details system requirements. See sections on "Fertilizer Storage and Handling" and "Pesticide Storage and Handling".

Backflow Preventers: All potable water must be protected against backflow to ensure that contaminated water is not mixed with that used for human consumption. Backflow or back-siphoning occurs when a negative pressure develops in the water supply line, causing water that has been contaminated to be drawn back into the supply lines. The National Plumbing Code requires that backflow preventers be installed on any supply fixture when the outlet may be submerged. Examples of this are a hose that fills a spray tank or barrel, a fertilizer injector, or an equipment wash tub. Backflow preventers should be installed when chemicals are injected into the irrigation water regardless of source. If water is supplied by a municipal water system, check local regulations prior to installation, as some companies require a complete break in the water system. If this is the case, a separate pump and supply tanks will be required. Water lines or hoses used to fill tanks during mixing should never be immersed in the solution because back-siphoning may occur.

Backflow prevention devices should be tested annually, and the date and results of the tests should be recorded and saved.

References

Cox, D.A 1993. *Groundwater and Your Greenhouse*.
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/water.html

Aldrich R.A. and J. Bartok, Jr. 1994. *Greenhouse Engineering*. NRAES-33.
http://www.nraes.org

CHECKLIST
WATER ANALYSIS

- ✓ Test water to be used for irrigation by a reputable laboratory to determine the quality of the water for irrigation, choice of fertilizers for optimum plant growth, and to minimize the risk of discharging pollutants to surface or ground water. At minimum, test for total alkalinity and soluble salts.

- ✓ Test potential irrigation water prior to new construction. Monthly analysis is recommended for new water sources. Existing greenhouse operations should monitor water quality at least twice a year (summer and winter); more frequent monitoring is needed to alter production practices in response to changes in water quality.

- ✓ When collecting a water sample, run the water at full flow for five minutes before collecting one pint of water in a tightly sealed plastic bottle. For best results, fill a clean 5 gallon bucket with water and submerge the sample bottle, then seal with the cap under water. Do not use metal lids. The bottle should be totally full with no air space remaining.

Collecting a Water Sample
Photos: Tina Smith, UMass Extension

WATER ANALYSIS

Many factors taken together determine the quality of water for irrigation of plants. The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients.

Water Analysis

Once the source of water is identified, water to be used for irrigation should be tested by a reputable laboratory to determine the quality of the water to be used for irrigation, to aid in the choice of fertilizers for optimum plant growth, and to minimize the risk of discharging pollutants to surface or ground water.

Prior to new construction, potential irrigation water should be tested. Monthly analysis is recommended for new water sources. Existing greenhouse operations should monitor water quality at least twice a year (summer and winter); more frequent monitoring is needed to alter production practices in response to changes in water quality.

Collecting a Water Sample

When collecting a water sample, run the water at full flow for five minutes before collecting one pint of water in a tightly sealed plastic bottle. For best results, fill a clean 5 gallon bucket with water and submerge the sample bottle, then seal with the cap under water. Do not use metal lids. The bottle should be totally full with no air space remaining.

Testing by Laboratories

Analysis for inorganic elements should include electrical conductivity (soluble salts), pH, alkalinity, nitrate nitrogen, ammonium nitrogen, calcium, magnesium, sodium, potassium, phosphorus, zinc, copper and aluminum.

Testing water for pesticides, herbicides or fuel oil is very expensive, particularly if the contaminant is unknown.

Analysis for biological or disease organisms is not generally recommended since many plant pathogens are always present in water at some level.

A list of commercial greenhouse water testing laboratories is available under “Resources” at the end of the document.

On-Site Water Testing

Electrical conductivity and pH are two characteristics of water quality that can be tested periodically at the growing facility. This helps the grower get an indication of the consistency of the water supply and check the results of treatments to reduce pH or soluble salts. pH meters range from inexpensive pen types to more sophisticated units. It is recommended to purchase one that can be calibrated using calibration solutions. This ensures that the meter is giving correct readings. Electrical conductivity meters are generally more expensive than pH meters. However, they are very useful for testing water quality and media fertilizer levels during crop growth.

Table 1. Target range and Acceptable range of nutrients and other components of irrigation water. Note: The target range is desirable levels, while acceptable levels are broader.

	Target Range in ppm (parts per million) except for pH and EC (electrical conductivity)	[x]**Acceptable Range (in ppm except for pH and EC)**
pH	5.5 to 7.0	4 to 10
EC	0.2 to 0.8 mS (milliSiemen)	0 to 1.5 mS (milliSiemen)
Sodium	0 to 20	less 50
Chloride	0 to 20	less 140
Alkalinity[y]	40 to 160	0 to 400
Ammonia N	NA	less 10
Boron	less 0.1	less 0.5
Nitrate N[z]	NA	less 75
Phosphate	NA	less 30
Potassium	NA	less 100
Magnesium	10 to 30	less 50
Calcium	25 to 75	less 150
Sulfate	0 to 40	less 100
Manganese	less 1	less 2
Iron	less 1	less 4
Boron	less 0.1	less 0.5
Copper	less 0.1	less 0.2
Zinc	less 0.5	less 0.3
Fluoride	less 0.1	less 1
Molybdenum	less 0.1	less 1

[x] No expected crop damage under average environmental conditions. Higher rates of macronutrients may lead to undesired plant growth as in the case of plugs. The acceptable limits for trace elements and fluoride are dependent on medium pH. These levels may be too high for growing medium pH less than 5.8.

[y] Usually depends on the volume of medium and volume of water applied. The medium pH with smaller volumes of media such as with plugs may be stable with 40 to 80 ppm while medium pH in larger pots with higher rates of fertilization may stabilize at 120 to 160 ppm.

[z] NA – Not applicable
Note: Levels of NO_3 over 10 ppm may indicate a significant level of contamination and health hazard in drinking water.

Reference

Biernbaum, J.A. 1995. *Water Quality.* Tips on Growing Bedding Plants. The Ohio Florists' Association.

CHECKLIST
WATER QUALITY FOR CROP PRODUCTION

- ✓ Have water tested at a laboratory that is equipped to test water for irrigation purposes. Irrigation water tests should always include pH and alkalinity.

- ✓ Reclaimed water, runoff water, or recycled water may require reconditioning before use for irrigation since disease organisms, soluble salts and traces of organic chemicals may be present.

- ✓ Water quality should be tested to ensure it is acceptable for plant growth and to minimize the risk of discharging pollutants to surface or ground water.

- ✓ Use filtration to remove suspended solids from water to prevent clogging of piping, valves, nozzles and emitters in an irrigation system. Suspended solids include sand, soil, leaves, organic matter, algae and weeds.

- ✓ Water pH may need to be adjusted before being used for mixing some pesticides, floral preservatives, and growth regulators.

WATER QUALITY FOR CROP PRODUCTION

Irrigation water quality is a critical factor for production of greenhouse crops. There are many factors which determine water quality. Among the most important are alkalinity, pH and soluble salts. But there are several other factors to consider, such as whether hard water salts such as calcium and magnesium or heavy metals that can clog irrigation systems or individual toxic ions are present. In order to determine this, water must be tested at a laboratory that is equipped to test water for irrigation purposes.

Poor quality water can be responsible for slow growth, poor aesthetic quality of the crop and, in some cases, can result in the gradual death of the plants. High soluble salts can directly injure roots, interfering with water and nutrient uptake. Salts can accumulate in plant leaf margins, causing burning of the edges. Water with high alkalinity can adversely affect the pH of the growing medium, interfering with nutrient uptake and causing nutrient deficiencies which reduce plant health.

Reclaimed water, runoff water, or recycled water may require reconditioning before use for irrigation since disease organisms, soluble salts and traces of organic chemicals may be present.

Water quality should be tested to ensure it is acceptable for plant growth and to minimize the risk of discharging pollutants to surface or ground water.

Filters

Suspended solids need to be removed from water to prevent clogging of piping, valves, nozzles and emitters in an irrigation system. Suspended solids include sand, soil, leaves, organic matter, algae and weeds. Ground water, although usually clean, may contain fine particles of sand. All of these can be removed through filtration.

Before selecting a filter, a water analysis should be done. The type and quantity of solids should be determined taking in consideration seasonal changes such as algae growth or spring runoff. Other considerations include the flow rate needed to supply the irrigation system and the level of filtration needed to determine the type of filter. Screen or disk filters work well for most applications. A 200 mesh filter is usually recommended for micro-irrigation. The filter should be sized so that the flow rate is large enough to handle the peak demand.

Maintenance of a filter is important. Installing pressure gauges on both sides of the filter will indicate when it is becoming clogged. When the pressure variation between the two gauges exceeds about 10% the filter should be cleaned.

pH and Alkalinity

Alkalinity and pH are two important factors in determining the suitability of water for irrigating plants. pH is a measure of the concentration of hydrogen ions (H^+) in water or other liquids. In general, water for irrigation should have a pH between 5.0 and 7.0. Water with pH below 7.0 is termed "acidic" and water with pH above 7.0 is termed "basic"; pH 7.0 is "neutral". Sometimes the term "alkaline" is used instead of "basic" and often "alkaline" is confused with "alkalinity".

Alkalinity is a measure of the water's ability to neutralize acidity. An alkalinity test measures the level of bicarbonates, carbonates, and hydroxides in water from the geologic materials of the aquifer from which the water is drawn, such as limestone and dolomite. Test results are generally expressed as "ppm of calcium carbonate ($CaCO_3$)". The desirable range for irrigation water is 0 to 100 ppm calcium carbonate. Levels between 30 and 60 ppm are considered optimum for most plants.

Irrigation water tests should always include both pH and alkalinity tests. A pH test by itself is not an indication of alkalinity. Water with high alkalinity (i.e., high levels of bicarbonates or carbonates) often has a pH value of 7 or above, but water with high pH does not always have high alkalinity. This is important because high alkalinity exerts the most significant effects on growing medium fertility and plant nutrition.

A recent University of Massachusetts Extension greenhouse water study found that pH in the range of 7-8 is common in most waters in Massachusetts. This is not a problem unless the alkalinity exceeds the acceptable range. High pH/high alkalinity water is common in Berkshire County and sometimes is found in other parts of the state.

Potential adverse effects on nutrition

In most cases irrigating with water having a "high pH" causes no problems as long as the alkalinity is low. This water will probably have little effect on growing medium pH because it has little ability to neutralize acidity. This situation is typical for many growers using municipal water in Massachusetts, including water originating from the Quabbin Reservoir.

Of greater concern is the case where water having both high pH and high alkalinity is used for irrigation. In Massachusetts this situation is most common in Berkshire County. One reason is that the pH of the growing medium may increase significantly with time. This increase may be so large that normal lime rates must be reduced by as much as 50%. In effect the water acts as a constant and dilute solution of limestone! The problem is most serious when plants are grown in small containers because small volumes of soil are poorly buffered to pH change. Therefore, the combination of high pH and high alkalinity is of particular concern in plug seedling trays. Trace element deficiencies such as of iron and manganese and imbalances of calcium (Ca) and magnesium (Mg) can result from irrigating with high alkalinity water.

Potential beneficial effects on nutrition

Water with moderate levels of alkalinity (30-60 ppm) can be an important source of Ca and Mg for some greenhouse operators. With the exception of a few fertilizers, many water soluble fertilizers do not supply Ca and Mg. Also, the Ca and Mg from limestone may be inadequate for some plants. Moderately alkaline water could be beneficial as a source of extra Ca and Mg for crops prone to Ca and Mg deficiencies.

Table 2 gives recommended irrigation water alkalinity upper limits for different production systems. In general, the larger the rooting volume, the higher the allowable alkalinity because the media has at least a limited ability to supply H^+ ions to neutralize the alkalinity of the water applied.

Table 2. Recommended irrigation water alkalinity upper limits in parts per million (ppm).

Container	Minimum alkalinity (ppm)	Maximum alkalinity (ppm)
Plugs or seedlings	0.75	1.3
Small pots / shallow flats	0.75	1.7
4 - 5 inches pots / deep flats	0.75	2.1
6 inches pots / long term crops	0.75	2.6

Effects of High pH and High Alkalinity on Pesticides
In addition to nutritional disorders of plants, water with high alkalinity can cause other problems. Bicarbonates and carbonates can clog the nozzles of pesticide sprayers and drip tube irrigation systems with obvious effects. The activity of some pesticides, floral preservatives, and growth regulators is markedly reduced by high alkalinity. When some pesticides are mixed with water they must acidify the solution to be completely effective. Additional acidifier may be needed to neutralize all of the alkalinity.

If water pH is above 7.0, and the chemical requires a lower pH, a buffering (acidifying) agent should be added to lower the pH of the water for mixing the spray. Buffering agents can be obtained from greenhouse and nursery supply companies. Buffering agents should not be used with pesticides containing fixed copper or lime such as copper sulfate, or lime sulfur. Too much buffer should not be used as it may cause the water to become too acid and phytotoxicity may result. A pH of 6.0 is satisfactory for most pesticides.

To determine if a chemical is affected by high alkalinity, carefully review the product's label. A list of chemicals and their ideal water pH range can be found at
http://floriculture.osu.edu/archive/apr04/SpraySolutionPH.html
A call to the manufacturer may be needed to find the information for some chemicals.

Adjusting Alkalinity with Acids
Many greenhouse operators inject acid (e.g., phosphoric, nitric, or sulfuric acid) into water with problematic high levels of alkalinity. *Acidification of water having high pH but low alkalinity is rarely necessary.* The use of acid injection should be considered very carefully for several reasons. First, it is an extra step in production which will require additional materials and equipment. Second, acids are dangerous to handle and may damage some injectors and piping systems. Third, phosphoric or nitric acid are sources of P and NO3, so the regular fertilizer program may need to be modified to take into account the addition of these nutrients. This would depend on how much acid must be used to neutralize the alkalinity and reduce pH. Fourth, sometimes acid injection causes the solubilization of normally precipitated (unavailable) forms of trace elements resulting in levels toxic to plants.

The amount of acid required to reach the desired pH (i.e., neutralize alkalinity) is determined by laboratory titration of a water sample with the appropriate acid or by a calculation procedure. Some "fine-tuning" may be needed later when actual inject ion is started. Acid is always added prior to the addition of fertilizer or other chemicals.

Acids have been and always will be an excellent tool for growers to exert better control of irrigation water alkalinity (mostly bicarbonates and carbonates) and growing media pH. Once the role of alkalinity is understood, the grower may consider the following practical step to control alkalinity using acids through an injector system.

Acid Type

The acids commonly available to growers include phosphoric, sulfuric, nitric, and citric. Table 3 lists criteria for choosing the right acid for your situation: relative safety, neutralizing power, cost, and nutrient content. In our experience, the most effective and widely used acid is sulfuric acid; however, this is one of the most hazardous acids to use. For low amounts of alkalinity removal, phosphoric acid may be the acid of choice. However, we do not advocate adding more than 2.25 fluid ounces of this acid to 100 gallons of water, because of the amount of P one would add. Nitric acid is theoretically ideal because it adds nitrate nitrogen; but it fumes and is highly oxidizing, making it very difficult and potentially dangerous to handle. Citric acid is a weak organic acid and a solid, making it safer than the other three; but it is much less effective, and therefore more expensive to use.

Using the Correct Injector

Once you choose an acid to use, make sure your injector can handle the task. Read the injector manual to get this information or call the manufacturer of the injector. *Note: Some injector manufacturers state that a maximum of 5 percent acid can be used. This equates to approximately 6 fluid ounces of acid/gallon of water - an uncommonly high concentration of acid.*

Table 3. Characteristics of acids used to neutralize water alkalinity.

Acid type	Typical strength	Relative hazard	Nutrient content (ppm)[z]	Neutralizing power[y]	Specific gravity	ml acid/ppm alkalinity/100gal[x]
Phosphoric	75%[w]	Moderate	25.6 P, as PO_4	45.0[u]	1.381	0.70
Sulfuric	93%v	High	43.6 S, as SO_4	136.0	1.835	0.23
Nitric	63%	High	14.6 N, as NO_3	52.3	1.381	0.56
Citric	100%	Low	None	N/A	N/A	N/A

[z] Nutrient content when 1 fl. oz. is added to 100 gallons of water. Make appropriate adjustment to fertilizer program.
[y] Amount of alkalinity (mg CaCO3/liter) neutralized when 1 fl. oz. of acid is added per 100 gallons of water.
[x] Conversion factor of strength of acid at the specific gravity stated. Example: If you have an alkalinity of 250 and you want to target 150, then you need to neutralize 100 mg $CaCO_3$/liter. If you use sulfuric acid, then 100 x 0.23 = 23 milliters (ml) /100 gallons. 23 ml needed/29.6ml/fl. oz. = 0.77 (0.75 fl. oz.)/100 gallons. Rates will depend on exact strength and specific gravity.
[w] Phosphoric acid comes in many strengths, but 75% is most common. Use heavy free grade or food grade, if possible.
[v] 93% sulfuric acid is also known as 66 be' (Baume') acid. Battery acid electrolyte is recommended by some and is about 35% strength.
[u] Assumes about one-third of acid is effective since phosphoric acid does not completely dissociate.

Calculating the Amount of Acid to Use

It is suggested to use enough acid to reduce water alkalinity to within a target range. Table 4 provides suggested target alkalinity ranges based on container size. First, have your water analyzed for alkalinity. You can have a lab test your alkalinity or you can use a kit to measure it yourself (alkalinity test kits can be purchased through greenhouse or scientific supply distributors). Then, calculate the amount of acid needed to get the water into your target alkalinity range. (Current alkalinity - desired alkalinity = alkalinity to be neutralized). Table 3 lists the amount of acid to use for a certain ppm (parts per million) of alkalinity per 100 gallons of water. Now you are ready for your pilot calibration run.

Safety First

Acids are hazardous chemicals. When concentrated acids are mixed with water, a tremendous amount of heat is generated (which can even distort or melt plastic). Improper mixing can result in bodily injury. *Always wear the proper safety equipment when using acids.* This includes safety glasses, face shield, respirator, rubberized apron or coveralls, and acid-resistant gloves and boots. You should be able to find safety equipment distributors in the Yellow Pages under "Safety". Federal and state safety laws and codes should be followed for storing, mixing and handling acids.

Proper Mixing

Use acid-resistant containers for containing the acidic stock solution. Heavy duty polyethylene trash cans are adequate.

Always mix acid to water. Fill the stock container to about half the final volume you wish to mix with water. (Note: Since this is a pilot run, you do not want to make up a full amount of acidified stock solution because you may wish to adjust the amount of acid or to add fertilizer to the stock solution later.) Measure the acid carefully using a good measuring vessel. Then add acid to water, slowly and carefully to the center of the water surface. If dispensing acid from a large drum or container, you should invest in an acid-resistant, hand-activated pumping/dispensing device ("Industrial Suppliers in the Yellow Pages"). During and after adding acid to the water, *you must stir the acid in the water*. Acid is heavier than water, so don't think it will mix easily just because it's a liquid. Stir! Avoid splashing!

Table 4. Suggested alkalinity guidelines (mg $CaCO_3$/liter)[z].

Container size	Acceptable alkalinity	Concern level[y]
Plugs	60-100	<40, ><40, >120
Small pots	80-120	<40, >140
4-5" pots	100-140	<40, >160
>6" pots	120-180	<60, >200

[z] Alkalinity levels recommended through Scotts Testing Lab. Actual levels may vary depending on crop type and desired plant response.
[y] Low levels may result in media pH decrease, and high levels may result in media pH increase. These trends are highly dependent upon fertilization rate.

Pilot Run or "Calibration" Measurement

After you have prepared the acidified stock solution, you should then determine if you have attained the target irrigation water alkalinity for your application. Run the injector at the appropriate dilution ratio for 5 to 10 minutes, then take a sample. It's best to run the water you wish to test into a 5-gallon bucket and take a sample out of the 5-gallon bucket. Test the alkalinity. Make adjustments as necessary. Once you are done, it is prudent to send another sample of the acidified water to an analytical lab to obtain a full test. This informs you if anything else has changed besides alkalinity.

Fertilizer Compatibility

Many growers want to use one injector and mix acid with fertilizers. The use of sulfuric, nitric and citric acid is compatible with most water-soluble fertilizers. Phosphoric acid is not compatible with calcium-containing fertilizers like calcium nitrate or formulations like 15-0-15 and 17-0-17 in concentrated form.

Mixing Fertilizer with Acid

If you are diluting the acid out of a separate injector, disregard this step. Remember, you only put in some of the acid to carry out the calibration run (half volume of stock solution). Add the remainder of the acid for the total amount of acid you wish to make. You may add more water, allowing "room" for fertilizer addition. Add the fertilizer carefully to avoid splashing, and add enough water to attain your final volume -- mix thoroughly. Again, test the injection of the acidified nutrient solution to make sure the irrigation water is within the target alkalinity range. You're done!

Soluble Salts

Soluble salts in water are measured by electrical conductivity (ECw) expressed as millimhos per centimeter (mmhos/cm), which is equivalent to milliSiemens per centimeter (mS/cm). Electrical conductivity is also referred to as specific conductance or salinity.

EC (electrical conductivity) measures the levels of natural salinity and salinity caused by fertilizer residues in water and soils. In Massachusetts high EC water is not a common problem. However, high EC may occur in water from containment ponds rich in fertilizer residues, certain wastewaters used for irrigation, water contaminated by road salt, and rarely from saltwater intrusion in coastal wells. Irrigation water to which water-soluble fertilizer has been added has an EC of about 1.5-2.5 mS/cm, so, to avoid plant injury, the untreated water should have an EC no higher than the acceptable range of 0-1.5 mS/cm, although values of less than 1 are recommended for plugs. Excess soluble salts impair root function, which can lead to reduced water uptake and nutrient deficiencies.

Hardness – Calcium and Magnesium

Hardness is an indication of the amount of calcium and magnesium in the water. Calcium and Magnesium are essential elements for plant growth that are reported in parts of element per million parts water (ppm) on a weight basis. Calcium in the range of 40 - 100 ppm, and magnesium in the range of 30 - 50 ppm are considered desirable for irrigation water.

Sodium and Chloride
Irrigation water from rivers, streams, private wells, and private ponds may contain excess sodium (Na) and chloride (Cl). A University of Massachusetts water study found that water from shallow private wells or private ponds was most likely to contain elevated Na and Cl due to road salt contamination. The contamination was most acute when these sources were located close to a road or parking lot. Municipal water generally had acceptably low Na and Cl levels probably because road salt applications are reduced in areas close to public wells and reservoirs. In wells and ponds Na and Cl levels were highest in the spring when runoff from snowmelt was highest or in the summer when water levels were drawn down to low levels during droughty periods. To properly assess how serious the Na and Cl contamination is, a series of water tests should be run during these periods to determine how high the levels are and their duration. This information will be useful in deciding what remedial measures to take.

While likely sources of Na and Cl in the Northeast is road salt, water softeners and some fertilizers may also be contributors. High sodium acts to inhibit plant uptake of calcium, and may result in excess leaching of calcium and magnesium from the media.

There is also the possibility of foliar absorption of sodium, resulting in leaf burn. Sodium levels of about 50 ppm or less are considered acceptable for overhead irrigation. Because of its effects on calcium and magnesium availability, the amount of sodium in irrigation water should be evaluated when you consider whether you have adequate calcium and magnesium. The effect of sodium is calculated as the sodium adsorption ratio (SAR). If the SAR is less than 2 and sodium is less than 40 ppm, then sodium should not limit calcium and magnesium availability.

Excess Sodium and Chloride: Acceptable levels of Na and Cl for ornamentals are less than 50 ppm and 140 ppm, respectively, however higher levels may be tolerated depending on crop sensitivity. Na and Cl can be directly toxic to plants, may contribute to raising the soluble salts (EC) level of the growing medium, or may inhibit water uptake by plants. Plant problems include injury from excess soluble salts, growth reduction, and increased susceptibility to disease. Foliar chlorosis caused by high Na and Cl is similar in appearance to that caused by deficiencies of nitrogen, iron, and magnesium. Increasing the level or frequency of water-soluble fertilizer should not be used as a corrective measure for this problem.

If high levels of Na and Cl are suspected as plant problems, the suspicion should be confirmed by water testing every week or two weeks during the production season. If Na and Cl levels remain significantly above acceptable levels for weeks at a time then remedial measures should be considered. Changes in fertilization or other cultural practices do not provide solutions for this problem. The best approach is to change salting practice to prevent contamination of the water source. Other remedies for road salt contamination are more expensive and involve changing water sources by drilling deeper wells away from roads and parking lots, switching to municipal water, or collecting and irrigating with rainwater. Another remedy would be water treatment by reverse osmosis. Municipal water, rainwater, or RO water can be mixed with saline water to dilute the Na and Cl levels.

Chloride: Wells and municipal water sources may contain high chloride levels in association with sodium. The concern with chloride is the possibility of excessive foliar absorption under overhead irrigation or leaf edge burn caused by excessive root uptake in sensitive plants. If concentrations are less than about 100 ppm, there is no concern from excessive foliar absorption. If concentrations are less than about 150 ppm, there is no concern about toxicity resulting from root uptake.

Potassium and Phosphate: These plant nutrients generally occur in water at very low levels. Presence in irrigation water at levels higher than a few parts per million may indicate the presence of pollution from fertilizers or other contaminants.

Sulfate: Sulfur is an essential element for plant growth that is not commonly incorporated in fertilizers. It is measured in irrigation water to give an indication of possible deficiency problems. If the concentration is less than about 50 ppm, supplemental sulfate may need to be applied for good plant growth.

Ammonium and Nitrate: These nutrients are tested to give an indication of possible contamination of the water source. If present in significant amounts (e.g., >5 ppm nitrate), they should be taken into account in the fertility program. Fertilizer practices should be reviewed and corrected to prevent further contamination.

Micronutrients and Trace Minerals

The most important micronutrients are copper, zinc, manganese, iron and boron. They can occur in excessive or deficient quantities.

Excess iron and manganese compounds may result in unsightly residues on foliage under overhead irrigation. Fluoride may be present in levels high enough to damage foliage plants and Easter lilies. Concentrations in irrigation water should be less than 0.75 ppm. There may be a problem with the use of some fluoride-treated municipal water supplies.

Table 5.

Water purification methods and their applications

	Total Dissolved Solids	Bicarbonate & Carbonate	Calcium & Magnesium	Dissolved Iron & Manganese	Oxidized Iron & Manganese	Borate	Fluoride
Reverse Osmosis	**X**	**X**	**X**	**X**		**X**	**X**
Deionization	**X**	**X**	**X**	**X**		**X**	**X**
Anion Exchange		**X**				**X**	**X**
Water softening (cation exchange)			**X**	**X**			
Activated carbon							**X**
Activated Alumina							**X**
Oxidation/Filtration				**X**			
Chelation				**X**			
Filtration					**X**		
Acid Injection		**X**					

Correcting Water Quality Problems

There are three major categories of water quality problems that can be corrected by chemical or physical treatment systems.

Alkalinity can be neutralized by addition of acids described in the alkalinity section. Total dissolved solids, the soluble salts measured together as EC and individually in ppm of the element, can be removed by several water purification systems. Individual elements can be removed from the water if total dissolved solids are not high enough to warrant total salts removal. Before investing in any treatment system, however, it may be advisable to investigate the possibility of switching to an alternate water source, or mixing water sources, if it is an economical alternative for solving a water quality problem. Water purification methods and their applications are summarized in Table 5.

Water Purification to Remove Total Dissolved Solids
Two systems to remove total dissolved solids are reverse osmosis and deionization. Distillation and electrodialysis are water purification processes that can produce very high quality water, but at a prohibitive cost.

Reverse Osmosis (RO)
This type of system removes 95 to 99 percent of the total dissolved salts. The system works by osmosis, which is the passage of a solvent (water) through a semi-permeable membrane separating two solutions of different salts concentrations.

A semi-permeable membrane is one through which the solvent can pass but the solutes (salts) can not. If pressure is applied on the solution with a high salt content (the irrigation source water), the solvent (water) is forced to move through the membrane leaving behind the salts. Relatively pure water accumulates on the other side of the membrane.

Maintenance and replacement of membranes are a significant part of the cost of reverse osmosis systems. Less efficient and less costly membranes are available that require less energy because of their lower operating pressures.

The amount of purified water delivered in a given time and the degree of salts removed depends on the pressure of the system, membrane type, total dissolved solids of the water being purified and temperature. Efficiency is strongly dependent on the integrity and cleanliness of the membranes. Chlorine can cause rapid degradation of the membranes and sediments cause clogging. For this reason, water to be purified by RO is usually pretreated to remove suspended solids, calcium carbonates and chlorine, and the pH is adjusted down if it is above 7.

Although total salts removal can be 95 to 99 percent, individual salts are removed with varying efficiency. In general, calcium, magnesium and sulfate are removed more efficiently than potassium, sodium, lithium, nitrate, chloride and borate.

A disadvantage of reverse osmosis systems is that salty wastewater is produced. Disposal of this waste may fall under government regulation.

Deionization
The soluble salts in water carry a charge that is either positive (cations) or negative (anions).

Examples of cations are: sodium (Na^+), calcium (Ca^{++}), magnesium (Mg^{++}), iron (Fe^{++}) and potassium (K^+). Examples of anions are: chloride (Cl^-), sulfate ($SO_4^=$), bicarbonate (HCO_3^-), and fluoride (F^-).

Deionization is a process that removes ions from water using exchange resins. These are usually solid beads that are covered with fixed negative or positive charges. A cation exchange resin has fixed negative charges that are neutralized by H^+. When the irrigation water is passed over the resin, cations in the water replace the H^+ ions and are held on the resin. Likewise, an anion exchange resin has fixed positive charges that are neutralized by hydroxide ions (OH^-). When the irrigation water is passed over the resin, anions in the water replace the OH^- ions and are held on the resin. The H^+ and OH^- ions released from the resins combine to form water. A deionization unit will contain both anion and cation resins so that all salts are removed.

Deionization is very effective and produces a higher quality water than is generally needed in crop production. The cost increases with the amount of salts in the water to be removed. The higher the salts content, the more frequently the resins need to be regenerated or replaced. Cost of deionized water is generally five to six times higher than that of water purified by RO. If high-quality water is required (as for holding cut flowers) and the initial salts content of the water is high, RO can be used as an initial purification step and final quality be achieved by deionization. Final costs may actually be lower than with deionization alone.

Removing Individual Salts

Iron and Manganese

Iron and manganese in water become oxidized to insoluble forms that are responsible for black or brown stains on foliage of plants that are overhead irrigated. Iron concentrations of less than 0.3 ppm are required for micro-irrigation systems.

There are several ways to remove these elements. If enough space is available, the least expensive approach is to pump the source water into a pond or tank where the insoluble iron and manganese compounds can precipitate and settle out. The water is often pumped in as a spray for rapid oxidation of the iron and manganese to insoluble forms.

Enough time must be allowed for the iron and manganese to settle out, and the holding pond or tank must be large enough to accommodate the irrigation volume needs of the facility without disturbing the bottom layer of sediment containing the iron and manganese.

Oxidation filters also oxidize the iron and manganese to insoluble forms using air, potassium permanganate or chlorine. The sediments are removed by filters that must be periodically cleaned, usually by backflushing. Sand may also be used as a filter. If a chemical oxidant is used, this must be renewed as it is used up. Manganese is slower to oxidize and settle out of the water.

For efficient removal of manganese, chemical coagulation before sedimentation and filtering may be required. If iron and manganese bacteria are present, oxidizing filters should not be used. The oxidizing filters will be quickly blinded by the bacteria. Another approach to eliminating problems of precipitates is to keep the iron and manganese in soluble form. Polyphosphate chelates added to water attach to the soluble iron and manganese and keep them from becoming oxidized. The chelate-iron (-manganese) complex then passes through the irrigation system and is not precipitated on plants. Chelation generally works if the soluble iron and manganese concentration in the water is low (less than 1 - 2 mg/l). Furthermore, iron and manganese in the water that has already been oxidized by exposure to air cannot be chelated.

Water to which chelates have been added cannot be heated, because heating causes the polyphosphates to break down and release the iron and manganese.

Calcium and Magnesium

Calcium and magnesium may need to be removed from hard water to eliminate salt deposits left on foliage by overhead irrigation. This can be achieved by water softening; that is, replacing the calcium and magnesium with potassium.

Note that the usual water softening unit uses sodium, not potassium. High levels of sodium may be harmful to plants and a softening unit that uses potassium should be used instead. Total salt content of the water is not changed and the potassium is used by the plants. Over fertilization with potassium may occur if the water is very hard. The potassium chloride in the softening unit must be recharged.

Fluoride

Fluoride can be removed from irrigation water by adsorption using activated alumina or activated carbon. When using activated alumina, the pH of the water is first adjusted to 5.5 The activated alumina unit can be regenerated with a strong base, such as sodium hydroxide, and reused. Water pH does not have to be adjusted before treatment with an activated carbon unit and the carbon is usually replaced when its adsorption capacity is used up. Fluoride is not soluble above pH 6 so maintaining a media solution pH above this level will prevent most fluoride toxicity problems.

Boron

Boron occurs in many irrigation water sources in the anionic borate form. Anion exchange resins similar to those described for deionization systems can be used, but at considerable expense. To increase the boron-removal efficiency of a reverse osmosis system, the pH of the water needs to be adjusted to be slightly alkaline (pH 7.5). Thin film composite type membranes that are more tolerant of the higher pH should be used.

Blending with Rainwater and Other Non-problem Water: Rainwater can be collected from roof runoff structures, such as greenhouses, where it is then stored in a cistern to be used as irrigation water. Collected rainwater could also be blended with problem waters such as those with high alkalinity, high EC, or excess Na and Cl or to improve the quality of recycled tailwater and industrial wastewaters with high nutrient content used for irrigation. Other non-problem sources of water could also be used for blending. Rainwater has a natural pH of about 5.6 and a very low mineral content. Acidic rainwater with a pH in the range of 4.0-5.0 is acceptable for irrigation; it’s poorly buffered and will have little effect on growing medium pH. Water with a pH below 4.0 should not be used as it may injure seedlings and young transplants. Rainwater should be collected from clean, well-maintained structures free from mineral contaminants such as zinc and other metals. Water should be tested for pH and minerals at least twice a year.

References

Bartok, J.W., Jr. 2009. *Protect Your Water System with a Good Filter*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_waterfilters.pdf

Biernbaum, J.A. 1995. *Water Quality*, Tips on Growing Bedding Plants. The Ohio Florists' Association.

Cox, D.A Greenhouse *Irrigation Water Quality: pH and Alkalinity*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/waterph.html

Cox, D.A *Adjusting Alkalinity with Acids.*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/adjalkal.html

Cox, D.A *UMass Extension Floriculture Water Quality Project: I. Salinity, Sodium and Chloride*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/water_project06.htm

Cox, D.A *UMass Extension Floriculture Water Quality Project: II. pH, Alkalinity, Calcium, Magnesium, and Other Elements*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/water_project2.htm

Faust, J. E. and E. W. *Irrigation Water Quality for Greenhouse Production*, Agricultural Extension Service, University of Tennessee.
http://www.utextension.utk.edu/publications/pbfiles/pb1617.pdf

Smith, T.M. 2004. *Effects of pH on Pesticides and Growth Regulators*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/ph_pesticides.htm

Rainwater Collection System
Photos: Tina Smith, UMass Extension

Rainwater Holding Tank

IRRIGATION SYSTEMS

Greenhouse crops are irrigated by means of applying water to the media surface through drip tubes or tapes, by hand using a hose, overhead sprinklers and booms or by applying water through the bottom of the container through subirrigation, or by using a combination of these delivery systems. Overhead sprinklers and hand watering have a tendency to "waste" water and also wet the foliage, which increases the potential for diseases and injury. Drip and subirrigation systems are the most efficient and provide greater control over the amount of water applied. Also, since the foliage does not become wet there is a reduced potential for diseases and injury.

Drip Irrigation

Drip irrigation can be a valuable tool for accurate growing medium moisture control. It also saves water and labor, and reduces the potential for groundwater pollution. Drip irrigation systems eliminate runoff of water missing the pot during overhead irrigation and the volume of water applied to the pot can be controlled. In theory it should be possible to greatly reduce or eliminate leaching from pots by simply turning the system off as container capacity is reached. Controlling drip systems with the use of a tensiometer placed in the growing medium to sense moisture tension (level) and a small computer programmed to turn the system on or off when preset moisture tensions are reached has been shown to reduce runoff from potted chrysanthemums and poinsettias to nearly zero.

Drip Irrigation
Photo: Tina Smith, UMass Extension

Vegetable crops when grown in ground beds, bags or pots are commonly watered with drip tapes. Tubing is placed atop the ground or container or woven through the bags.

Water Trays and Saucers

In this system, water is applied to the surface and is collected under the container through collection trays or saucers Water trays and saucers, depending on their shape and spacing on the bench, can greatly reduce runoff and leaching by containing the water draining from pots and holding the water which misses the pot during overhead watering. They are inexpensive and reusable. Water which collects in them should be given adequate time to evaporate or be absorbed by the plant before further irrigation. Avoid tight plant spacing and poor ventilation to prevent disease problems when using this technique.

Collection Saucers
Photo: Douglas Cox, UMass

Subirrigation

Subirrigation systems, also know as zero runoff, are an environmentally responsibly alternative that conserves water and fertilizers. They are being installed by greenhouse growers to improve product quality, achieve more uniform growth and increase production efficiency.

In subirrigation systems, water and nutrient solution provided at the base of the container rises by capillary action through holes in the bottom and is absorbed by the growing media. These systems are adaptable to crops grown in pots or flats.

Advantages of subirrigation systems

- Water and nutrient solutions are contained and recycled
- Water and fertilizer usage decreases at least 50% over conventional systems
- Uniform watering of all containers
- Pot size and placement can be easily changed
- More vigorous plant growth
- Foliage remains dry
- Labor input is reduced

Examples of Subirrigation Systems

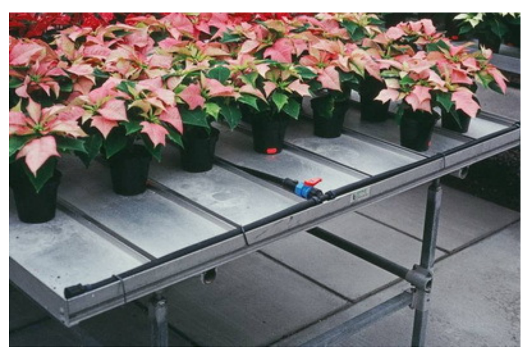
Capillary mat systems

In a capillary mat system the pots are set on a mat that is kept constantly wet with a nutrient solution. Several styles of fabric mats are available from ¼” to ½” thick. The pots take up the solution through holes in the bottom. The mat is places on a level bench over a layer of plastic. Water is supplied from drip tubes laid on top of the fabric.

To keep algae under control, a layer of perforated film plastic is sometimes placed over the top of the mat. Algicides are also used. Some growers turn the mat over when a new crop is started. Containers holding nutrient solution and piping should be enclosed in black plastic or painted black to eliminate light and algae formation.

Trough system

In this system, plastic or metal troughs are placed on existing benches or supported overhead from the greenhouse structure. The troughs are installed at a slight slope (3” to 6” per 100’) from one end to the other. Pots are spaced along the trough. Nutrient solution, supplied from spaghetti tubes, is pumped to the high end, flows past the base of the pots and is collected in a cross gutter at the low end. The solution returns to a storage tank under the benches or below ground to be recycled.

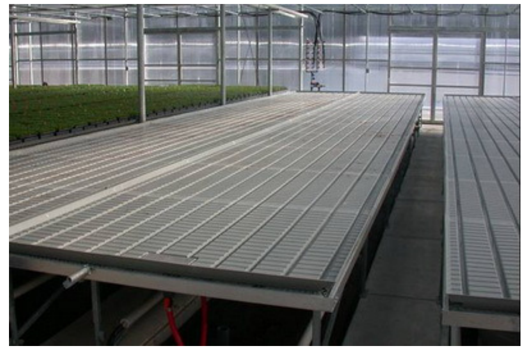


Trough System
Photo: Douglas Cox, UMass

One advantage to this system over other ebb and flow systems is the air circulation that occurs between the troughs. Another is the ability to space the troughs for different size pots. Trough systems tend to be less expensive than bench systems and can be easily installed in existing greenhouses.

Ebb and flood benches and movable trays

This system uses 4' to 6' wide watertight benches or water-tight movable trays to contain the nutrient solution. The benches, usually of plastic or fiberglass construction are installed perfectly level to maintain a uniform depth of liquid. They can be installed as either fixed or movable depending on the crops to be grown. Channels in the bottom of the bench allow the water to distribute evenly and to drain rapidly when the water supply is shut off. This allows the bench top to dry reducing algae growth and disease potential.



Ebb and Flood Bench
Photo: Douglas Cox, UMass

In operation nutrient solution is pumped from a holding tank to a level of ¾" to 1" depth in the bench and held there for 10 minutes or long enough for the media in the container to absorb the solution. A valve is then opened and the liquid is quickly drained by gravity back into the tank. Low cost PVC pipe is used as it is not affected by the fertilizer in the water. A filter removes any solid matter. The holding tank, usually located in the floor below the benches should have a capacity for about ½ gallon/sq ft of bench area.

The nutrient solution is used over again but adjustments in pH and soluble salts may have to be made as water is added. Water treatment with chlorine, ultra violet (UV) light or ozone is used by some growers to prevent diseases. Control of the nutrients and flow can be manual or with a controller. Watering may be once or twice a week to several times a day depending on the weather and the size of the crop.

Flood Floors

Flooded floors work on the same principle and with the same equipment as ebb and flow benches. A watertight concrete is necessary for the floor surface and it must be installed as smooth as possible to avoid pockets. A laser transit is used to get a perfect slope, usually ¼" in 10'. A concrete contractor having experience with flood floor system should be hired. Berms may be installed at the post line in gutter-connected houses to create zones. PVC pipe with slots or holes is usually installed in the floor in the center of the bay to supply and remove the nutrient solution as quickly as possible.

Flood Foor Irrigation
Photo: Tina Smith, UMass Extension

Large holding tanks are necessary, usually made of concrete and lined with plastic or coated with an epoxy paint. Typically a 21' x 200' bay will require 2000 to 3000 gallons of solution. In larger greenhouses, the tank has to be large enough to hold the liquid from several bays that are operated as a single zone. New flood floors can register high alkalinity as bicarbonates in the floor dissolve.

PVC piping is used to transport the nutrient solution as it is inert to fertilizers. Monitoring of the nutrient solution is done by a computer. Fertilizer is added, usually as individual elements, to maintain the desired nutrient level.

Best results are obtained if a floor heating system is installed. This provides uniform heat in the root zone area and quickly dries the floor after the solution is drained to reduce algae formation and lower disease potential. A horizontal air flow (HAF) circulation system will reduce moisture in the plant foliage. To save handling labor, a fork lift transport and spacing machine could be used.

References

Bartok, J.W., Jr. 2009. *Subirrigation for Greenhouses*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_subirrigation_whatsnew.pdf

Cox, D.A *Use "BMPs" to Increase Fertilizer Efficiency and Reduce Runoff*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/bmp.html

Weiler, T.C and M. Sailus. 1996. *Water and Nutrient Management for Greenhouses* NRAES, Cooperative Extension
http://www.nraes.org

Drip system for crop growing in crates or ground beds.

Photo: Tina Smith, UMass

CHECKLIST
EFFECTS OF GROWING MEDIA CHARACTERISTICS ON WATER AND NUTRIENT MANAGEMENT

- ✓ Avoid compaction of growing media. Containers should be lightly filled and the excess brushed off the top. Do not stack growing containers or pre-fill them too far in advance.
- ✓ Add water to peat-based mixes before filling plug trays to help create more aeration.
- ✓ Test the media pH, electrical conductivity and wettability before use.
- ✓ Do not make changes to your current growing media without experimenting first to see if changes may affect your cultural practices.
- ✓ If mixing your own media, thoroughly mix components, but do not over-mix, especially if a media contains vermiculite or controlled release fertilizer.
- ✓ Do not store media that contains fertilizer especially if the media is moist.
- ✓ Avoid contamination of components for finished media by keeping amendments in closed bags or by covering piles.
- ✓ Avoid contamination of bagged commercial media by keeping any broken bags covered.
- ✓ It is advisable to wear a dusk mask when handling dry peat moss or vermiculite to avoid inhaling these materials.
- ✓ Use surfactants occasionally to assure rapid wetting of the media.

Pallets of bagged soilless growing media commonly used in greenhouse production.

Photo: Tina Smith, UMass Extension

EFFECTS OF GROWING MEDIA CHARACTERISTICS ON WATER AND NUTRIENT MANAGEMENT

Growing media consist of mixtures of components that provide water, air, nutrients and support to plants. The media provide plant support, while the nutrients are provided by added fertilizers. Water and air are provided in the pore spaces in the media. Four main factors affect air and water status in containers: the media components and ratios, height of the media in the container, media handling and watering practices.

Only a portion of the water added to media is available for root uptake. Available water-holding capacity is the amount of water held in the root zone and available to plants between irrigating and when the plant wilts. In a 6-inch pot, approximately 65 percent of the pore space is filled with water after the pot has been saturated and allowed to drain. Generally only about 70 percent of that water is available; the rest is called unavailable water. The amount of available water depends on how tightly the water is held to the particles of materials that make up the media (matric tension). For example, peat has relatively higher unavailable water contents at a given matric tension compared to rock. This variability in the availability of water in different types of media components means no two media are exactly alike in terms of providing water to plants. This makes knowing when to water difficult. Another important characteristic of media components that influences watering practices is wettability, i.e., the ability of dry media to rapidly absorb water when moistened. A surfactant used occasionally can help media rewet more readily. The choice of media should be influenced by irrigation systems and practices.

Media Column Height and Containers

Another factor relating media to air/water relations in the root zone is the size of the growing container. With media in containers, the amount of air and water held in a given growing medium is a function of the height of the column of media. The taller the column of medium, the smaller the ratio of water-filled pore spaces will be to air-filled spaces. This is most important in plug production where the small cells drain very poorly or not at all, resulting in poor root zone aeration. In all containers, there will be a certain amount of saturated medium at the bottom of the container after drainage. This is due to what is called a perched water table. The saturation zone is a larger part of the total volume of the growing medium in a very short container, such as a plug cell.

Handling Growing Media

How soilless growing media are handled can greatly influence their air and water characteristics. The major concern is to avoid compaction. Containers, including plug trays, should be lightly filled and the excess brushed off the top. Air space can be drastically reduced by compaction. At no time should any growing containers be stacked. The moisture content of the medium prior to filling containers may also be important. Adding water to peat-based mixes before filling plug trays causes the media to swell and helps create more aeration. Water added to about 100 percent by weight of the media is sufficient for cell packs. Plug mixes should have about 200 percent by weight water added before filling plug trays. Moistening of the medium before filling larger containers does not have much benefit.

Growing Media Components

Growing media for use in container production in greenhouses contain a variety of soilless ingredients such as peat moss, vermiculite, perlite, shredded coconut husks (coir), composted bark or other composted materials. Field soils are generally unsatisfactory for the production of plants in containers because soils do not provide the aeration, drainage and water holding capacity required and they need to be pasteurized or fumigated to prevent diseases and weeds. Most commercial greenhouse media for container crop production contains 30 to 60 percent peat moss alone or in combination with composted pine bark. Other materials such as vermiculite and perlite are added to affect water retention and aeration.

Growing media are designed to achieve high porosity and water retention while providing adequate aeration. A nutrient charge is added and the pH adjusted to approximately 6.0. A non-ionic wetting agent is generally added to peat and pine bark-based media to improve initial wetting. Both can become hydrophobic when the moisture content drops below 40 percent. For most greenhouse crops, the initial pH of growing media should be between 5.8 and 6.2. Since most components of media are acidic, dolomitic limestone (calcium and magnesium carbonates) is added to start at an acceptable pH range and provide Ca and Mg for plant growth. The smaller the particle size of the ground limestone, the quicker is the increase in media pH. Commercially blended media typically have limestone already incorporated.

Variations in the recipes result in media designed for particular situations. For example, a formulation for plug production may have high porosity for adequate aeration in small growing cells, be buffered against rapid pH changes and contain a light nutrient charge and low level of wetting agent. Applications requiring rapid drainage, such as outdoor-grown mums and perennials, benefit from a high-porosity medium based on pine bark.

Premixed media is common in the greenhouse industry. Suppliers offer a diversity of mixes in either prepacked (bags, bales, super sacks) or bulk forms. Recipes are specially formulated for propagation, specific crops or general crops. If significant quantities are required, growers can purchase media customized to their specific operation by requesting specific amendments including lime, wetting agents and fertilizer.

Use of Composts in Growing Media

While most growers use soilless peat-based growing media, there is a growing interest in using composts as a substitute for traditional soilless media, especially for organic crop production. Compost-based mixes can be purchased just as soilless mixes are, or growers can compost organic waste and create their own mixes. See section on organic waste management for details about composts.

Research has shown that organic materials that have been properly composted can be successfully used in potting mixes. However, when used as a component in a potting mix, most of the time, the compost cannot supply enough nutrients and additional fertilizer must be applied.

While it is possible to use 100% compost for container grown greenhouse crops, the commonly accepted recommendation is to use compost at about 30-40% by volume. Most composts are too heavy, hold too much water or drain too much, or have too high a starting EC to be used 100%.

Marigolds (left) and tomatoes (right) were grown in Metro Mix (top) and wood products compost (bottom). No fertilizer has been applied to either flat since the seeds were sown about 4 weeks earlier. Low fertility accounts for the small plants growing in the compost.

Photo: Douglas Cox, UMass

Organic Growing Media

Many materials used to make growing media in "traditional" greenhouses such as peat moss, vermiculite and perlite can be used for organic production. Check with an organic certifier.

Recipes for Organic Growing Media

Many different organic media can be formulated from a host of organic-approved materials and additives available. A good starting point would be to follow a proven recipe and then make your own modifications later. The NCAT (ATTRA) publication "Potting Mixes for Certified Organic Production" lists about 30 different growing Media recipes available from www.attra.ncat.org.

Here are two simple mixes made of commonly available materials.

Notice that the mixes do not contain wetting agent or starter fertilizer. It should wet up without a problem, but make sure these mixes are thoroughly moistened before planting and fertilizing should start shortly after planting.

Classic 1:1:1 Soil-based Mix
⅓ yd^3 mature compost
⅓ yd^3 field soil
⅓ yd^3 field sharp sand or perlite
5 lbs limestone

Classic Cornell Mix
½ yd^3 sphagnum peat moss
½ yd^3 perlite
10 lbs. bone meal
5 lbs. limestone
5 lbs. blood meal

The main differences between the classic 1:1:1 mix and the original Cornell Mix is the use of bone meal and blood meal to supply N and P instead of a chemical fertilizer. You could add greensand for K or apply a fertilizer after planting supplying potassium (K). Liquid fish fertilizer and/or a kelp extract fertilizer would be likely choices.

Here are two more complicated mixes that are often cited for organic greenhouse production.

"John Biernbaum's Michigan State University Mix"
60-70%/yd^3 peat moss
30-40%/yd^3 vermiculite or perlite
20-40 lbs./yd^3 Bradfield Alfalfa 3-1-5 Fertilizer
5 lbs. limestone
No wetting agent
No chemical fertilizer

The Bradfield Alfalfa Fertilizer seems to be enough to carry bedding plants to maturity, but supplemental applications of liquid fish fertilizer should be considered.

"Eliot Coleman's Recipe"
1. Mix equal parts of blood meal + rock phosphate + greensand.
2. Mix 14 lbs. of #1 per yd^3 of soilless mix (peat moss + perlite or vermiculite).
3. Allow the complete mix to sit for a month or more before planting.

The blood meal, rock phosphate, and greensand supply N, P, and K. The month after mixing and before planting presumably allows the fertilizer materials to partially breakdown and release plant-available nutrients. Test this recipe on a small number of plants before you adopt it for all your plants.

Commercial Organic Mixes
Don't want to make your own mix? Some of the familiar manufacturers of soilless mixes are making organic versions such as Sungro Horticulture, Fafard and Premier Horticulture. Currently, Sungro Horticulture lists several types of organic media packaged for growers. Most are OMRI-approved.

Bag Culture
Plastic bags filled with soilless growing media are often used to grow crops such as greenhouse tomatoes. Bags are usually placed in rows on the floor and are drip irrigated. The relatively low water holding capacity necessitates frequent irrigation and precise control of water distribution and nutrient levels. Soil testing should be done weekly to monitor plant nutrition.

In-Ground Culture

Ground Beds
Growers of greenhouse vegetables grow crops and cut flowers may grow directly in the ground, or raised beds.

Soil compaction often occurs during greenhouse construction which can limit plant growth. Even when the topsoil is worked, plants may suffer once roots reach the compacted subsoil. The best approach to in-ground culture is to deeply amend the greenhouse soil with compost or peat moss. Test the soil to monitor soluble salts and take precautions to avoid over-fertilization.

When growing directly in the ground, the soil is steam treated to kill pathogens and nearly all weed seeds. Treatment with steam is preferred over fumigants because it is faster, very effective and safe. See information on steam treatment under the Disease Management section.

In addition to treating the soil with steam or fumigation for disease management, greenhouse tomato plants are often grafted to disease resistant rootstock for disease management. See information under Disease Management.

References

Cox, D.A. 2008. *Organic Growing Media and Fertilizers for Greenhouses.* http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/dc_organic_fert.html

Faust, J. E. and E. W. *Growing Media for Greenhouse Production,* University of Tennessee. http://www.utextension.utk.edu/publications/pbfiles/PB1618.pdf

Kuepper, G. and K. Everett. 2004. *Potting Mixes for Certified Organic Production* http://attra.ncat.org/attra-pub/PDF/potmix.pdf

Robbins, J.A. and M. R. Evans. *Growing Media for Container Production in a Greenhouse or Nursery*, University of Arkansas Division of Agriculture, Cooperative Extension Service http://www.uaex.edu/Other_Areas/publications/PDF/FSA-6098.pdf

Herbs Growing in Ground Beds and Containers
Photo: Tina Smith, UMass Extension

CHECKLIST
NUTRIENT MANAGEMENT

- ✓ Check fertilizer injectors prior to each crop cycle to be sure they are operating accurately. This can be done by testing the electrical conductivity (EC) of the fertilizer solution and comparing the results to an EC chart from the fertilizer manufacturer. To check a fertilizer solution, use a good conductivity meter or send a sample to the University of Massachusetts soil test laboratory, http://www.umass.edu/soiltest/index.htm .

- ✓ Match fertilizer application with plant nutrient needs as the plant grows. Consider plant growth rate and environmental conditions as part of a nutrient management program.

- ✓ Avoid excess leaching to reduce ground water contamination.

- ✓ Stop or limit nutrient and water loss from irrigation and leaching by containing the effluent and by reducing the leaching fraction waste during watering.

- ✓ When choosing a fertilizer consider the ratio of ammonium to nitrate-N, trace element charge, content of calcium and magnesium, and potential acidity or basicity.

- ✓ Consider the frequency of application when developing a fertilizer program.

- ✓ Consider the volume of fertilizer solution applied.

- ✓ When using controlled release fertilizers, choose the correct product for the particular crop being grown and use the correct rate rate.

Fertilizer Injector
Photo: Tina Smith, UMass Extension

NUTRIENT MANAGEMENT

Most potting mixes have little ability to supply or retain nutrients in amounts to sustain plants without applications of fertilizer. Nutrients are delivered using various water-soluble fertilizers through a fertilizer injector, through the use of controlled-release fertilizers (CRF), or a combination of controlled-release and water-soluble fertilizers. Nitrates and phosphates from fertilizer are potential environmental hazards if they enter groundwater or surface water by runoff or leaching. Nitrate-N (NO3-N) is the major element of concern, but other elements are potential pollutants as well. Current standards for drinking water in most states, including Massachusetts, allow no more than 10 ppm NO3-N. Most fertilizer programs apply 200 - 300 ppm N and container leachates commonly have levels of NO3-N well above 10 ppm.

If not used carefully, fertilizers and other agricultural chemicals can contaminate both ground and surface water. Buffer zones around water bodies and well heads, using only the nutrients necessary, and other practices can help to minimize these problems. Nutrient management is key not only to crop health, but also to protecting water resources.

Fertilizer Injectors

Fertilizer proportioners or injectors are used in liquid feeding systems to eliminate the need for large volumes of stock solution tanks. They allow for the measured injection of highly concentrated fertilizer solutions. These devices "inject" a small quantity of concentrated fertilizer solution (stock solution) into the irrigation line so that the water leaving the hose (dilute solution) supplies the proper concentration of fertilizer. Most growers apply water-soluble fertilizers at a dilute concentration on a "constant feed" basis (with mostly every watering) to insure an adequate supply of the essential elements for plant growth.

Rates of fertilization are often given in parts per million (ppm) of nitrogen (N), which is a way of expressing fertilizer concentration. One ppm is equivalent to 1 milligram/liter (mg/l). It is important to remember that an injector does not deliver a fixed ppm N. The amount of fertilizer to dissolve per gallon of water (stock solution) to make the appropriate concentrate for a specific injector setting needs to be determined. An injector setting of 1:100 indicates that 1 gallon of fertilizer concentrate delivers 100 gallons of final solution. This is not an indication that the injector is delivering 100 parts per million (ppm) nitrogen. Note that fertilizer should be measured by weight for mixing, not volume. Also, while color dyes are used to indicate the presence of fertilizer, fertilizer solution color is not a reliable gauge for fertilizer concentration. For more information on injector ratios, ppm Nitrogen and fertilizer calculations see: http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/fert_injector.html

Some injectors (Hozon, Smith) have a fixed (nonadjustable) injector ratio whereas other injectors (Dosatron, Anderson, Dosmatic) have adjustable ratios. Many growers prefer injectors with adjustable ratios so that different fertilizer rates can be applied to crops with different nutrient requirements.

Many injectors have dual settings, in percent and ratio. A 1 percent setting is the same as a 1:100 ratio, a 2 percent setting is the same as a 1:50 ratio and a 0.5 percent setting is the same as a 1:200 ratio.

The reliable proportioner makes liquid feeding of crops a simple procedure, but the output from the proportioner must be monitored and the chemicals in the stock solution must be compatible and mixed properly. Some chemicals are not compatible in highly concentrated stock solutions because they form solid precipitate. The most common problems occur when fertilizers containing calcium are mixed with fertilizers containing sulfate or phosphate, or if iron compounds are mixed with phosphate. This can be solved using a twin-headed injector or by using two injectors.

Fertilizer injectors should be checked periodically to be sure they are operating accurately. This can be done by testing the electrical conductivity (EC) of the fertilizer solution and comparing the results to an EC chart from the fertilizer manufacturer. To check a fertilizer solution, use a good conductivity meter or send a sample to the University of Massachusetts soil test laboratory, http://www.umass.edu/soiltest/index.htm .

Procedure to check the EC of a fertilizer solution:

1. Let plain water (no fertilizer) run a little, then collect water in a clean bucket. Take a sample of the plain water from the bucket. Check the EC of the untreated water supply.
2. Mix up your fertilizer as you normally do and run it through the injector and hose. Let it run a little to be sure you get an accurate sample. Fill a clean bucket with fertilizer-injected water from the end of the hose and use your meter or soil test laboratory to check the EC of the sample.
3. Subtract the EC value of the untreated water from the EC value of the fertilizer water.
4. Compare the results to an EC chart from the fertilizer manufacturer or fertilizer bag. The chart will correlate the EC measurement with the ppm nitrogen so you can determine if your injector and mixing procedure is accurate.

Increasing Fertilizer Efficiency and Reducing Runoff

Water-soluble fertilizers are often used at rates in excess of the plants' needs without regard for volume applied and frequency of application. Nutrient management BMPs should promote the efficient use of fertilizer and reduce nutrient loss by maximizing the amount of nutrients used by the plant or retained in the plant container for potential use. Growers should attempt to meet three goals in developing a nutrient BMP program:

- Match fertilizer application with plant nutrient needs as the plant grows.
- Stop or limit the loss of nutrients from the plant container during topwatering in an open system.
- Stop or limit nutrient and water loss from irrigation and leaching by containing the effluent and by reducing the leaching fraction waste during watering.

Matching Fertilizer Application with Plant Nutrient Needs

It would be very useful when developing fertilizer programs to know the specific nutrient requirements of greenhouse plants both in amount and in time. Farmers of field crops have extensive information on how much N, P, or K is needed to grow a crop and at what time during crop development fertilizer will be most beneficial; unfortunately information of this type is very limited for the thousands of greenhouse crops.

Nutrient balance sheets

One approach to studying nutrient needs is to construct a "nutrient balance sheet" showing where the applied element(s) go and where improvements in fertilizer efficiency can be made. Fertilizers or fertilizer programs can be compared as in the example of 4-inch seed geraniums (Table 1). Here the plants received the same amount of N and water as they grew and where the fate of the N was kept track of until flowering. The balance sheet shows that the largest amount of N was recovered by the plants fertilized with ammonium nitrate; N leaching was greatest with ammonium sulfate and calcium nitrate; unaccounted for N (presumably lost as ammonia gas) was highest for ammonium sulfate and urea; and the amount retained by the potting mix was about the same for all N sources. The balance sheet clearly shows the magnitude of N loss by leaching and the importance of N source in maximizing fertilizer efficiency. Interestingly, about 1.0 gram of N was required to grow the geraniums in this study; a level very close to estimates made for other floriculture crops. Complete balance sheets for floriculture crops are rare because the research needed to construct them is expensive and time-consuming.

Table 1. Nitrogen balance sheet for 4-inch seed geranium.[z]

	Percentage (%) of applied N			
N Fertilizer	Plant	Medium	Leached	Unacct. for
Ammonium sulfate	27	19	43	11
Ammonium nitrate	47	18	32	3
Calcium nitrate	33	18	46	3
Urea	37	19	21	23
Osmocote 14-14-14	38	26	30	6

[z]Cox, D.A. 1985. *HortScience*. 20:923-925.

Nutrient uptake patterns

Plant nutrient requirements change as the plant grows and enters new developmental stages (e.g., vegetative vs. reproductive). Ideally fertilizer should be applied during periods of highest demand and reduced or stopped at other times. Using this approach could reduce runoff and prevent harmful nutrient deficiencies or excesses. Some plants such as chrysanthemum and marigold have distinct vegetative and reproductive phases of growth and they show a pattern of increasing N uptake during vegetative growth and a leveling off or decline following the appearance of visible buds. Nitrogen is most critical during the vegetative phase and fertilization can be reduced after visible bud. On the other hand, New Guinea impatiens, which do not have distinct vegetative and reproductive phases and they show a continuous, gradual increase in N uptake as they grow. New Guineas do best with low fertility early on and fertilization becomes more critical as the plant gets older and larger.

Nutrient uptake patterns have been determined for only a few crops, but some information is already available to enhance postharvest longevity and reduce nutrient runoff by reducing fertility in the latter stages of growth (Table 2).

Table 2. Fertilization recommendations for improved postharvest performance of selected greenhouse crops.[z]	
Crop	Nitrogen recommendation
Ageratum, marigold, petunia	Cut nitrogen rate in half at visible bud stage.
Celosia	Cut N rate in half 1-2 weeks before sale.
Snapdragon	Reduce fertilization when flower spike starts to elongate.
Begonia	Reduce fertilizer rate at the end of the production period.
Poinsettia	Stop fertilizing 2 weeks before sale to reduce leaf drop.
Potted chrysanthemum	Stop fertilizing at visible bud, or use 150 ppm for entire production (instead of 450 ppm) to increase postharvest life 7-14 days.
Easter lily	Stop fertilization prior to marketing of lilies that are to be stored at 35 F. This will improve postharvest foliage color.
Azalea	Stop fertilizing 2-4 weeks before cooling to reduce leaf browning.
Exacum	Reduce fertilizer levels during production to increase postharvest longevity.
[z]McAvoy, R.J. 1995. *Connecticut Greenhouse Newsletter*, Issue 184, February/March.	

Types of Common Fertilizers

Peat-Lite Specials (15-16-17, 20-10-20)

These fertilizers are among the most popular for routine fertilization of spring crops. Both are high (>50%) nitrate fertilizers. However these fertilizers also have elevated trace element levels which may raise Fe and Mn to toxic levels at low pH. Both are acid-forming fertilizers (see the box), but 20-10-20 has the higher potential acidity (397 vs. 210).

15-15-15 Geranium Special

"Triple 15" is a good alternative to the Peat-Lite Specials for crops sensitive to trace element toxicities. Trace element levels supplied by this fertilizer are lower than the Peat-lite Specials. Otherwise, at the same rate of N, plant response will be very similar to 15-16-17. This is an acid-forming fertilizer also; the potential acidity (261) is slightly higher than 15-16-17.

20-20-20 General Purpose

Growers who use this fertilizer on soilless media risk ammonium toxicity because the N in this fertilizer is 75% ammonium and urea. Some growers who use media containing soil do not appear have problems. If 20-20-20 is used, the growing medium should be tested frequently for ammonium especially during cool growing conditions. 20-20-20 supplies trace elements and has the highest potential acidity (597) of fertilizers commonly used in Massachusetts greenhouses.

Low Phosphorus Fertilizers (20-0-20, 20-1-20, 15-0-15)

These fertilizers can be tried as an alternative to chemical growth regulators for bedding plants. This technique of growth control is sometimes called "phosphorus starvation". It is generally believed that more P than necessary is being applied to greenhouse crops. Fertilizer formulations with phosphorus levels of 5% or less are recommended. Too much P may cause plants to stretch and P is a pollutant. Unfortunately, in terms of height control, low P fertilizers will be of no benefit if they are applied to a growth medium containing superphosphate. On the other hand, there is a risk of P deficiency if the fertilizers are used continuously with low P growth media. More practical research is needed to learn how to use these fertilizers effectively.

The low P fertilizers are quite different in many ways. 15-0-15 and 20-0-20 supply Ca. 15-0-15 is a basic fertilizer containing about 95% nitrate and 20-0-20 is a neutral fertilizer and is 50% nitrate. 20-1-20 is an acidic fertilizer and it does not supply Ca, but it is about 70% nitrate.

Calcium Nitrate and Potassium Nitrate

Use of this fertilizer combination greatly reduces the chance of trace element toxicities. Some growers alternate its use with the Peat-Lite Specials on a 2-3 week basis to supply Ca and to counter the acidic effect of the Peat-lites. However, both superphosphate and a trace element fertilizer must be incorporated in the growing medium if this combination is to be used as the sole fertilizer.

Controlled Release Fertilizers

Controlled-release fertilizers (CRF) are fertilizers that have an outer shell like an M&M candy that are released by temperature, and the presence of moisture. The coating protects the nutrients in the "prill" from releasing all at once. As water vapor enters the covered prill, pressure builds up on the inside and the ingredients in the prill will escape through pores in the coating. The release of nutrients varies depending on the technology used to formulate the coating. The basic principle with most CRF products involves taking a soluble form of fertilizer and coating it so it is "controlled release." The technology of the coating and how that coating affects the release is what makes each CRF product somewhat different.

Organic Fertilizers

In addition to chemical fertilizers, some growers especially greenhouse vegetable growers are interested in using organic fertilizers. Organic fertilizers can be incorporated in the growing mix prior to planting to provide nutrients, used post-plant (fish emulsion) or a combination of the two. Incorporating bulk fertilizers like dried blood, bone meal, and rock phosphate in the medium before planting limits the control of nutrition as the plants grow, unlike water-soluble fertilizers. The growing media also plays an important role in organic nutrient management. For information on organic growing media, see section "Effects of Growing Media on Water and Nutrient Management".

Pre-plant Organic fertilizers: Many organic bulk materials can be incorporated in the growing mix prior to planting to provide nutrients. How effective these materials are depends on the nutrient analysis, amount added, and the needs of the plant. The Organic Materials Review Institute (OMRI) maintains an extensive list of these materials on their website www.omri.org.

The challenge when using these fertilizer materials is the rate of nutrient release and how it matches the nutrient requirement of your plants. Nitrogen is the most likely element to become deficient in both "traditional" and organic production. In most chemical fertilizers N is immediately available, but it is more slowly available in most organic sources.

N in organic matter is released from complex molecules like protein, but it must be converted to ammonium and nitrate ions before it can be taken up by plants. This process is natural and occurs because of the activity of a number of bacterial species found in most potting media. This process can be unpredictable and it's important that the mix be well-aerated and otherwise supportive of active microorganisms (so no chemicals!). It may be necessary to apply a "soluble" fertilizer after planting to boost the level of plant available nutrients. This is where liquid fertilizers like fish emulsion become important.

Pre-plant Organic Fertilizers

Fertilizer material	Estimated NPK	Nutrient release
Alfalfa meal	2.5-0.5-2.0	Medium-fast
Blood meal	12.5-1.5-0.6	Slow
Cottonseed meal	7.0-2.5-1.5	Slow-medium
Crab meal	10.0-0.3-0.1	Slow
Feather meal	15.0-0.0-0.0	Slow
Fish meal	10.0-5.0-0.0	Medium
Granite meal	0.0-0.0-4.5	Very slow
Greensand	0.0-1.5-5.0	Very slow
Bat guano	5.5-8.6-1.5	Medium
Kelp meal	1.0-0.5-8.0	Slow
Dried manure	Variable	Medium
Seabird guano	12.3-11.0-2.5	Slow-medium
Rock phosphate	0.0-18.0-0.0	Slow-very slow
Soybean meal	6.5-1.5-2.4	Slow-medium
Wood ash	0.0-2.5-5.0	Fast
Worm castings	1.5-2.5-1.3	Medium

Post-plant Organic Fertilization: Organic Materials Review Institute (OMRI) -approved liquid fish fertilizers are the closest organic fertilizer to water-soluble, chemical types in terms of application method. Liquid fish fertilizer can be used alone or as a supplement to pre-plant organic fertilizers. Liquid fish fertilizer has a very low NPK analysis (2-4-1), a rather thick consistency, and some users object to its odor. However, it has the advantage of being compatible with most equipment and systems growers already use to apply water-soluble fertilizer. It can be successfully used to fertilize plants including greenhouse tomatoes irrigated using drip irrigation. Since between 15 and 25% of the N in fish fertilizer is water-insoluble it may be necessary to increase the level rate of application.

Fertilizer Programs for Greenhouse Crops

Providing the proper combination of pH and fertility requirements for specific greenhouse crops can be a challenge for growers. For information on rates, consult the plant nutrition section of the

UMass Extension Greenhouse Crops and Floriculture website for information: http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management.html . Information can also be found in the plant culture sections of the catalogs.

Considerations for Fertilizing Greenhouse Crops

Fertilizer type: Important considerations are ratio of ammonium to nitrate-N, trace element charge, content of calcium and magnesium, and potential acidity or basicity. Ideally no more than 50 percent of the total nitrogen supplied to plants grown in soilless media should be in the ammonium form. Ammonium toxicity can occur in soilless media due to high levels of ammonium or urea fertilizer. The toxicity occurs on some plants when the soil is cool and waterlogged, when the ammonium is converted to ammonia.

Fertilizer rate: Traditionally fertilizer rate (ppm) has been the main focus of greenhouse fertilizer programs, but rate interacts with the other five factors on this list to determine the success of a fertility program.

Frequency of application: How many times water-soluble fertilizer is applied is often overlooked as a factor in developing a good fertilizer program. What does the term "constant liquid feed" (CLF) really mean - every watering, once a week, or twice a week? At a given ppm level, more frequent applications will lead to a higher fertility level simply because fertilizer is applied more often.

Volume of fertilizer solution applied: As the volume of water-soluble fertilizer increases the quantity of nutrients delivered to the plant also increases. Doubling the volume applied also doubles the amount of each nutrient potentially available to the plant.

Leaching fraction: Leaching fraction is the proportion of fertilizer solution or irrigation water applied that is lost from the plant container by leaching. The lower the leaching fraction, the greater the quantity of nutrients and salts retained in the growth medium. Leaching fraction is strongly affected by volume applied (i.e., factor 4). Avoiding excess leaching is critical to reducing both fertilizer costs and ground water contamination. Lower fertilizer concentrations with less leaching (10-15 percent) can be just as effective as higher concentrations and heavy leaching.

Plant growth rate and environmental conditions: In general, nutrient requirements of greenhouse crops are greatest during periods of rapid growth. Two major influences on growth rate are the inherent growth pattern followed by the plant and the environment in which it is grown. Too much fertilizer during slow growth periods may lead to excess soluble salts; failure to provide enough fertilizer during periods of rapid growth will lead to deficiency.

Potential Acidity and Basicity of Greenhouse Fertilizers

Fertilizers may raise or lower the pH of the growth medium. Fertilizers are rated as to their potential acidity or potential basicity. This value is determined largely by the amount and sources of nitrogen in a formula. Fertilizers that contain more urea and ammonical nitrogen are acidic in reaction, while those that contain primarily nitrate nitrogen are basic. The numbers used to express these potentials refer to the pounds of limestone (calcium carbonate) that it takes to either neutralize (potential acidity) or be equivalent in reaction to (potential basicity) on ton of that fertilizer. For example, 15-16-17 has a potential acidity of 215 lbs. of calcium carbonate per ton of fertilizer. This means it would take 215 lbs. of calcitic limestone to neutralize the acidic effect caused by the application of one ton of 15-16-17. On the other hand 15-0-15 has a potential basicity of 420 lbs. of calcium carbonate per ton of fertilizer. A ton of 15-0-15 would raise the pH of the growth medium as much as 420 lbs. of calcitic limestone. In each case, the larger the number the greater the potential effect the fertilizer on pH. Information on potential acidity or basicity of a fertilizer can be found on the fertilizer bag of most brands. In theory, by alternating fertilizers, the medium pH should be able to be stabilized. In reality, the pH of the medium is a dynamic system and is influenced by many other factors such as irrigation water alkalinity, fungicide drenches and root exudates.

Limiting the Loss of Nutrients in an Open System

The term "open system" refers to crop systems which allow any effluent from irrigation and leaching to escape from the pot to the greenhouse floor. "Closed systems" are those which contain the effluent for treatment or reuse (e.g. an ebb and flood subirrigation bench). Most growers in New England use an "open system" to grow plants.

Use of Controlled-release fertilizers: The major advantage of using controlled-release fertilizers (CRFs) is that the loss of nutrients from spills during fertigation is eliminated. However, nutrient leaching from the pot can still be as high with CRFs if the rates are too high or if the wrong product is chosen for the crop. In a study conducted at the University of Massachusetts, the same amount of N and water was applied to 4-inch marigolds from water-soluble 20-10-20 and Osmocote 14-14-14. Contrary to expectations, more N leached by 30 days after planting and at the end (60 days) with CRF incorporated in the mix at planting than with regular application of water-soluble fertilizer. The performance of CRF, in terms of N leaching, was improved when the fertilizer was applied to the surface of the mix or when CRF was applied in two smaller doses 30 days apart. Although more labor is required, splitting a single application into smaller amounts and applying them two times during the growing season greatly reduces NO3-N in the leachate.

Important factors when using CRFs are the choice of product and rate of application. A single, high rate of a CRF product applied shortly after planting is not recommended for greenhouse crops because large quantities of NO3-N and other nutrients are released at this time when the plants do not need it. Although Osmocote 14-14-14 was used in the study, it is not the best product for greenhouse crops any longer. When using CRFs, use the correct CRF product for greenhouse crops and use the lowest recommended rate according to the manufacturer to control nutrient leaching.

Stop or limit leaching: This is difficult to achieve when top-watering with a hose because it requires precise control of the volume of irrigation solution applied. Traditionally the recommendation has been to water until about 10-15% of the volume applied drains from the pot to avoid excess soluble salts. In today's terminology this is described as a 0.1-0.15 "leaching fraction" (LF). Most growers probably greatly exceed this LF; probably LFs of 0.4-0.6 are more common. The goal is to achieve a LF of zero, but for many getting the LF down to the recommended range of 0.1-0.15 would be a big step in reducing greenhouse runoff. The best way to stop or limit leaching with an open system is by the use of a carefully-controlled spaghetti-tube irrigation system with drip emitters. Irrigation solution should be applied slowly and in small volumes for the best results. Also, researchers have found that "pulse irrigation" - brief periods of fertigation - is best for efficient application of water and nutrients.

Achieving 0 LF with a hose is probably impossible, but reducing LF is possible if the waterer takes the time to observe how much water is applied or how much time passes before leaching begins as each pot is watered. The "fire hose" method of indiscriminate watering is a definite "no-no" with zero leaching! Maintaining a small leaching percentage and reducing the amount of water which misses the pot during hose watering would go a long way toward reducing water consumption and chemical leaching.

It is important to remember that any significant reduction in LF should be accompanied by a reduction in fertilizer rate (ppm) and/or frequency of application. If LF is reduced or there is no leaching, more fertilizer will stay in the pot and soluble salts could increase to a harmful level. Therefore, fertilizer rate should be cut at least 25%. Also, soluble salts should be monitored more frequently when leaching is stopped or cut back.

Low phosphorus fertilizer programs: Most researchers agree that the typical greenhouse fertilizer program provides significantly more P than crops require. There are several fertilizers with low P analysis (e.g., 15-0-15, 20-1-20, 20-2-20) on the market which could be included in a routine fertilizer program to reduce P enrichment of effluent. Also, carried a little farther, incipient P deficiencies have been shown to have a desirable growth-retarding effect on many bedding plants without any foliar symptoms or major delay in plant development. Like chemical growth retardants low P has the greatest growth inhibiting effect during the early stages of vegetative growth. Carefully test this method on a small number of plants before committing the whole crop. Never try to grow a crop without any P!

Limiting Nutrient and Water loss by Containing the Effluent

Subirrigation and reuse: This is the best method for eliminating runoff from the greenhouse and increasing water and fertilizer efficiency because all of the liquid is contained in the system by a water-tight growing area or in a supply tank. Unfortunately this is also the most expensive approach. Since no leaching occurs, fertilizer rate and soluble salts must be monitored very carefully. Fertilizer rate should be about 25-50% less than conventional top-watering in an open system. Many growers who ebb-flood like the way the crops grow and the labor savings in irrigation time so much that they are able to justify the investment and have started adding them to their greenhouses.

A lot of water and fertilizer is lost during fertigation from overhead systems as the hose or boom moves between pots. These "spills" may account for as much as 60% of the water and nutrient loss during top-watering. Large improvements can be made here at relatively low cost. See section on irrigation systems.

Pot spacing: Take some empty round pots and space them pot to pot. Even at this spacing there is a lot of space for irrigation solution to spill as the pots are watered. Some improvement can be made by staggering the rows of pots. Much greater improvement can be made by using square pots and tray to tray spacing of bedding plants. But, did you ever grow poinsettias pot to pot all the way to flowering? Probably not! So, while close spacing reduces water and fertilizer loss, there are only certain crops that will end up of acceptable quality when spaced pot-to-pot.

Saucers and trays: Various types of saucer or collection tray systems can be used to reduce loss from spills between pots and the use of saucers is also an inexpensive way to learn about subirrigation. Some saucers are designed to cover most of the space between the pots, channel the water to the base of the pot, and capture leachate. Simple round saucers hold leachate but are much less effective at capturing spills. Round saucers could be filled with fertilizer solution for subirrigation.

Fertilizer rate (ppm) and/or application frequency should be reduced in saucer and tray systems because whatever is held in the saucer can be absorbed or reabsorbed by the pot as the growth medium dries. Also, plants could become overwatered if the solution stands in the saucer for too long.

Capillary mats: Capillary mats have been used for many years for watering and fertilizing plants by subirrigation. They may also be used to irrigate potted plants amended with CRF. A slightly different use would be to topwater the plants and rely on the capillary mat to soak up and hold any spills or effluent from the pots. Of course cap mats can absorb only so much water before they start to drip, so watering must be done carefully. Perhaps this is a way of learning to efficiently apply water with a hose and reduce LF.

References

Cox D.A. *Fertilizing Bedding Plants*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/bedfert.html

Cox, D.A. 1985. *Nitrogen recovery by seed geranium as influenced by nitrogen source*. HortScience 20:923-925.

Cox, D.A. 2008. *Organic Growing Media and Fertilizers for Greenhouses.*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/dc_organic_fert.html

Cox D.A. *Use "BMPs" to Increase Fertilizer Efficiency and Reduce Runoff*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/bmp.html

Smith, T.M. 2009. *Fertilizer Injectors for Greenhouses*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/fert_injector.html

CHECKLIST
SOIL TESTING

- ✓ Conduct pre- plant media analyses to provide an indication of potential nutrient deficiencies, pH imbalance or excess soluble salts. This is particularly important for growers who mix their own media.

- ✓ Conduct media tests during the growing season to manage crop nutrition and soluble salts levels.

- ✓ Always use the interpretative data for the specific soil testing method used to avoid incorrect interpretation of the results.

- ✓ Take the soil sample for testing about 2 hours after fertilizing or on the same day. If slow-release fertilizer pellets are present, carefully pick them out of the sample.

- ✓ In a greenhouse where a variety of crops are grown, take soil samples from crops of different species.

- ✓ If a problem is being diagnosed, take a sample from both normal and abnormal plants for comparison.

- ✓ Be consistent in all sampling procedures each time you sample.

- ✓ ***Do not*** compare soil test results from one lab to those obtained from another. Testing methods may vary. ***How the soil test is interpreted is the key to what action you should take based on the soil test!***

SOIL TESTING

A soil test is important for several reasons: to optimize crop production, to protect the environment from contamination by runoff and leaching of excess fertilizers, to aid in the diagnosis of plant culture problems, to improve the nutritional balance of the growing media and to save money and conserve energy by applying only the amount of fertilizer needed. Pre- plant media analyses provide an indication of potential nutrient deficiencies, pH imbalance or excess soluble salts. This is particularly important for growers who mix their own media. Media testing during the growing season is an important tool for managing crop nutrition and soluble salts levels. To use this tool effectively, you must know how to take a media sample to send for analysis or for in-house testing, and be able to interpret media test results.

Determining the pH and fertility level through a soil test is the first step in planning a sound nutrient management program. Soil samples from soilless mixes are tested differently than samples from field soil. There are three commonly used methods of testing soilless media using water as an extracting solution: 1:2 dilution method, saturated media extract (SME), and leachate Pour Thru. The values that represent each method of testing are different from each other. For example, 2.6 would be “extreme” (too high) for the 1:2 method, “normal” for SME, and “low” for leachate Pour Thru. Likewise, values for specific nutrients are likely to differ with testing methods. Always use the interpretative data for the specific soil testing method used to avoid incorrect interpretation of the results. See Table 2, Soluble salts levels determined by different methods of soilless media analysis.

Most fertilizers (except urea) are salts and when placed in solution they conduct electricity. Thus, the electrical conductivity (EC or soluble salts) of a substrate solution is indicative of the amount of fertilizer available to plant roots. In addition to carrying out a complete soil test, growers should routinely check the EC and pH of their growing media and irrigation water. These checks can be done onsite using portable testing meters, or samples can be sent to the University of Massachusetts soil test laboratory. Depending on the crop, and fertilizer practices, growing media should be tested at least monthly.

Sending the leachate solution collected from the Pour Thru method for laboratory analysis at least once during the growing season is a good idea, so that actual nutrient levels in the container can be determined and corrected if needed. The accuracy of EC and pH meters can also be checked by sending a leachate sample to the laboratory at least once during the growing season.

pH and EC Monitoring Equipment

Many horticulture supply companies carry pH and EC testing equipment, usually in the form of pens or meters. Most pens and meters are temperature-compensating; however, the instructions that come with the equipment will help growers determine if any adjustments are necessary related to environmental conditions. A buffer (standardizing) solution (pH 4 or 7) should be purchased with pH meters or pens. A standard solution should also be purchased with EC pens and meters to assure that equipment is calibrated and working properly.

Saturated media extract (SME)
SME is currently "the" method of testing soilless greenhouse media and it is almost universally done by commercial and university labs, including the UMass Soil and Plant Tissue Testing Lab. In this test a paste is made using soil and water and then the liquid portion (the extract) is separated from the solid portion for pH, soluble salt, and nutrient analysis. Special skills and laboratory equipment are required to perform this test. SME is probably not suitable for a grower to use unless the greenhouse operation is large enough to support a lab, a technically trained person is hired to carry out the tests, and there is a commitment to frequent testing and tracking of the results.

1:2 dilution method
This method has been used for many years and has good interpretative data to back it up. In this test an air-dried sample of soil and water are mixed together in the volume ratio of 1 part soil to 2 parts water (e.g., using a measuring cup, 1 fl. oz. of soil + 2 fl. oz. of water). The liquid extract is then separated from the solids using laboratory grade filter paper or a common coffee filter. The extract is then ready for analysis. This is a very easy test to master and quite suitable for on-site greenhouse testing of pH and soluble salt using meters available from greenhouse suppliers. The 1:2 method is a very good choice for occasional pH and soluble salts testing by growers on-site.

Leachate Pour Thru Method
In addition to collecting a soil sample to test, growers can collect leachate from container grown plants using the Pour Thru method. One of the major advantages to leachate pour thru is that there is no media sampling or preparation. Unlike SME and 1:2 methods, plants do not have to be sacrificed or disturbed for testing because the extract is the leachate collected from the container during routine irrigation. The leachate can be analyzed on-site using the pH and EC pens or it can be sent to a commercial laboratory for a complete nutrient analysis. In the reference section there is a fact sheet from North Carolina State University which provides detailed information on the leachate pour thru method or see:
http://www.ces.ncsu.edu/depts/hort/floriculture/Florex/PourThru%20Handout%20123s.pdf

Leachate pour thru is best used for continuous monitoring and graphical tracking of pH and soluble salts. To make this method work best an irrigation and leachate protocol must be established and carefully followed when sampling takes place. Leachate pour thru is not a good choice for casual checks (use 1:2 method for this). Unfortunately, with casual use, the "numbers" are often quite variable, inconclusive, and probably unreliable.

Sampling Instructions for Media Testing
A soil test can aid in the diagnosis of plant problems and in quality plant production. Sampling can be done at any time; but if pH adjustments are necessary, test as early as possible prior to planting. Avoid sampling soils that have been fertilized very recently. Follow instructions for specific testing methods.

Sampling for 1:2 and SME testing methods
The goal of sampling for a soil test is to efficiently collect samples which best represent the nutrient status of the crop or the problem to be diagnosed. The first step is to identify the crop unit(s) to be sampled - bench, greenhouse, etc. In a mixed greenhouse, crops of different species

must be sampled separately for the tests to have any value. If a problem is being diagnosed, it is best to have a sample from both normal and abnormal plants for comparison.

After selecting and recording the crop unit, take several samples of soil at root depth from several pots or from several areas of bag culture or bed (cut flowers, greenhouse vegetables) and mix it together in a clean container. Sampling in this fashion is important because a sample from one pot or flat could be an anomaly (values too high or too low) which does not represent the crop as a whole. Sampling and analyzing soil *separately* from 10 *different* pots would be the best way but also the most expensive way!

For the 1:2 and SME tests the actual soil sample is taken by either a core or composite sample from all depths in the pot or from the root zone only (i.e., portion where roots are most active). Never sample from just the surface 1-2" of the pot - nutrient and soluble salts levels will be always be much higher here than in the root zone and composite samples and, as a result, will overestimate fertility.

Sample about 2 hours after fertilizing or at least on the same day. If slow-release fertilizer pellets are present, carefully pick them out of the sample. If the pellets are left in, they can break during testing and this may result in an overestimation of fertility.

Finally, be consistent in all sampling procedures each time you sample. A lot of variability can be introduced to tests due to inconsistent sampling and this diminishes the value of testing especially if you are trying to track fertility.

Take about one cup of the soil mixture and dry at room temperature. Put the dry soil in a sandwich size zip-type bag and close it tightly. Identify each sample on the outside of the bag for your use. Complete and attach the "Greenhouse Media Submittal Form" available from http://www.umass.edu/umext/floriculture/grower_services/soil_testing.html with the following information:

- Name, address and phone number
- Is the sample from a newly-prepared mix or from a mix where a crop is currently being grown?
- Crop being grown, and crop age or development
- Is the sample a soilless mix? If so, what is the commercial brand?
- Does the sample have field soil in it?
- What fertilizer is in use, and what is the rate and frequency of application?
- Is this a routine sample to determine nutrient status or is it for a problem diagnosis?

Label the outside of the bag clearly with your name, address, and your name for the sample (ID).

Send the sample with payment to the University of Massachusetts Soil and Tissue Testing Laboratory, West Experiment Station, 682 North Pleasant Street, UMass, Amherst, MA 01003. For more information, see link to Soil and Tissue Testing Service under Resources.

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Soil samples from container crops can be tested onsite for pH and EC. For information, access the online fact sheet “How to Use pH and EC ‘Pens’ to Monitor Greenhouse Crop Nutrition”

http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/phecpens.html

Photo: Douglas Cox, UMass

Procedure for Collecting and Testing Leachate from Containers for Pour Thru Method

1. Irrigate your crop one hour before testing. Make sure the substrate is saturated. If the automatic irrigation system is variable, water the pots/flats by hand. If using constant liquid feed, irrigate as usual. If using periodic feeding (weekly, etc.): a) irrigate with clear water, b) test a day or two before you are to fertilize, and c) test on the same day in the fertilizing cycle each time. *Consistency is very important!*

2. Place saucer under container. After the container has drained for an hour, place a plastic saucer under the container

3. Pour enough distilled water on the surface of the substrate to get 1.5 oz of leachate. The amount of water needed will vary with container size, crop and environmental conditions. Use values in Table 1 as a guide.

Table 1. Amount of water to apply to various container to obtain 1.5 ounces (50 ml of leachate

Container Size	Water to Add: milliliters	Water to Add: ounces
4 inch 5 inch 6 inch	75	2.5
6.5 inch azalea	100	3.5
1 quart	75	2.5
1 gal.	150	5.0
Flats 606 (36 plants) 1203 (36 plants) 1204 (48 plants)	50	2.0
Containers should be brought to container capacity 30 to 60 minutes before applying these amounts. ***These amounts are estimates. Actual amounts will vary depending on crop, substrate type, and environmental conditions.*		

4. Collect leachate for pH and EC. Make sure to get about 1.5 oz (50 ml) of leachate each time. Leachate volumes over that amount will begin to dilute the sample and give you lower EC readings.

Either, send the leachate to a soil test laboratory or test the leachate on-site using a meter and following steps 5 and 6.

5. Calibrate your pH and EC meters prior to testing. The test results are only as good as the last calibrations. Calibrate the instruments every day that they are used. Always use fresh standard solutions. Never pour used solution back in the original bottle.

6. Measure pH and EC of your samples. Test the extracts as soon as possible. EC will not vary much over time provided there is no evaporation of the sample. The pH will change within 2 hours. Record the values on the charts specific to each crop.

Interpretation of a Soil Test Report

Interpreting a soil test involves comparing the results of a test with the normal ranges of pH, soluble salts, and nutrient levels set by the testing laboratory. Normal ranges are specific to the lab and its method of testing (Table 2). Some interpretation may be done for you, often by a computer program. Best interpretations take into account the crop, its age or stage of development, the growth media (soil or soilless media), the fertilizer program (specific fertilizer, rate, frequency of application) and any problems with the crop.

If used correctly, the three methods of soil testing outlined here give valuable and useful results for greenhouse crops. To optimize the value of soil tests, care in taking and describing the samples is very important.

Table 2. Soluble salts levels determined by different methods of soilless media analysis.

1:2	SME	PourThru	Indication
0-0.03	0-0.8	0-1.0	Very low
0.3-0.8	0.8-2.0	1.0-2.6	Low
0.8-1.3	2.0-3.5	2.6-4.6	Normal
1.3-1.8	3.5-5.0	4.6-6.5	High
1.8-2.3	5.0-6.0	6.6-7.8	Very high
>2.3	>6.0	>7.8	Extreme

pH or Soil Acidity

Most greenhouse crops can grow satisfactorily over a fairly wide pH range. What action to take on pH depends on the specific requirements of the plants being grown and knowledge of the factors which interact to affect the pH of the media. Limestone (rate, type, neutralizing power, particle size), irrigation water pH and alkalinity, acid/basic nature of fertilizer, and effects of mix components (container plants) are major influences on pH.

Optimum pH values have been established for soilless media and media with 20% or more field soil. Optimum pH values are shown in Table 3. The difference in optimum pH between the two types of growing media is related to pH effects on nutrient availability in each.

Table 3. Optimum pH Values	
	pH
Soilless media	5.5 - 6.0
Media with 20% or more field soil	6.2 - 6.5

Low pH (values below the optimum range) is the most common pH problem found in greenhouse growth media in Massachusetts. At low pH, Ca and Mg may be deficient. Low pH is also part of the cause of molybdenum (Mo) deficiency in poinsettia. Other trace elements such as iron and manganese may reach phytotoxic levels when pH is low (<5.8). Excess iron and/or manganese can be toxic to geraniums, New Guinea impatiens, and many bedding plants. Proper liming prior to planting is the best way to avoid low pH problems. As a general recommendation, growers should add no less than 5 lbs. of dolomitic limestone per yd^3 of growth medium. Greater amounts (8 to 10 lbs. per yd^3) of limestone may be needed depending on the materials used to make the medium, irrigation water pH and alkalinity, and acid forming tendency of the fertilizer in use. ***Do not add limestone to commercial brands of growth medium.*** It is much more difficult to raise pH after planting. To raise pH, try irrigating with a commercial "liquid limestone" product.

Electrical conductivity (EC)

Soluble salts are the total dissolved salts in the root substrate (medium) and are measured by electrical conductivity (EC). Measuring EC or soluble salts provides a general indication of nutrient deficiency or excess. A high EC reading generally results from too much fertilizer in relation to the plant's needs, but inadequate watering and leaching or poor drainage are other causes. Sometimes high EC levels occur when root function is impaired by disease or physical damage. ***Always check the condition of the root system when sampling soil for testing.***

The accompanying table shows the "normal range" of soluble salts levels for common greenhouse crops using the SME (saturated media extraction) method. Seedlings, young transplants, and plants growing in media containing 20% or more field soil are less tolerant of excess soluble salts. Soluble salts **above** the normal range for prolonged periods may cause root injury, leaf chlorosis, marginal burn, and sometimes, wilting. Soluble salts **below** the normal range may indicate the need for increased fertilization.

Soluble Salts Levels (mS/cm)	
	Normal range
Seedlings and young transplants	0.7-1.0
Established plants	
Soilless growth media	1.5-3.0
Growth media containing 20% or more field soil	0.8-1.5

Ammonium

Some ammonium in the fertilizer program is beneficial, but ammonium and urea should not exceed 50% of the total N supplied in soilless growing media. Excess ammonium can cause injury to most greenhouse crops and the occurrence of injury is highest in soilless growth media.

Calcium and Magnesium

In general the major source of calcium (Ca) and magnesium (Mg) is limestone, therefore low pH is often accompanied by low Ca and Mg. Many commercial water-soluble fertilizers supply no Ca and very little Mg. If the soil test indicates low Ca, levels can be increased by alternating application of calcium nitrate and the usual N fertilizer. If Mg is low, apply a solution of Epsom salts every 2 to 3 weeks. This solution is prepared by dissolving 2 to 3 lbs. of Epsom salts in 100 gallons of water.

Common Nutrient Problems

Excess soluble salts

High growth medium electrical conductivity (EC) can injure or inhibit the growth of young transplants. Use low rates (50-100 ppm N) for slowing-growing species in the one to two weeks following transplanting. Whenever a high EC problem occurs, check for root disease.

Iron/manganese toxicity

Fe/Mn Toxicity on Geraniums
Photo: Douglas Cox, UMass

Some crops, especially zonal geranium, and all types of impatiens are the most susceptible plants to iron (Fe)/manganese (Mn) toxicity. This disorder is sometimes called "bronze speckle" due to the appearance of numerous small brown spots on the leaves. Growth medium pH should be maintained in the recommended range by adequate liming prior to planting, careful selection of fertilizers with low potential acidity, pH monitoring, and the use of liquid limestone Preparations to raise pH after the plants are established in their containers. Some growers make a routine liquid limestone treatment once the plants are established after transplanting. Raising the pH (6.2-6.5) limits the availability of Fe and Mn and prevents toxicity. Consult the "iron out" nutrient management fact sheet from the University of New Hampshire, http://extension.unh.edu/Agric/AGGHFL/IRONOUT.pdf for more information on this problem.

Iron deficiency

Iron Deficiency on Petunia
Photo: Douglas Cox, UMass

Iron deficiency symptoms generally show up as an interveinal chlorosis, normally starting at the shoot tips, but often they occur throughout the entire plant. Sometimes the leaves of some Fe deficient plants turn almost white. Calibrachoa, scaevola, snapdragons, and petunias are the vegetative annuals most susceptible to iron deficiency. Preventing Fe deficiency can be accomplished by maintaining a low pH and using an iron chelate fertilizer.

Acid pH favors the availability of Fe to plants, therefore the target pH range for crops susceptible to Fe deficiency is fairly low, 5.5 to 6.0. Most commercial soilless media have pHs in this range and the use of an acid-forming fertilizer like 20-10-20 may be enough to keep the pH in this range. A major exception would be if the irrigation water is highly alkaline and then acid injection would be needed. If a grower mixes his/her own sphagnum peat-based growth medium dolomitic limestone should be added at a rate of no more than 5 lbs./yd. Too much limestone is a aggravating factor contributing to Fe deficiency.

Probably the least complicated way of preventing Fe deficiency is to fertilize with Fe chelate fertilizer from time to time. Most greenhouse supply companies carry Sprint 330® (10% iron), Sprint 138® (6% iron), or similar iron chelate products. Sprint 138®, however, is the preferred chelate if it is available. Sprint is generally applied as a soil drench at the rate of 8 oz./100 gal. (½-¾ tsp. gal.). The chelate is also soluble enough to make a concentrated solution for injection and low rates can be mixed and injected with other fertilizers. At the rate recommended here, Fe chelate can be applied every 3 or 4 weeks if desired.

References

Cox D.A. *Current Methods of Greenhouse Media Testing and How They Differ*. University of Massachusetts Extension.
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/ghmedia_tests.htm

Cox D.A. *How to Use pH and EC "Pens" to Monitor Greenhouse Crop Nutrition*. University of Massachusetts Extension.
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/phecpens.html

Cox D.A. 2001. *How to Prevent Iron Deficiency in Spring Greenhouse Crops*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/irondef.html

Fisher P.R. and W.R. Argo. 2001. *Iron-Out : A nutritional program for geraniums and other crops prone to iron and manganese toxicity at low media-pH*, University of New Hampshire,
http://extension.unh.edu/Agric/AGGHFL/IRONOUT.pdf

Whipker, B.E., Cavins, T.J. and W. C. Fonteno. *1, 2, 3's of PourThru*. North Carolina State University.
http://www.ces.ncsu.edu/depts/hort/floriculture/Florex/PourThru%20Handout%20123s.pdf

CHECKLIST
FERTILIZER STORAGE

- ✓ Store fertilizers separate from other chemicals in dry conditions.
- ✓ Extra care needs to be given to concentrate stock solutions. Secondary containment should be used.
- ✓ Provide pallets to keep large drums or bags off the floor. Shelves for smaller containers should have a lip to keep the containers from sliding off easily. Steel shelves are easier to clean than wood if a spill occurs.
- ✓ If you plan to store large bulk tanks, provide a containment area large enough to confine 125 percent of the contents of the largest bulk container.
- ✓ Keep the storage area locked and clearly labeled as a fertilizer storage area. Preventing unauthorized use of fertilizers reduces the chance of accidental spills or theft. Labels on the windows and doors of the building give firefighters information about fertilizers and other products present during an emergency response to a fire or a spill.
- ✓ Provide adequate road access for deliveries and use, and in making the storage area secure, also make it accessible, to allow getting fertilizers and other chemicals out in a hurry.
- ✓ Never store fertilizers inside a wellhouse or a facility containing an abandoned well.

FERTILIZER STORAGE AND HANDLING

Greenhouse fertilizer storage areas contain concentrated nutrients that must be stored and managed properly. Fertilizers can cause harm if they reach surface or ground water. Excessive nitrate concentrations in drinking water can cause health risks, especially in young children. Phosphorus can be transported to surface waters and cause algae blooms and eutrophication; resulting in poor water quality. Storing fertilizers separate from other chemicals in dry conditions can minimize these risks. Extra care needs to be given to concentrate stock solutions. Secondary containment should always be used.

Untimely application of fertilizer leads to excessive release from the production system to surface and/or ground water. Potential problems can be minimized through adequate environmental awareness, employee training, and emergency preparedness. Below are guidelines for properly storing and handling greenhouse fertilizers.

Storage Location

Greenhouse fertilizer storage areas contain relatively large quantities of concentrated chemicals. Risks in storage areas include release through broken, damaged, or leaking containers; loss of security leading to irresponsible use; accumulation of outdated materials leading to excessive quantity of fertilizer thus unnecessarily raising risk level; and combustion of oxidizing compounds in fertilizer (e.g., nitrates) caused by fire or another disaster event.

The least amount of risk involves having a building or area dedicated to fertilizer storage; separated from offices, surface water, neighboring dwellings and bodies of water; separate from pesticides and protected from extreme heat and flooding. The storage area should have an impermeable floor with secondary containment, away from plant material and high traffic areas. Clean-up equipment should be readily available.

Storage areas should not contain pesticides, or other greenhouse chemicals; storage areas may contain general greenhouse supplies; there should be no food, drink, tobacco products, or livestock feed present.

- Provide pallets to keep large drums or bags off the floor. Shelves for smaller containers should have a lip to keep the containers from sliding off easily. Steel shelves are easier to clean than wood if a spill occurs.
- If you plan to store large bulk tanks, provide a containment area large enough to confine 125 percent of the contents of the largest bulk container.
- Keep the building or storage area locked and clearly labeled as a fertilizer storage area. Preventing unauthorized use of fertilizers reduces the chance of accidental spills or theft. Labels on the windows and doors of the building give firefighters information about fertilizers and other products present during an emergency response to a fire or a spill. It is a good idea to keep a separate list of the chemicals and amounts stored. If a fire should occur, consider where the water used to fight the fire will go and where it might collect. For example, a curb around the floor can help confine contaminated water.

- Provide adequate road access for deliveries and use, and in making the storage area secure, also make it accessible, to allow getting fertilizers and other chemicals out in a hurry.
- Never store fertilizers inside a wellhouse or a facility containing an abandoned well.

Sound containers are your first line of defense against a spill or leak. If a container is accidentally ripped open or knocked off a shelf, the spill should be confined to the immediate area and promptly cleaned up. The building should have a solid floor and, for liquid fertilizers, a curb. The containment volume should be large enough to hold the contents of the largest full container.

Containers
Fertilizer should be stored in their original containers unless damaged; labels should be visible and readable; food or beverage containers should never used for storage. Labels should be in plain sight; no containers should come in contact with floor; all containers should be stored up-right; aisles should be wide enough to comfortably accommodate workers; containers should not be crowded on shelves or pallets.

Partially-used Containers
Paper bags and boxes should be opened with a box cutter or scissors; open containers should be resealed and returned to storage; all open paper bags should be sealed inside another, larger container, sealed and labeled.

Damaged Containers
Containers should be checked often for damage; when damaged containers are noticed, contents should be repackaged and labeled or placed in suitable secondary containment which can be sealed and labeled.

Containment
There should be no floor drain; the floor should provide containment in the event of a spill; there should be secondary containment routinely used for most open containers; damaged or leaking containers should be repaired and/or replaced as soon as possible; all spilled material should be cleaned up upon discovery; and cleanup materials should be discarded promptly and properly.

Fire Prevention and Suppression
Fire detection and alarm system should be present; oxidizers and flammable materials should be stored separately; fire extinguisher should be immediately available; the fire department should be notified at least annually of current inventory.

Inventory and Recordkeeping
Inventory should be actively maintained as chemicals are added or removed from storage; containers should be dated when purchased; outdated materials should be removed on a regular basis; inventory should be controlled to prevent the accumulation of excess material that may become difficult to use

Lighting
Electrical lighting should allow view into all areas and cabinets within the storage area.

Monitoring
There should be monthly inspection of storage for 1) signs of container corrosion or other damage - leaking or damaged containers should be repackaged as appropriate, 2) faulty ventilation, electrical, and fire suppression systems – problems should be reported and corrected.

Security
The storage room should be locked and access restricted to trained personnel.

Signage
There should be signs posted; warning signs should be used as needed; emergency contact information should be posted.

Temperature Control
There should be active mechanical temperature control and no direct sources of heat (sunny windows, steam pipes, furnaces, etc.).

Ventilation
Mechanical ventilation should be working and used.

Storage and Record Keeping
Fertilizer stock tanks should be labeled with fertilizer formulation and concentration; records should be kept of fertilizer formulation, concentration, date, and location of application; records should be kept of media nutrient analyses.

Containment of Concentrated Stock
Concentrated stock should be stored near the injector in high density polyethylene or polypropylene containers with extra heavy duty walls; secondary containment should be provided.

Disposal
Sufficient planning should be made to eliminate the need for disposal; empty fertilizer containers should be discarded based on latest advice from environmental protection authorities.

Precipitate and Residue Disposal
Fertilizer systems should be cleaned. Solids and rinse solution should be composted.

Spill Prevention and Preparedness
Opening fertilizer product containers, measuring amounts, and transferring fertilizer to the delivery system involves some level of risk from spills. Secondary containment should be used for fertilizer stock tanks routinely; spill clean-up materials should be used for liquids (e.g., absorbent materials) and solids (e.g., shovel, dust pan, broom and empty and/or buckets) should be available within the general area.

Delivery System
The fertigation equipment should be checked monthly for accuracy; containment tanks, back flow preventors and any equipment that holds fertilizer in the dry or liquid form should be inspected; stock tanks should be inspected weekly for deterioration and cracks; the manufacturer recommendations should be followed when calibrating or working on fertilizer injector equipment; stock solution tanks and the areas surrounding fertilizer injectors and concentrated solutions should be kept clean and free of debris.

References
AEM Tier II Worksheet, Fertilizer Storage & Handling in the Greenhouse, Agriculture Environmental Management (AEM)
http://www.agmkt.state.ny.us/SoilWater/aem/forms/Greenshouse%20Fertilizer%20Storage.pdf

Pesticide and Fertilizer Storage, United States Environmental Protection Agency
http://www.epa.gov/oecaagct/ag101/pestfertilizer.html

CHECKLIST
MASSACHUSETTS PROHIBITED PLANTS

- ✓ Do not grow or sell plants identified as either noxious and/or invasive. The Massachusetts Department of Agricultural Resources (MDAR) bans the importation and sale of more than 140 plants identified as either noxious and/or invasive in the Commonwealth.

- ✓ See the list of plant material (effective 1/1/06) that is in Appendix A and is also available on the MDAR website
http://www.mass.gov/agr/farmproducts/Prohibited_Plant_Index2.htm

- ✓ For more information, see *Strategic Recommendations for Managing Invasive Plants in Massachusetts*
http://www.mass.gov/dfwele/dfw/nhesp/conservation/pdf/invasive_plant_strategicplan.pdf

Purple loosestrife *Lythrum salicaria,* is a common invasive plant in Massachusetts.

Photo: Randy Prostak, UMass Extension

MASSACHUSETTS PROHIBITED PLANTS

The Massachusetts Department of Agricultural Resources (MDAR) bans the importation and sale of more than 140 plants identified as either noxious and/or invasive in the Commonwealth. The Department derives its authority to take this action under Massachusetts General Law including but not limited to, Chapter 128 Section 2 and sections 16 through 31A.

The list of prohibited plant material (effective 1/1/06) is in Appendix A and is also available on the MDAR website (http://www.mass.gov/agr/farmproducts/Prohibited_Plant_Index2.htm).

The Massachusetts Invasive Plant Advisory Group (MIPAG) represents numerous public and private interests working together since 1999 to develop an effective response to the problem of invasive plant species. The MIPAG offers its strategic recommendations to prevent, control and, where possible, eradicate invasive plant species in the Commonwealth of Massachusetts. These recommendations complement efforts at both the regional and national levels to establish an early detection and rapid response system for invasive plants.

Reference

Strategic Recommendations for Managing Invasive Plants in Massachusetts
http://www.mass.gov/dfwele/dfw/nhesp/conservation/pdf/invasive_plant_strategicplan.pdf

CHECKLIST
WORKER PROTECTION STANDARD

- ✓ Become familiar with the Environmental Protection Agency's (EPA's) Worker Protection Standard (WPS) which is a regulation aimed at reducing the risk of pesticide poisonings and injuries among agricultural workers and pesticide handlers.

- ✓ All agricultural employers, owners, and managers, as well as labor contractors, are required to comply with the WPS when pesticides with labeling that refers to the WPS have been used on an agricultural establishment.

- ✓ Consult the EPA Web site http://www.epa.gov/oecaagct/htc.html which provides information to help employers comply with the WPS, including a Quick Reference Guide, sample forms, fact sheets, and checklists. The document can be downloaded as one large file or in smaller sections by unit.

WORKER PROTECTION STANDARD

The Environmental Protection Agency's (EPA) Worker Protection Standard (WPS) is a regulation aimed at reducing the risk of pesticide poisonings and injuries among agricultural workers and pesticide handlers. The WPS contains requirements for pesticide safety training, notification of pesticide applications, use of personal protective equipment, restricted entry intervals following pesticide application, decontamination supplies, and emergency medical assistance.

All agricultural employers, owners, and managers, as well as labor contractors, are required to comply with the WPS when pesticides with labeling that refers to the WPS have been used on an agricultural establishment. Most WPS requirements apply to agricultural workers or pesticide handlers, but there are some requirements that apply to all persons and some that only apply to certain persons such as those who handle pesticide application equipment or clean pesticide-contaminated personal protective equipment. EPA's National Agriculture Compliance Assistance Center provides information and numerous resources to assist the regulated community with WPS compliance.

Implementation of the Worker Protection Standard

Implementing the WPS is a key part of EPA's strategy for reducing occupational exposures to agricultural pesticides. EPA has taken a number of steps to ensure effective national implementation and enforcement of the WPS regulation. EPA works closely with its state pesticide regulatory and extension partners to communicate WPS requirements to the regulated community and assure the regulation is being adequately implemented and enforced. State pesticide regulatory agencies, which have primary jurisdiction over pesticide use enforcement, have conducted thousands of WPS inspections nationwide, resulting in numerous enforcement actions for WPS violations. For additional information, please visit EPA's Office of Enforcement and Compliance Assurance Web page about national WPS inspection and enforcement accomplishments.

Certification and Training

To protect the health and safety of workers and handlers, employers are responsible for training them in the safe use of pesticides.

Certification and training regulations require pesticide applicators to meet certain training and/or testing requirements before they use or supervise the use of pesticides labeled "restricted use." In addition, the pesticide label indicates how a pesticide may be used and what protective clothing or other measures may be necessary for maintaining worker safety.

Training Manual

The *Worker Protection Standard for Agricultural Pesticides How To Comply Manual* provides detailed information on who is covered by the WPS and how to meet regulatory requirements. The updated manual will facilitate better protection from the potential risks of pesticides to pesticide workers and handlers in agriculture.

Reference
http://www.epa.gov/oecaagct/htc.html

CHECKLIST
PESTICIDE STORAGE, HANDLING AND DISPOSAL

- ✓ Limit the amounts and types of pesticides stored.
- ✓ Storage of pesticides should not be in basements or areas prone to flooding and should be accessible in the event of an emergency.
- ✓ The storage cabinets should be kept locked and the door to the storage area should be properly identified with a sign.
- ✓ Mixing should be avoided in areas where a spill, a leak or overflow could allow pesticides to get into water systems.
- ✓ Absorbent material such as re-usable gelling agents, vermiculite, clay, pet litter or activated charcoal should be on hand along with a garbage can and shovel to quickly contain and clean up any spills. The spilled pesticide should be contained - it should not be hosed down.
- ✓ Washing and rinsing of pesticide residues from application equipment, mixing equipment or other items used in storing, handling or transporting pesticides should occur on a pad.
- ✓ No pesticide application equipment or mix tank should be filled directly from any source waters unless a back siphon prevention device is present.
- ✓ Materials Safety Data Sheets for each pesticide should be posted in a prominent location.
- ✓ An emergency response plan should be developed. Such a plan lists actions to take and personnel to contact in the event of a spill or accident.
- ✓ An automatic smoke detection system or smoke and heat detection system should be installed. The appropriate fire prevention and emergency procedures should be devised in consultation with the local fire department. Suitable methods for extinguishing fires should be installed
- ✓ Personal protection equipment such as respirators, chemical resistant (CR) gloves, CR footwear, coveralls with long sleeves, protective eyewear, CR headgear, CR aprons and a first-aid kit should be available immediately outside the storage area.
- ✓ Rinse liquid pesticide containers three times when emptied. The rinse material should be poured into a spray tank and applied to a registered site. Triple-rinsed containers are considered non-hazardous and should be disposed of according to state recommendations.

PESTICIDE STORAGE, HANDLING AND DISPOSAL

The storage of pesticides is regulated under the **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)** http://www4.law.cornell.edu/uscode/7/ch6schII.html , which governs the sale, distribution and use of pesticides in the U.S. Pesticides are regulated under FIFRA until they are disposed, after which they are regulated under the **Resource Conservation and Recovery Act (RCRA)** http://www4.law.cornell.edu/uscode/42/ch82.html which ensures responsible management of hazardous and nonhazardous waste. Some, but not all, pesticides are regulated as hazardous waste when disposed. The Department of Transportation (DOT) regulates the transport of hazardous materials http://www.phmsa.dot.gov/hazmat . Some, but not all, pesticides are regulated as DOT hazardous materials while in commerce. The Massachusetts Department of Agricultural Resources has developed several guidance documents on storage, mixing and loading. The Department of Environmental Protection (MassDEP) regulates and provides guidance on hazardous waste disposal.

This section contains excerpts from "Pesticide Storage Mixing and Loading guidelines for applicators" http://www.mass.gov/agr/pesticides/waste/docs/mixload_medlarge.pdf from MDAR. For more information on pesticide storage and disposal see: http://www.mass.gov/agr/pesticides/waste/index.htm

Poorly stored pesticides and improper mixing/loading practices can present a potential risk to our health and to the integrity of the environment. The quality of surface water, groundwater and soil can be degraded in areas where pesticides are stored under inappropriate conditions, improperly mixed and loaded into application tanks and where equipment is washed and rinsed after application. Accidents involving spills or leakages may have serious health and environmental consequences. The purpose of this section is to provide guidance to individuals looking for information on appropriate techniques and approaches for the mixing, loading and storage of pesticides. It is important to remember that mixing, loading and storage needs will vary greatly from situation to situation and site to site. No document could specify exactly what approach should be taken in each situation. As such, it should be kept in mind that this document is intended as general guidance only. These recommendations are designed to assist pesticide users in managing their storage areas and conduct their mixing/loading operations in ways that will help minimize exposure to pesticides and reduce the risks to public health and the environment. These are not intended to be regulations and are not enforceable by any state or local agency.

Pesticide Storage

Safety is the key element in pesticide storage. The safest approach to any pesticide problem is to limit the amounts and types of pesticides stored. It is also important that the storage facility (cabinet, room, building, etc.) can be locked and can limit access to only those individuals who are properly trained in the use of pesticides.

Selecting a Storage Location

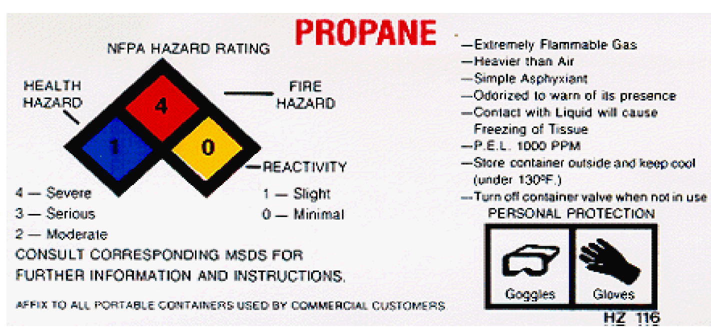
An existing or proposed area should be carefully evaluated to determine its suitability for pesticide handling and storage. In particular the potential harm to human health and the environment due to spills, contaminated runoff or fires should be assessed. Pesticide storage should be restricted to a first story room or area which as direct access to the outside (according to the Board of Fire Prevention). Pesticides cannot be stored in basements. Pesticides should not be stored outdoors.

If possible, the area should be located at least four hundred feet (preferably down hill or down gradient) from any public or private drinking water supplies and two hundred feet (preferably down hill or down gradient) from surface water. Separation from water resources should be greater in areas of sandy soil or fractured bedrock. Storage sites should not be located in areas prone to flooding. Runoff from adjacent areas resulting from a 25 year 24 hour storm should be diverted around the facility. The site location should be accessible in the event of an emergency situation. The pesticide storage area should be located away from direct sunlight, freezing temperatures and extreme heat.

Where practical, the mixing area should be located close to the storage facility to minimize the distance that chemicals are carried. Consideration should also be given to the additional area required by a mixing pad when selecting the site for storage.

Pesticides should be stored away from fertilizer, food, feed, potable water supplies, veterinary supplies, seeds and personal protective equipment to avoid contamination.

Storage Practices
The storage area should be properly identified with signs such as, "Pesticide Storage Area." In addition, a NFPA Hazardous Rating Placard (http://www.nfpa.org/faq.asp?categoryID=928) should be posted at entrances to the pesticide storage facility. These ratings are located in the Material Safety Data Sheets. Emergency responders will be able to make an assessment on how to respond to an incident (spill, fire, etc.) based on this placard.



A list (inventory) of the products being stored should be posted on the outside of the storage facility. It is also a good idea to have Material Safety Data Sheets for stored pesticides available in a location adjacent and/or outside of the storage facility.

Pesticides should be stored in accordance with their label requirements in their original container with the label clearly visible. Unless otherwise indicated on pesticide labels, temperatures in the storage area should be kept between 40F and 100F.

They should always be kept off the ground to prevent the accumulation of water in or under the containers.

Separation of pesticides by hazard and function is essential. Flammable pesticides should be stored separately from non-flammable pesticides, in a fire proof cabinet for example. Fungicides, herbicides and insecticides should be stored in separate locations of the storage area to prevent cross contamination and accidental misuse.

Dry pesticides should be stored separately from liquid pesticides to avoid wetting from spills. Particular care should be taken if storing phenoxy herbicides (such as 2,4-D and MCPA) due to their volatility. Pesticides shall not be stored in the same place as ammonium nitrate fertilizer (according to the Board of Fire Prevention).

Exposure to sunlight can cause chemical breakdown. Pesticides should not be stored in front of windows, unless the windows are covered. Extremes in temperatures can also lead chemical breakdown of stored pesticides. Because shelf life is difficult to predict, pesticides should not be stored longer than two years and therefore the purchase date can written on the pesticide container.

Storage of Medium Quantities of Pesticides Inside an Existing Building

For storage of medium quantities (less than 500 pounds or 220 gallons) of pesticides inside an existing building, metal cabinets work well. Metal cabinets should be double walled and constructed with 18-gauge sheet metal. Steel cabinets for storing hazardous materials such as pesticides are available commercially in different dimensions of various capacities. Capacities range from one gallon cans to five gallon cans and fifty five gallon drums. Frequently, cabinets feature built in secondary containment systems such as deep, leak-proof sumps. Wooden cabinets can also be used but should be constructed from 1" thick exterior grade plywood and finished with a chemically resistant product that permits easy cleanup. Shelves can be wooden (if finished with a chemically resistant product) or metal. The door sill to the cabinets should be high enough -at least 5"- to contain up to 5 gallons of spilled liquid. The cabinets should be locked at all times and identified as a place of pesticide storage. The cabinets should be located along an outside wall in an area away from extreme heat or freezing.

In the absence of cabinets, storage containers can be placed on impermeable shelves (steel or painted wood) with a lip to catch minor spills or leaks. Storing the containers in plastic leak proof trays to contain any leaks is recommended. Other options include spill containment pallets or floor pallets. Access should be unimpeded. Leaks should be detectable. If containers are in danger of leaking, they should be placed in an oversized plastic container or plastic lined (leak proof) cardboard box with vermiculite or other non flammable absorbent material for spill protection. Flammable pesticides should be stored separately from non-flammable pesticides in a fire proof cabinet.

For information on storage facilities for **large quantities of pesticides**, mixing/loading pads and other details see: Pesticide Storage Mixing and Loading guidelines for applicators, http://www.mass.gov/agr/pesticides/waste/docs/mixload_medlarge.pdf

Pesticide Mixing and Loading Sites

Mixing should be avoided in areas where a spill, a leak or overflow could allow pesticides to get into water systems. The mixing and/or loading of pesticides should not occur within four hundred feet of any private or public drinking water supply or two hundred feet of surface water. No pesticide application equipment or mix tank should be filled directly from any source waters unless a back siphon prevention device is present. Mixing should not occur on gravel or other surfaces that allow spills to move quickly through the soil.

Appropriate personal protective equipment (PPE) should be worn before opening a pesticide container. The label should be checked for Agricultural Use Requirements. PPE should include chemical resistant gloves and front protection such as a bib top apron made of butyl, nitrile, or foil laminate material. A face shield, shielded safety glasses or goggles should be worn. When pouring any pesticide from its container, container and pesticide should be kept below face level. A respirator will ensure protection against dusts or vapors. A tank should never be left unattended while it is being filled. If the pesticide user should splash or spill pesticides on his person, he should stop the operation, wash thoroughly with a mild liquid detergent and water, put on clean PPE and clean up the spill.

Guidelines for Mixing Safely

- Obtain the proper training before mixing pesticides. See section on pesticide licensing.
- Wear personal protection equipment specified on the label.
- Mix in a well ventilated area.
- Measure using appropriate scale or measuring cup.
- Ideally your waist should be even with the opening of the tank.
- Pour pesticide down the side of the tank to avoid splashing.
- Make sure you have a solid footing while pouring.
- Do your calculations prior to mixing.
- Mix during daylight hours if possible.
- Water supply is required to have a back flow prevention device - to prevent back flow into the water supply.
- Water should be carefully added to the pesticide mix by pouring down the side of the tank.
- Do not submerge the end of the water supply hose into the pesticide mix as it could back siphon. Pipe or hosing should be suspended over the opening of the tank
- Wash gloves before removing them.

All transfers of pesticides between containers, including mixing, loading and equipment cleaning, should be conducted over a spill containment surface designed to intercept, retain and recover spillage, leakage and wash water. Containment needs depend on the quantities of pesticides that are being mixed and loaded. If mixing small quantities, a tarpaulin can be sufficient to contain any spills. Spills can be then cleaned up with an absorbent material. If mixing large quantities regularly, the construction of a mixing/loading pad is an option to consider. The important point to keep in mind, whichever approach is used, is that incidental spills or accidental spills can be contained and cleaned up.

Absorbent material such as re-usable gelling agents, vermiculite, clay, pet litter or activated charcoal should be on hand along with a garbage can and shovel to quickly contain and clean up any spills. The spilled pesticide should be contained - it should not be hosed down. Absorbing materials should be used to soak up the pesticide which can then be shoveled into a leak proof drum. Portable rolls of sorbent materials can be used to contain the spill while the spill is soaked up.

Washing and Rinsing Operations

Washing and rinsing of pesticide residues from application equipment, mixing equipment or other items used in storing, handling or transporting pesticides should occur on a pad. In order to reduce the need to frequently wash the application equipment and to avoid cross contamination, application equipment should be dedicated for use for certain types of pesticides. For example, if a backpack sprayer is used only for applying herbicides it would not necessarily be washed after each use. On the other hand if the backpack sprayer was used to apply both herbicides and insecticides it would be necessary to always clean the equipment to avoid cross contamination.

Emergency Response Plan

An emergency response plan should be developed. Such a plan lists actions to take and personnel to contact in the event of a spill or accident. The plan should begin with a current listing of the pesticides used or stored at the facility and should include the following information:

- Names and quantities of pesticides;
- Location of the property including a map with directions;
- Names, addresses and telephone numbers of the owner and key employees;
- Plan of the facility showing pesticides locations, flammable materials, electrical service, water supply, fuel storage tanks, fire hydrants, storm drains, and nearby wetlands, ponds, or streams;
- Location of emergency equipment supplies including breathing equipment and protective equipment; Copies of the emergency response plan should be located near the entrance to the pesticide facility and with business records. Copies should also be given to the local police department and fire department. Contacts should include the following: fire department; police; spill clean up firm; nearest hospital; MDAR Pesticides Program; board of health; owner of the facility. The plan should be available in both English and the language or languages understood by workers if this is not English.

Fire Prevention

An automatic smoke detection system or smoke and heat detection system should be installed. The appropriate fire prevention and emergency procedures should be devised in consultation with the local fire department. Suitable methods for extinguishing fires should be installed, such as the appropriate type and number of fire extinguishers. The number and placement of fire extinguishers should conform with the National Fire Protection Association (NFPA) Standard No. 10. All electrical fixtures and appliances should be non-sparking units approved for use in facilities storing flammable and combustible liquids. In the event of a fire it is frequently more environmentally sound to allow the fire to burn itself out if it can be contained within the area. This avoids the likelihood of pesticides being released into the ground as a result of water being added.

Personal Safety

Personal protection equipment such as respirators, chemical resistant (CR) gloves, CR footwear, coveralls with long sleeves, protective eyewear, CR headgear, CR aprons and a first-aid kit should be available immediately outside the storage area. The first-aid kit should include the following items: adhesive strips, tape, eye pads, gauze bandages and tweezers. The phone number 800-222-1222 for the Poison Control Center should be posted in a prominent location.

It is essential that protective eyewear be worn during mixing/loading. The protective eyewear should consist of safety glasses that provide front, brow and temple protection, goggles or a face shield. Workers should be instructed in the correct procedure for the removal of contaminated clothing. Eye wash stations or portable eye wash bottles should be easily accessed by each person engaged in the operation and should be capable of flushing eyes for a minimum of fifteen minutes. At a minimum, a hose and nozzle should be on hand. Routine wash up facilities, equipped with soap, hand cleanser and single use paper towels should be available near the storage area.

Pesticide Spills and other Accidents

An absorbent material such as re-usable gelling agents, vermiculite, clay, pet litter or activated charcoal should be on hand along with a garbage can and shovel to quickly contain and clean up any spills. All discharges to the environment or spills should be recorded. The records should include the date and time of the incident and the cleanup. The Massachusetts Department of Agricultural Resources must be notified within 48 hours if a pesticide spill leads to pollution.

Site Security

The storage cabinets should be kept locked and the door to the storage area should contain a weather proof sign warning of the existence and danger of pesticides inside. The door should be kept locked. The sign should be visible at a distance of twenty five feet and can contain a notice such as:

DANGER PESTICIDE STORAGE AREA, ALL UNAUTHORIZED PERSONS KEEP OUT, KEEP DOORS LOCKED WHEN NOT IN USE

The sign should be posted in both English and the language or languages understood by workers if this is not English.

Pesticide Disposal

Proper disposal of pesticides and their containers is an important phase of pesticide management. An improperly disposed product can be hazardous to people and the environment. Rinse liquid pesticide containers three times when emptied: fill the containers about one-third full and swish it around. Allow the containers to drain well between each rinse (30 or more seconds). The rinse material should be poured into a spray tank and applied to a registered site. Triple-rinsed containers are considered non-hazardous and should be disposed of according to state recommendations. Never reuse an empty pesticide container. If an empty triple-rinsed container cannot be disposed of immediately, store it in a safe, locked area. Before throwing out powders or granular pesticide containers, be sure to remove all contents from the containers.

Plan ahead in preparing spray mixtures! Mix only the amount of pesticide you need to do the job. Left over spray mixture needs to be applied according to the label instructions. When cleaning equipment be sure rinse water will not collect or contaminate groundwater or surface water.

A pesticide product that can no longer be used according to the label instructions because it is no longer registered (or for some other reason) is considered hazardous waste. Applicators are advised to use pesticides in the same year of purchase and to store pesticides properly in order to avoid the accumulation of unusable pesticide products. For current state regulations on pesticide

disposal, contact the Massachusetts Department of Agricultural Resources, 617.626.1771.
http://www.mass.gov/agr/pesticides/waste/index.htm

Pesticide Transportation
Depending on the hazard and the quantities of pesticides and hazardous materials (fertilizers, fuel, etc.) being transported, drivers may need to obtain a Massachusetts Commercial Driver's License with HazMat and/or Tank Endorsements (please refer to MassRMV website http://www.mass.gov/rmv/license/8cdl.htm#applying). There may be additional requirements for placards, training, and record keeping under the Federal Transportation Regulations (please refer to MDAR website http://www.mass.gov/agr/pesticides/waste/index.htm)

At a minimum the following checklist can be helpful for transporting pesticides

Driver is a licensed or certified pesticide applicator
Inspect vehicle for leaks or other problems
Pesticide containers secured in place
Pesticide containers stored in a dry and lockable portion of the vehicle but not in the same compartment of driver
Binder of pesticide labels and MSDS
Emergency phone numbers
First aid kit
Fire Extinguishers
Cleaning up supplies for spills (kitty litter, shovel, plastic bags, etc)
PPE (gloves, goggles, coveralls, etc)
At least 5 gallons of potable water for emergency eye or skin decontamination
Obey all traffic laws and use signals

References
Pesticide Storage Mixing and Loading Guidelines for Applicators
http://www.mass.gov/agr/pesticides/waste/docs/mixload_medlarge.pdf

Pesticide storage and disposal state regulations: Massachusetts Department of Agricultural Resources
http://www.mass.gov/agr/pesticides/waste/index.htm

CHECKLIST
PESTICIDES AND GROUNDWATER PROTECTION

- ✓ Extra precautions should be taken to protect ground water in areas where it is close to the soil surface.
- ✓ When using any pesticide product, follow label directions to minimize its environmental impact.
- ✓ Mixing areas should be over an impervious surface to prevent a spill from soaking into unprotected soil.
- ✓ Measure concentrated pesticides carefully and accurately.
- ✓ Never leave a tank while it is being filled.
- ✓ Calibrate spray equipment to use the right amount of product on the crop. Over application increases the risk of contaminating water.
- ✓ Maintain spray equipment. Check all nozzles for possible clogs. Clean equipment inside and out by triple rinsing and dispose of rinsate according to label instructions.
- ✓ Know where the wells are located and condition of the well. Know the depth to groundwater and where surface water and make plans for protecting them.

PESTICIDES AND GROUNDWATER PROTECTION

Many factors affect pesticide persistence and movement in soils. These factors should be considered when developing a pest management strategy, in order to protect both crops and our ground and surface water resources.

Most pesticides detected in ground water are those which are incorporated into the ground soil rather than those sprayed onto growing crops. Pesticides reach groundwater through runoff and leaching. Runoff carries pesticides over the ground in rain or irrigation water. Runoff is the movement of chemicals in water over a sloping surface. Runoff can carry pesticides mixed in water or bound to eroding soil. In addition, pesticides can move from the point of application by volatilization and plant uptake.

Leaching pesticides can move with the infiltrating water through the soil profile to the water table. The closer the water table is to the surface, the greater is the risk that it may become contaminated. In some situations, pesticides that are tightly bound to the soil may only move a few inches from the point of application regardless of the amount of infiltrating water, while in other situations pesticides have been shown to move many feet. Pesticides that are highly water soluble, relatively persistent, and not readily adsorbed by soil particles have the greatest potential for movement. In addition, relatively sandy soils that are low in organic matter are the most vulnerable to groundwater contamination due to their lower adsorptive capacity and higher infiltration rates.

There are several factors that determine the likelihood of a pesticide reaching surface or ground water: The properties of the pesticide, properties of the soil, conditions of the site and pesticide management practices.

Properties of Pesticides

Solubility

Some pesticides are more soluble in water than others. Highly soluble pesticides have a greater tendency to move by runoff or leaching from the point of application.

Degradation

Pesticide persistence is usually expressed in terms of half-life, which is the typical length of time needed for one-half of the total amount of chemical applied to break down to non-toxic substances. Sunlight, temperature, soil and water pH, microbial activity and other soil characteristics may affect the breakdown of pesticides. Microbial degradation is the breakdown of chemicals by microorganisms. Soil organic matter and soil properties such as moisture, temperature, aeration, and pH all affect microbial degradation. Weather is also an important factor, as it affects both the persistence and movement of pesticides. Rainfall and irrigation can move surface-applied pesticides into the soil. The longer a pesticide persists in the environment, the longer it is subject to movement deeper into the soil profile.

Adsorption

Adsorption is the binding of chemicals to soil particles. Pesticide adsorption varies with the properties of the chemical, as well as the soil's texture (relative proportions of sand, silt and clay), moisture level and amount of organic matter. Soils high in organic matter or clay tend to be most adsorptive and sandy soils low in organic matter tend to be least adsorptive.

Volatility

Highly volatile chemicals are more likely lost to the atmosphere than to water supplies. However, highly volatile compounds may contaminate water if they are also highly soluble.

Properties of Soil

Soil Texture

The proportions of sand, silt and clay in the soil affect the movement of dissolved pesticides through soil. Soils with more clay and organic matter tend to hold water and dissolved chemicals longer. Pesticides have a greater chance of reaching ground water through coarse textured, sandy soil. Clay soils are more prone to rapid runoff – leading to surface water contamination.
Soil Permeability – The measure of how fast water can move downward through a particular soil is called soil permeability. High permeability soils lose dissolved chemicals with the percolating water.

Organic Matter

The content of organic matter in soil influences how much water a soil can hold, and how well it will be able to adsorb pesticides. Increasing the soil's organic content increases the soil's ability to hold water and dissolved pesticides in the root zone, to be available to plants and subject to eventual degradation.

Site Conditions

Site conditions should be considered to protect groundwater supplies.

Depth to Ground Water: The shallower the depth to ground water, the less soil there will be to impede the flow of contaminants and fewer opportunities for degradation or adsorption of pesticides. Growers should take extra precautions to protect ground water in areas where it is close to the soil surface.

Geologic Conditions: The permeability of the geologic layers between the soil and ground water such as gravel deposits, allow water and dissolved pesticides to percolate downward to ground water. Layers of clay are less permeable and inhibit the movement of water. Ground water quality is most vulnerable in areas where permeability of geologic layers is rapid.

Climate: High rates of rainfall or irrigation may result in large amounts of water percolating through the soil and are highly susceptible to pesticide leaching and contamination caused by runoff.

Handling Practices

When using any pesticide product, follow label directions. The label provides important instructions for obtaining the greatest benefit from the product and minimizing its environmental impact. Label directions include proper mixing and application, as well as pesticide storage and disposal.

More pesticide spills happen while measuring and mixing pesticides than in any other phase of application. Make sure mixing areas are over an impervious surface such as concrete to prevent a spill from soaking into unprotected soil. Measure the concentrate carefully and accurately. Never leave a tank while it is being filled. Overfilling the tank and spilling pesticide out on the ground can easily be prevented.

Calibrate spray equipment. Accurately calibrating application equipment is vital to spraying the right amount of product on the crop. Over application increases the risk of contaminating water. It may also overload the protective mechanisms of degradation, adsorption and result in water contamination.

Maintain spray equipment. Application equipment should be tested frequently to determine if it is working properly. A trial run with plain water helps to determine the spray pressure needed to cover a specific area at the labeled rate. Check all nozzles for possible clogs. After each use, clean equipment inside and out by triple rinsing and dispose of rinsate according to label instructions.

Knowledge of the site and application methods are helpful for preventing water contamination. Know where the wells are located and condition of the well. Know the depth to groundwater and where surface water is located. After identifying these factors, make plans for protecting them.

References

Newman, J. 2008. *Greenhouse and Nursery Management Practices to Protect Water Quality,* University of California Agriculture and Natural Resources Publication 3508.

Clean and Green, Water Quality Action Manual for Greenhouse and Nursery Growers, 1992 Horticultural Water Quality Alliance. Printed by Florists' Mutual Insurance Company.

Jenkins J. and T. Smith. 1989. *Understanding Pesticide Persistence and Movement in Soils for Groundwater Protection.* Nursery Notes: 2(1).

CHECKLIST
PESTICIDE LICENSING

- ✓ A Massachusetts Pesticide License issued by the Massachusetts Department of Agricultural Resources (MDAR) is required in Agriculture when an individual is going to use a Restricted Use Pesticide (RUP). If an individual is using a General Use Pesticide, then he/she does not need to have a pesticide license. However, that individual would need to be trained as a handler to comply with the Worker Protection Standard.

- ✓ An individual making a restricted use pesticide application for greenhouse crop production, would need to obtain a Private Certification License.

- ✓ For information about how to obtain a Massachusetts pesticide license or certification contact the MDAR Pesticide Bureau at http://www.mass.gov/agr/pesticides or call (617) 626-1785.

- ✓ If needed, attend optional 2-day workshops held by the UMass Extension Pesticide Education program. The workshops are designed to help individuals prepare for the pesticide applicator license exam. Preregistration is required. For information contact the UMass Extension Pesticide Education Program at http://www.umass.edu/pested/ or call (413) 545-1044.

PESTICIDE LICENSING

"General use" pesticides are chemicals that can be purchased and used by the general public. "Restricted use pesticides" are chemicals that can be purchased and used only by certified and licensed pesticide applicators.

A Massachusetts Pesticide License issued by the Massachusetts Department of Agricultural Resources (MDAR) is required in Agriculture when an individual is going to use a Restricted Use Pesticide (RUP). If an individual is using a General Use Pesticide, then he/she does not need to have a pesticide license. However, that individual would need to be trained as a handler to comply with the Worker Protection Standard.

In greenhouse production, the individual making the Restricted Use Pesticide Application would need to obtain a Private Certification License. There are several categories associated with this type of license and the individual would need to pick the appropriate category depending on the type of Agriculture facility. For example an individual who is applying an RUP in a greenhouse would get a Private Certification License with a Category in Greenhouse (#26).

In accordance with the Massachusetts Pesticide Control Act and the current pesticide regulations, the MDAR conducts written examinations to measure competency to use, sell, and apply pesticides in Massachusetts. Information about how to obtain a Massachusetts pesticide license or certification is available from the MDAR Pesticide Bureau Web site http://www.mass.gov/agr/pesticides or by calling (617) 626-1785.

Optional 2-day workshops by the UMass Extension Pesticide Education program are designed to help individuals prepare for the pesticide applicator license exam. Preregistration is required. For information contact the UMass Extension Pesticide Education Program at http://www.umass.edu/pested/ or call (413) 545-1044.

Frequenty Asked Questions

Each year, the Massachusetts Department of Agricultural Resources (DAR) receives numerous questions on the pesticide licensing requirements. It is important to remember that the licensing requirements for Agriculture are different from the requirements for the commercial industry such as Structural Pest Control and/or Landscapers. Below are some commonly asked questions about the Agriculture license requirements.

When do I need to get a Massachusetts Pesticide License?

A Massachusetts Pesticide License is required in Agriculture when an individual is going to use a Restricted Use Pesticide (RUP). If an individual is using a General Use Pesticide, then he/she does not need to have a pesticide license. However, that individual would need to be trained as a handler to comply with the Worker Protection Standard.

What kind of license is needed?

The individual making the Restricted Use Pesticide Application would need to obtain a Private Certification License. There are several categories associated with this type of license and the individual would need to pick the appropriate category depending on the type of Agriculture facility. For example an individual who is applying an RUP in a greenhouse would get a Private Certification License with a Category in Greenhouse (#26).

If I have a Private Certification license can I supervise someone without a license to make a Restricted Use Pesticide application?
No. In order to "supervise" an RUP application, the individual making the application would need to have the Commercial Applicators License (commonly referred as the Core license). This does not occur very often in Agriculture, because an individual without a license is able to take the Private Certification exam immediately without a two year waiting period. In other words, an application of an RUP cannot be done by someone without a license (supervised or not).

How many credits do I need in order to maintain my license?
To maintain a Private Certification license, the license holder needs to obtain 12 Continuing Education Units (CEU) during their three year cycle. It is also important to remember that an individual needs 12 credits for each category. For example, if an individual has a Private Certification license with two categories (greenhouse & tree fruit) he/she would need 24 credits in total.

How do I know when my three year cycle resets?
When you receive your new license each year, you cycle is listed on the card the license come in.

Do I need to send in my CEU's when I receive them?
No. Hold onto your CEU's and only send them into the Department if you receive an audit letter asking for them.

What is the "E-Licensing"?
E-Licensing will hopefully streamline and quicken the licensing process. When complete, an individual will be able to do the following on line:

Sign up and pay for the exam
Check their license status
Renew license
Obtain a "temporary" two week license immediately after passing the test

I have heard that the Private Certification categories are changing is that true?
Yes. The Department along with the University of Massachusetts Extension Services is currently working on new study materials and new exams for the Private Certification Licenses. This will also include combining some categories that are closely related and eliminating some categories that are no longer relevant. The Department will notify existing license holders of this change when it is complete.

If anyone has a question in regards to their license, please call the Department at (617) 626-1700 and ask for someone in the licensing division and someone will help you.

Reference
http://www.mass.gov/agr/pesticides

CHECKLIST
INTEGRATED PEST MANAGEMENT

- ✓ Before introducing a crop into a greenhouse remove weeds, algae, “pet plants,” and any plant and growing medium debris located throughout the greenhouse.

- ✓ Repair any drainage problems that may contribute to recurring arthropod pest outbreaks.

- ✓ Review previous pest problems and current pesticide application methods and make a note of crops growing in adjacent greenhouses or outdoors.

- ✓ Consider how the variety of plants to be grown in the same area may influence ease of pesticide applications and spread of disease.

- ✓ Inspect incoming stock as soon as possible after arrival and before plants are moved into production areas for the presence of insects, mites, diseases, or cultural problems. If feasible, quarantine infested or problematic plants in an isolated greenhouse or area so they can be treated with a pest control material before they are placed in production areas.

- ✓ Scout propagation areas at least every 3 to 4 days.

- ✓ Wash hands thoroughly or wear disposable gloves and discard them after handling any plants suspected of being diseased as poor sanitation during scouting can spread pathogens.

- ✓ Use yellow sticky cards to monitor flying pests.

- ✓ Change the cards weekly, and place new cards in the same areas of the greenhouse to track pest trends.

- ✓ Use potato disks to monitor fungus gnat larvae.

- ✓ Use indicator plants to determine the efficacy of pest management tactics and to monitor susceptible crops for the viruses (tospoviruses) such as impatiens necrotic spot virus (INSV) and tomato spotted wilt virus (TSWV).

- ✓ Correctly identify pests and beneficials on sticky cards and plants. Record pest numbers, location within the greenhouse, and the number of plants inspected.

- ✓ Each week, review the scouting records to assess the effectiveness of those pest management tactics being implemented.

- ✓ Review scouting records at the end of each growing season to determine which pests were problems and which pest management strategies worked.

INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) is a strategy that prevents pest damage with minimum adverse impact on human health, the environment and non-target organisms. The term "pest" refers to more than one cause of problems including diseases, undesirable insects, mites, mollusks, nematodes and weeds. In IPM programs, growers use their knowledge of crop and pest biology to take actions that reduce the environment's suitability for pest establishment and increases in pest populations. IPM employs careful monitoring techniques and combinations of biological, cultural, mechanical, chemical and environmental or physical control. Pesticides are used only if monitoring indicates that they are needed. If pesticides are necessary, they are chosen and applied in a way that avoids disrupting other IPM practices.

Successful IPM programs have five key components:

- Prevent problems
- Regularly monitor crops and growing areas
- Accurately diagnose problems
- Develop control action thresholds and guidelines
- Use effective management methods

Prevent Problems

Many crop problems can be anticipated and avoided. Prevention is often least expensive and most effective, and sometimes the only control option available. By the time plants begin to appear unhealthy, many problems cannot be cured, and the crops may have already been seriously damaged. Key pest prevention techniques include:

- Planning your crop production and IPM program in advance
- Using good sanitation and exclusion
- Properly managing the environment
- Cultural practices.

Greenhouse Preparation and Scouting

Before introducing a crop into a greenhouse it is imperative to remove weeds, algae, "pet plants," and any plant and growing medium debris located throughout the greenhouse, particularly underneath benches, because these provide refuge for arthropod pests. In addition, repair any drainage problems that may contribute to recurring arthropod pest outbreaks. Crops growing in adjacent greenhouses or outdoors should be recorded.

Previous pest problems in the greenhouse and current pesticide application methods should be reviewed. A plan of action may then be developed to eliminate these problems prior to the arrival of the crop. Prevention of key pest problems may be more easily accomplished if the grower and scout take the time to identify, analyze and correct problems before crops are introduced. Also, consider how the variety of plants to be grown in the same area may influence ease of pesticide applications and spread of disease. For example, keep seedling and cutting geraniums separate to help minimize spreading bacterial blight. Keep propagation houses separate from other growing areas, and vegetable transplants separate from ornamentals to help reduce the incidence of Impatiens Necrotic Spot Virus when western flower thrips are present.

Inspect Incoming Plants

Monitoring, also called scouting, is the regular, systematic inspection of crops and growing areas. A regular monitoring program is the basis of IPM decision making, regardless of the control strategies used. By regular monitoring, a scout is able to gather current information on the identity and location of pest problems and to evaluate treatment effectiveness. An IPM scout can be the grower, an employee, a professional consultant or pest control advisor.

Inspect incoming stock as soon as possible after arrival and before plants are moved into production areas. Look for the presence of insects, mites, diseases, or cultural problems such as nutritional deficiencies. If feasible, quarantine infested or problematic plants in an isolated greenhouse or area so they can be treated with a pest control material before they are placed in production areas.

Scouting Guidelines

Small greenhouses (< 4,000 sq.ft.) can be scouted as one unit. Larger greenhouses should be divided into 2,000 to 3,000 sq. ft. sections for ease of scouting. Scout propagation areas at least every 3 to 4 days. In many cases there are no specific requirements for how many locations or plants to be monitored. The number of plants inspected will depend on factors such as the value of the crop, potential problems and size and type of greenhouses. The more plants or locations inspected, the more likely the sooner a problem will be detected, when management is easiest. In practice, scouting is a compromise between thoroughness (examining everything), efficiency (putting limited time to the best use), and cost (the value of improved management information). Sampling a predetermined number of each crop increases the likelihood of locating "hot spots," which are areas with high arthropod pest populations. Take advantage of previous experience by focusing on plant species that tend to be susceptible to arthropod pests.

One way is to spend a predetermined amount of time per area of growing space, such as 5 to 10 minutes for each 1,000 square feet of growing area, inspecting 20 or more randomly chosen plants. In addition to random selection, targeted scouting is a way to assess anticipated problems or problems that are known to exist. One approach is to use a combination of random and targeted scouting. Use each method to sample the same proportion of plants each week. For example, one-third of the plants could be randomly selection, while the other two-thirds are known or suspected to have problems.

Scouting should begin at the major doorway, which is usually an entry point of pests. Special attention should be paid to plants around any openings in the greenhouse. Scouts should walk every aisle and move from bench to bench in a snake-like manner. Plants should be inspected on every bench. Examine plant parts in a systematic manner. For example, begin with buds or flowers, then inspect new growth, younger leaves, older leaves and finally basal stems. Examine leaf axils and the tops and bottoms of leaves. Many pests prefer the undersides of leaves or inner, protected plant parts. Use a 10X, 5X or 20X hand lens to facilitate observation. If the plants are small, the sample unit may be an entire plant; for larger plants the sample unit may be a set number of shoots and leaves, such as 2 to 6 per plant. Hanging pots should also be inspected.

For at least several plants in each section, examine roots for root decay, root-feeding insects or other problems. Follow the same pattern of inspecting each plant every time. Wash hands thoroughly or wear disposable gloves and discard them after handling any plants suspected of being diseased as poor sanitation during scouting can spread pathogens.

Yellow sticky cards

Yellow sticky cards are commonly used in greenhouses to monitor winged pest populations. These cards capture adult whiteflies, thrips, fungus gnats, shore flies, leafminers, and winged aphids. Mites, mealybugs, scales, and non-winged aphids do not fly, so they are not captured on sticky cards.

Yellow sticky card used to detect flying insects.
Photo: Tina Smith, UMass Extension

Each yellow sticky card should be numbered and cards positioned throughout the greenhouse in a grid pattern. Use approximately 3–4 cards per 1,000 ft^2, or a minimum of one card per 1,000 ft^2, with additional cards placed near openings such as doors, vents, and sidewalls. Use clothespins and stakes to vertically attach sticky cards just above (4–6″ or 10–15 cm.) the crop canopy. As plants increase in height, move the sticky card upward (vertically) on the stake. Blue sticky cards are also attractive to thrips (and even shore flies) and may be used to detect low thrips populations on susceptible crops (e.g., impatiens and begonias). However, thrips and other insect pests captured on yellow sticky cards are easier to observe than on blue sticky cards. When monitoring for fungus gnat adults, place yellow sticky cards horizontally or flat, near the growing medium surface because more fungus gnat adults will be captured compared to placing sticky cards vertically above the crop canopy.

Change the cards weekly, and place new cards in the same areas of the greenhouse to track pest trends. Brief, concise and accurate information is one of the best tools available to make a pest management decision. Identify and record pest numbers. Over time, population trends will emerge and provide direction for your pest management program.

Potato disks

Potato disks are used to monitor for fungus gnat larvae. Cut a fresh potato into disks 1″ (2.5 cm.) in diameter and ¼–½″ (0.6 to 1.2 cm) in thickness; then press the disks into the growing medium in tagged or flagged pots. For plug trays, potatoes may be cut into small “French fry” shapes or wedges and inserted into the growing medium. In general, use 5–10 potato wedges per 1,000 ft^2 of greenhouse production area. After two days, inspect the undersides of the potato disks and/or wedges for the presence of fungus gnat larvae, which have distinct black head capsules. Record the number of larvae located on each potato disk or wedge, and those present on the surface of the growing medium.

Indicator plants
Indicator plants are typically used to determine the efficacy of pest management tactics or to monitor for the viruses (tospoviruses) such as impatiens necrotic spot virus (INSV) and tomato spotted wilt virus (TSWV) vectored by the western flower thrips (*Frankliniella occidentalis*). Before implementing any pest management strategy, select and tag (or flag) the leaves or stems of 1–5 infested plants per 1,000 ft^2. The tagged plant allows the scout to easily recognize it from a distance. After implementing any pest management tactic, inspect the indicator plants to assess if arthropod pests have been killed and evaluate the effectiveness and longevity of control.

The detection of the viruses transmitted by thrips involves the use of either dwarf fava bean (*Vicia faba*) plants or 'Summer Madness' petunias. Position a blue card with the sticky portion covered near the indicator plants in order to attract adult thrips. Blue plastic picnic plates (photo) cut in half work well in place of a sticky card to attract adult thrips. If thrips adults possess any tospovirus, a brown, necrotic spotting will be observed near white feeding scars on the plants within 48 hours. Rogue out any infected petunia or fava bean plants so as to remove any potential virus sources. Virus infections are systemic in fava bean but not petunia.

Petunia used as an indicator plant for INSV.
Photo: Tina Smith, UMass Extension

Pest Identification
Pest management decisions are initially based on correct/accurate identification and understanding of the insect or mite pest's life cycle (egg to adult). Effective pest management depends on a greenhouse grower's ability to determine which life stages are present and which are susceptible to available pest management tactics. For example, spraying a pest control material (in this case an insecticide) to manage whiteflies is most effective when they are in the nymphal stages. Misidentification of arthropod (insect or mite) pests or their life stages can be costly and lead to inadequate control such that arthropod pest populations increase to levels that cause crop damage. Arthropod pest identification can be improved by participating in state-wide workshops and integrated pest management (IPM) training programs; by referring to manuals, picture guides and fact sheets; by accessing web-based resources such as the images found on the New England Greenhouse Update Web site (www.negreenhouseupdate.info) or by using a text and image search engine such as Google (www.google.com); and by submitting specimens to an Extension entomologist. USDA Systematic Entomology Laboratory (SEL) provides specimen identification assistance as a free service. For information on sending samples see: http://www.ars.usda.gov/Main/docs.htm?docid=9353&pf=1&cg_id=0

Record Keeping and Decision Making
Each time the crop is scouted, record arthropod pest numbers, location within the greenhouse, and the number of plants inspected. Record arthropod pest counts by date, in a notebook or on a form so as to track population trends over time. Sample scouting forms are available online at the University of Massachusetts Web site

www.umass.edu/umext/floriculture/fact_sheets/pest_management.html. Data on arthropod pest abundance, location within the greenhouse, and population trends (increases, decreases, or stable) help determine the effectiveness of pest management tactics.

Each week, review the scouting records to assess the effectiveness of those pest management tactics being implemented. Early detection of arthropod pests helps prevent the need to deal with extensive populations that may cause crop damage. Pest numbers recorded from sticky card counts and foliar inspections, the use of indicator plants, and located reservoirs of pests will help to prioritize a pest-management strategy.

When problems are detected early, better pesticide coverage may be achieved due to a smaller canopy, and problem areas can be identified and treated, reducing the need for blanket pesticide applications. Also, "green pesticides" and biologicals may be more successfully incorporated into the pest management program. Over time, growers will determine their individual threshold for a given pest. One grower may accept 10-15 thrips per sticky card per week, while another grower with a history of Impatiens Necrotic Spot Virus will not accept 5 thrips per sticky card per week.

It is also helpful to review scouting records at the end of each growing season to determine which pests were problematic and which pest management worked. The weekly scouting reports and action taken is the basis for decisions about current and future pest management strategies and for judging the efficacy and cost of any management action.

Pest Management in Greenhouses Using Biological Control

Greenhouses provide a suitable environment (e.g., temperature and light) for numerous biological control agents or natural enemies including parasitoids, predators, and entomopathogenic nematodes. Many natural enemies are commercially available and can be incorporated into existing greenhouse pest management programs. In general, the use of biological control is most effective in extended cropping systems such as cut flowers and vegetables, however they are also being successfully used in short term ornamental cropping systems such as annual bedding plants. Biological control is much easier to implement in a monoculture (single crop) than in a polyculture (multiple crops).

Natural enemies cannot be used in the same manner as pest control materials (insecticides or miticides). Pest control materials are typically applied after arthropod pests reach damaging levels, and when effective, the designated pest control material reduces the arthropod pest population. Using natural enemies as a curative control is less successful compared to applying them preventively. Natural enemies should be released early in the cropping cycle when plants are small, arthropod pest populations are low, and before crop damage occurs. Releases of natural enemies may be required throughout the growing season in order to sustain arthropod pests at low populations. A biological control program can succeed if these recommendations are followed: 1) correctly identify all arthropod pests, 2) purchase natural enemies from a reliable biological control supplier, 3) make sure there is a consistent supply of high quality natural enemies, 4) emphasize that proper shipping procedures be followed, and 5) obtain directions from biological control suppliers on proper release rates and timing of application.

Start any new biological control program in a small isolated greenhouse, in propagation houses, or in a greenhouse where edible crops such as herbs are being grown. This approach allows you to gain experience and then have the opportunity to expand into other production areas. It is critical to implement a scouting program and establish a favorable relationship with your biological control supplier early. The success of any biological control program relies on patience and a ***strong*** commitment to detail (e.g., scouting and record-keeping). Photos of biological control agents and information on using biological control can be found at: http://www.negreenhouseupdate.info/ . Specific recommendations for biological control are also found in the current New England Greenhouse Floriculture Guide www.negreenhouse.org .

Arthropod pest identification is extremely important when initiating biological control programs in greenhouses because natural enemies, particularly parasitoids, are specific in the types of insect pests they use as hosts. For example, the aphid parasitoid *Aphidius colemani* attacks both the melon/cotton aphid (*Aphis gossypii*) and the green peach aphid (*Myzus persicae*), but does not attack the foxglove aphid (*Aulacorthum solani*). For arthropod pest identification information, consult trade journal articles, books, manuals, fact sheets, and picture identification guides, or send specimens to your Extension entomologist. USDA Systematic Entomology Laboratory (SEL) provides specimen identification assistance as a free service. For information on sending samples see: http://www.ars.usda.gov/Main/docs.htm?docid=9353&pf=1&cg_id=0

Sources of Natural Enemies: Sources of natural enemies can be found in the reference: *Suppliers of Beneficial Organisms in North America* (Sacramento: California Environmental Protection Agency, 1997) at www.cdpr.ca.gov/docs/pestmgt/ipminov/bensuppl.htm . Be sure to consult your biological control supplier to determine the availability of the natural enemy species you are interested in and designated shipping requirements for them.

Reference

Stack, L. Editor. *2009-2010 New England Greenhouse Floriculture Guide; A Management Guide for Insects, Diseases, Weeds and Growth Regulators*. Northeast Greenhouse Conference: http://www.negreenhouse.org/index.html

Predatory mites are being used to prevent thrips. The mites are mixed with bran and a small pile is placed on each seedling tray. Adult mites emerge from the pile and attack early larval stages of thrips.
Photo: Tina Smith, UMass Extension

CHECKLIST
PEST MANAGEMENT: PROPER USE OF PESTICIDES

- ✓ Obtain the proper training before mixing pesticides. See section on pesticide licensing.
- ✓ Reduce infestations from outside sources and incorporate non-chemical methods such as biological, cultural and sanitation controls in your pest management program.
- ✓ Limit the frequency of treatments whenever possible, particularly nerve toxins. Evaluate the cost-benefit economics and use scouting and thresholds to justify treatments.
- ✓ Treat small areas as much as possible, and whenever possible, only treat infested plant(s) rather than treating all plants in the greenhouse.
- ✓ Avoid persistent compounds and slow release/encapsulated formulations. Ideally, an effective insecticide should be applied at a concentration high enough to kill all individuals in a population, and then quickly disappear from the environment.
- ✓ Avoid treatments that apply selection pressures on both larval and adult stages.
- ✓ Avoid tank mixes (mixing two or more insecticides together to control a single pest) except in cases where research has demonstrated improved efficacy.
- ✓ Rotate insecticides with different modes of action.
- ✓ Use insecticides with non-specific modes of action whenever possible. The less specific the mode of action of an insecticide, the less likely it is that genetic mutations can be selected.
- ✓ Note that resistance can develop to products other than traditional chemical pesticides. Resistance has been reported in some species to *Bacillus thuringiensis* and to some insect growth regulators.
- ✓ Test the pH of the water and adjust the pH of the water before mixing pesticides.
- ✓ Measure accurately when mixing pesticides. Measure wettable powders by weight using a scale. Measure liquids by volume.
- ✓ After mixing an insecticide with water, spray immediately or within a few hours. Never allow a mixed chemical to stand overnight before applying.
- ✓ Treat according to label directions.
- ✓ Inform your local fire department before using a smoke formulation of pesticide.

- ✓ Apply pesticides during the cooler part of the day, such as the early morning or evening.
- ✓ Add surfactants only when recommended on the pesticide label.
- ✓ Never use a sprayer for insecticides that was previously used to apply herbicides.
- ✓ Apply pesticides only after crops have been irrigated and show no signs of moisture stress.
- ✓ Do not apply pesticides with a fertilizer unless indicated on the label.
- ✓ Never use broad-leaved weed killers and brush killers around the greenhouse.

PROPER USE OF PESTICIDES

Before using pesticides, obtain the proper training. See section on pesticide licensing.

Delaying Pesticide Resistance

To use fewer pesticides, it is important that pesticides, when used, are effective at killing pests. Pests can become resistant to pesticides making the pesticide ineffective for management. Resistance is genetic in nature, and an insect or mite cannot become resistant or acquire resistance during its life (that is, within one generation). Resistance is stimulated by widespread application of a pesticide but some individual pests survive and pass on genetic factors to the next generation. A chemical cannot adjust in response to genetic changes in the pest population that help the pest survive the chemical application. Thus, the surviving pests can transfer the resistance factor(s) into the population, allowing the population to become resistant over a period of time. Repeat applications with one type of pesticide eventually remove almost all the susceptible individuals from a pest population and leave only those with the resistant gene.

Pests can become resistant to insecticides to which they have never been exposed. This can happen when two insecticides have a similar mode of action. Mode of Action (MoA) is how a pesticide specifically kills a pest. If two (or more) insecticides attack the pest in the same way, a resistance mechanism to one insecticide may also provide resistance to the other, even though the pest may never have been exposed to that second insecticide.

Tips for Delaying Pesticide Resistance:

- Reduce infestations from outside sources and incorporate non-chemical methods such as biological, cultural and sanitation controls in your pest management program.
- Limit the frequency of treatments whenever possible, particularly nerve toxins. Evaluate the cost-benefit economics and use scouting and thresholds to justify treatments.
- Treat small areas as much as possible, and whenever possible, only treating infested plant(s) rather than treating of all plants in the greenhouse.
- Avoid persistent compounds and slow release/encapsulated formulations. Ideally, an effective insecticide should be applied at a concentration high enough to kill all individuals in a population, and then quickly disappear from the environment.
- Avoid treatments that apply selection pressures on both larval and adult stages.
- Avoid tank mixes (mixing two or more insecticides together to control a single pest) except in cases where research has demonstrated improved efficacy. Take precautions when tank mixing. Phytotoxicity problems can occur with a mixture even though no problems were observed with either material used alone.
- Rotate insecticides with different modes of action. Unless otherwise directed on the pesticide label, switch to a pesticide with a different mode of action about every 2 to 3 pest generations or about every 2–3 weeks. Mode of Action (MoA) Classification provides information about pesticides and how they work. The actual length of an insecticide rotation depends on the time of year, as temperatures and season influence the length of insect life cycles. For example, warm temperatures often lead to overlapping generations and various stages of development present at the same time. As a result, more frequent applications and more frequent rotations of insecticides or miticides are needed.

In winter, pest development is slower and insecticides and miticides may not need to be rotated as often.

- Use insecticides with non-specific modes of action whenever possible. Most synthetic and botanical insecticides kill insects and mites by affecting very specific chemical pathways in the pest (interfere with nerve transmission, development, metabolism, digestion, etc.). The less specific the mode of action of an insecticide, the less likely it is that genetic mutations can be selected. Insecticidal soaps and horticultural oils both have broad modes of action and are, therefore, unlikely to allow for the development of resistance.
- Note that resistance can develop to products other than traditional chemical pesticides. Resistance has been reported in some species to *Bacillus thuringiensis* and to some insect growth regulators.

Improving Efficacy of Pesticides

- Test the pH of the water before mixing pesticides. Many pesticides, especially organophosphates, are not effective when mixed in water with a pH greater than 7. If necessary, use a commercially available buffering agent to adjust the pH of water to be neutral (pH 7) or slightly acidic. More information including a list of pesticides and their optimum pH ranges is available at: http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/ph_pesticides.htm
- Measure accurately when mixing pesticides. Use a scale to measure wettable powders by weight. Use a measuring cup to measure liquids by volume. Read labels carefully!
- After mixing an insecticide with water, spray immediately or within a few hours. Never allow a mixed chemical to stand overnight before applying.
- Treat according to label directions. Most pesticide labels now contain information on amounts to be applied to a certain area. This is important for delivering the correct amount of active ingredient for effective control.

Preventing Pesticide Damage to Plants (Phytotoxicity)

- Apply pesticides during the cooler part of the day, such as the early morning or evening. Treatments made in the early morning allow foliage to dry before temperatures reach 85–90°F. Take special precautions when using pesticides containing oil. Treat when conditions allow plants to dry quickly.
- Add surfactants only when recommended on the pesticide label.
- Avoid tank mixes. A mixture of insecticides may increase the chance of injury to plants.
- Never use a sprayer for insecticides that was previously used to apply herbicides.
- Apply pesticides only after crops have been irrigated and show no signs of moisture stress.
- Do not use more than one emulsifiable concentrate in a tank mixture.
- Do not apply pesticides with a fertilizer.
- Never use broad-leaved weed killers and brush killers around the greenhouse.

Reference

Stack, L. Editor. *2009-2010 New England Greenhouse Floriculture Guide; A Management Guide for Insects, Diseases, Weeds and Growth Regulators*. Northeast Greenhouse Conference: http://www.negreenhouse.org/index.html

CHECKLIST
DISEASE MANAGEMENT

- ✓ Before growing a crop, clear the greenhouse of plant debris, weeds, flats and tools. Wash and disinfect empty benches, potting tables, storage shelves, tools and pots.

- ✓ After the greenhouse has been sanitized, avoid recontamination with pathogens. Purchase seeds, bulbs and cuttings from reliable sources. Use culture-indexed cuttings, if available, to reduce the chance of introducing pathogens. Seeds and bulbs should be disinfected by chemical and/or heat treatment, preferably by the seed company.

- ✓ Provide a hook to keep hose nozzles off the floor.

- ✓ Use horizontal air flow to minimize temperature differentials and cold spots where condensation is likely to occur.

- ✓ Use resistant cultivars whenever possible.

- ✓ At the end of each cropping cycle, discard unsold stock. Plants carried over from previous crops may harbor plant pathogens.

- ✓ Maintain a disease prevention program for stock plants. Inspect stock plants for disease and do not take cuttings from infected plants.

- ✓ During propagation, dip cutting tools in a disinfectant before moving from one stock plant to another.

- ✓ Monitor seedlings for damping off and vegetative cuttings. Look for localized symptoms such as root lesions, cutting end rot, leaf spots, and shoot blights.

- ✓ Monitor roots for root rot symptoms.

- ✓ Inspect incoming cuttings.

- ✓ Properly identify the disease.

- ✓ To prevent root rot diseases, select a well-drained medium, test for soluble salts periodically, and apply water for optimum growth of the crop.

- ✓ Space plants for good air movement and sunlight. This results in rapid drying of foliage and better spray coverage.

- ✓ Irrigate early enough in the day to allow foliage to remain dry overnight.

- ✓ Water sparingly during periods of cloudy and rainy weather.

- ✓ Learn to manipulate the greenhouse environment for disease management. Heat and vent to lower humidity in the greenhouse.

- ✓ For most foliage diseases, fungicides should be applied when disease is first evident. For valuable crops or when conditions are known to be favorable for disease development, apply fungicides on a preventive basis.

- ✓ Biofungicides are fungicides that contain living organisms such as fungi and bacteria. They must be used preventatively as they will not cure diseased plants.

- ✓ When growing in ground beds (soil of the greenhouse), treat with steam to kill disease organisms. It may be necessary to wait several weeks to allow for the dissipation or conversion of ammonium. This time also allows beneficial microorganisms to reestablish.

- ✓ To prevent the development of resistance, alternate applications among different modes of action (MoA) groups, or mix or rotate systemic/protectant fungicides.

- ✓ Use grafted tomato plants to protect against some diseases.

- ✓ Do not reuse growing media.

- ✓ When working with plants such as cleaning or propagating, work in blocks and clean hands and tools between blocks. If gloves are worn, clean or change gloves between blocks.

- ✓ Use separate greenhouses for vegetable plants and ornamental plants.

DISEASE MANAGEMENT

It is important to know what disease you are trying to prevent or control. When diseases are not successfully controlled or become recurring problems, it is often because the cause was not accurately identified. Considering that many fungicides have a narrow spectrum of activity, an accurate diagnosis is particularly important. Also, non-infectious diseases can mimic those caused by microorganisms. Fungicides cannot correct a problem caused by high soluble salts, poor aeration or nutrient imbalance.

Become familiar with the major diseases that affect each crop, the symptoms associated with each disease, the conditions that favor disease development and how to manage each disease. Three components are required for disease to develop: a susceptible host plant, the pathogen and environmental conditions favorable for disease development. These three components comprise the three sides of the "disease triangle." Aim your management practices at reducing one or more sides of the triangle, thus reducing the amount of disease.

Important principles of plant disease management include the use of resistant cultivars, sanitation, sound cultural practices and often fungicides. A holistic or integrated approach to plant disease control is the best approach and is highly encouraged.

Resistant Cultivars

A safe and low input way to manage plant diseases is to grow resistant cultivars (varieties) of a crop. If a particular disease is prevalent in your geographic area, determine if appropriate resistant cultivars are available.

Sanitation

Sanitation greatly enhances management of greenhouse diseases. Remove all diseased plants from the greenhouse. At the end of each cropping cycle, discard unsold stock. Plants carried over from previous crops may harbor plant pathogens. Inspect each lot of plants and, if disease is present, discard or treat them immediately. Maintain a disease prevention program for stock plants. Inspect stock plants for disease and do not take cuttings from infected plants. If a knife is used to take cuttings, dip it in a disinfectant, such as a 10% household bleach solution, or commercial product for this purpose before moving from one stock plant to the next. Transport the cuttings in clean containers and work on a sanitized surface. Clean newspaper provides a relatively sanitary surface.

Before growing a crop, clear the greenhouse of plant debris, weeds, flats and tools. Wash and disinfect empty benches, potting tables, storage shelves, tools and pots to remove media and plant debris. Ventilate the area if using *sodium hypochlorite* (household bleach) for this purpose, as bleach can be toxic to some plants, especially poinsettia.

After the greenhouse has been sanitized, avoid recontamination with pathogens. Purchase seeds, bulbs and cuttings from reliable sources. Use culture-indexed cuttings, if available, to reduce the chance of introducing pathogens. Seeds and bulbs should be disinfected by chemical and/or heat treatment, preferably by the seed company.

Growing media are easily reinfested by way of dirty hose nozzles and tools. Provide a hook to keep hose nozzles off the floor. Hang up tools after cleaning them with soap and water. *Sodium hypochlorite* (household bleach) diluted at the rate of 1 part bleach (5.25%) to 9 parts water is a good general disinfectant for tools, pots and bench tops. Rinse with water after treatment to prevent corrosion of metallic surfaces. Commercial disinfectant products are available that are made for this purpose.

Keep hose nozzles off the floor.
Photo: Tina Smith, UMass Extension

When working with plants such as cleaning or propagating, work in blocks and clean hands and tools between blocks. If gloves are worn, clean or change them between blocks. The same is true when working with incoming plants, always work in blocks and if possible keep plants from different suppliers separated.

Cultural Practices
Soil-borne pathogens are spread by splashing of spores and/or contaminated soil. Drip irrigation and ebb-and-flow systems help minimize splashing and pot-to-pot splashing of soil associated with hand watering. They also eliminate the use of a hose nozzle, which may periodically touch the growing medium along the bench. However, ebb-and-flow systems can become contaminated with pathogens and result in rapid and widespread infection of the crop.

Root rots caused by the fungi *Pythium* and *Phytophthora* are enhanced by high soil moisture and high soluble salts. *Rhizoctonia* is favored by a drier medium. Select a well-drained medium, test for soluble salts periodically, and apply water for optimum growth of the crop.

Use separate greenhouses for vegetable plants and ornamental plants to protect vegetable plants from tospoviruses; protect cucurbit seedlings from powdery mildew and to make it easier to treat vegetable plants if pesticides are needed.

High relative humidity is one of the major factors contributing to mildew and disease problems in the greenhouse, especially *botrytis* blight. High humidity is especially troublesome when greenhouses are tightly sealed to conserve energy. Cool nights also increase humidity. Warm air holds more moisture than cold air. During warm days the greenhouse air picks up moisture. As the air cools in the evening, especially during spring and fall, the moisture-holding capacity drops until the dew point is reached and water begins to condense on surfaces.

Relative humidity can be lowered by three methods:
1. Keep the vents open an inch or so (or run exhaust fans at low capacity) when the heat comes on in the late afternoon. This allows cooler air to enter the greenhouse while warm moist air leaves. As the entering cooler air is heated, relative humidity drops. After 5 to 10 minutes, close vents or turn off fans.
2. When extremely moist conditions exist in a greenhouse, it may be necessary to exchange the air several times at night. Equipment can be purchased to turn on exhaust fans at

predetermined times. The fans should remain on long enough to exhaust one volume of air. Heat loss is small, since the mass of the exhausted air is small relative to the combined mass of the greenhouse structure, plants, media, floor, etc., which hold heat inside the greenhouse. Humidity can further be reduced by watering early in the day when the warm air can absorb moisture from wet surfaces.

3. Moving air in the closed greenhouse helps reduce water on plant surfaces. A horizontal air flow system or the overhead polyethylene ventilation tube system minimizes temperature differentials and cold spots where condensation is likely to occur. The horizontal air flow (HAF) system is described below.

Overgrown plants are more prone to diseases such as *Botrytis* and make it difficult to obtain adequate fungicide coverage. Proper planting dates, plant nutrition, watering practices and height management techniques help to prevent lush, overgrown plants. Proper spacing will also lower humidity within the plant canopy.

Horizontal Air Flow

Horizontal Air Flow (HAF) is based on the principle that air moving in a coherent pattern in a building such as a greenhouse needs only enough energy to overcome turbulence and friction losses to keep it moving. In other words, it just has to be "kicked along." The fans need to be sized and placed properly to do this.

Air is also heavy. The air over each square foot of floor area in a typical greenhouse weighs about one pound. A 30 by 100 foot greenhouse contains about 1.5 tons of air. Once the air is moving it coasts along like an auto traveling on a level road. That is why HAF is so efficient. It takes only four small fans to keep air moving at 50 to 100 feet/min in the above greenhouse.

Horizontal Air Flow Fan

Photo: Tina Smith, UMass Extension

Uniform Temperature

As air moves in a horizontal pattern down one side and back the other in a free-standing greenhouse or down one bay and back in an adjacent bay in a gutter-connected house, mixing occurs from side to side and floor to ceiling. Experiments instrumenting a number of houses seldom had more than 2 degrees F difference between any two points. Because of the constant movement of the air, heat supplied at one end is carried to all parts of the greenhouse quickly. Stratification is also eliminated.

Disease Prevention

Research has shown that air movement of 50–100 ft/min is adequate to keep nighttime leaf temperatures almost identical with the surrounding air. When leaf temperatures are allowed to cool much below the air temperature, the dew point is reached and condensation occurs, supporting disease organisms. Radiant cooling on clear nights, especially in non-IR poly covered houses, cools plant leaves several degrees below air temperature. HAF reduces this difference.

Carbon Dioxide

During daylight hours, photosynthesis depletes the carbon dioxide that is in the boundary layer of air next to the leaf. Moving air replaces this depleted air with fresh air having a higher carbon dioxide content. If carbon dioxide is being added, a lower level is usually adequate to get the same plant responses, for instance, 800–1000 ppm rather than 1200–1500 ppm.

Cooling Effect

During warm days in the spring and fall, solar radiation warms exposed leaf surfaces to as much as 15 degrees F above air temperature. This can cause burning of the leaves, flowers or fruit. HAF removes this excess heat and increases plant growth. These are some of the major benefits from HAF; now let's look at some of the installation techniques.

Fan Capacity

To keep the air mass moving at the 50–100 ft/min speed, requires a certain amount of energy to overcome turbulence and friction losses. A rule of thumb based on greenhouse trials and smoke bomb tests is 2 cu ft/min fan capacity for each square foot of floor area. For example, in a 30 by 100 foot greenhouse the total cfm fan capacity needed is 30 x 100 x 2 = 6000 cfm. Four 1600 cfm output fans would be needed. This can be reduced slightly in houses with plants grown only on the floor. It may need to be increased slightly in houses with crops such as tomatoes, roses or hanging baskets.

Type of Fan

Use a circulating fan, not an exhaust fan. Circulating fans operate against zero static pressure and have higher efficiencies than exhaust fans that are designed with higher static pressure to force air through louvers. Because the fans operate 24 hours/day for 8–9 months of the year, they should be as efficient as possible. Before purchasing, compare fans on an energy efficiency rating (EER), cfm output/watt of electricity input. If the manufacturer does not provide this information you can calculate it by dividing the cfm output by amps x volts. For example, a 1/15 hp, 16 inch diameter fan has an output of 1656 cfm and uses 0.9 amps @ 115 volts. EER = 1656/(0.9 x 115) = 16 cfm/watt. Efficiencies of 14–16 are standard. Better fans have efficiencies of 18 or higher.

Generally, permanent split capacitor (PSC) motors have a higher efficiency than shaded pole motors.

Multi-speed and Variable Speed Fans

This adds considerable cost to the fan and cannot be justified for most applications, as air movement to 150 ft/min does not affect plant growth.

Home Type Circulating Fans

These low cost fans have been used by some growers with good results and by others with poor results. One grower who installed a set of these had some fail after 4 months.

Fan Location

Correct location of fans is important for smooth air flow. In free-standing greenhouses, fans should generally be located 1/4 of the width from the sidewall. This puts them in the center of the air mass that is being moved. In gutter-connected houses, where the air mass is moving down one bay and back the other, the fan should be located in the center of the bay.

In both types of houses, the first fan is best located 10 to 15 feet from one end wall. This boosts the air coming around the corner. Subsequent fans are usually located 30 to 50 feet apart with the last fan at least 50 feet from the end wall. On the opposite side or bay, use the same spacing, with the first fan located 10 to 15 ft from the opposite end wall.

Height of the fans is not critical but should be above head height to be out of the way. In many greenhouses a truss or collar tie can be used for support. Note: to keep long hair from being drawn into the fan, blades should be enclosed with an OSHA approved guard. If the house contains hanging baskets, a location a couple of feet above or below them is best. One problem that can occur with a poor installation is short circuiting of the air across the house before it reaches the next fan. This shows up as cold spots or areas of poor growth and is caused by not adding enough energy to the air or having the fans too far apart. The easiest way to check this is to use a smoke bomb, available from heating system suppliers or Superior Signal Co., Inc., P.O. Box 96, Spotswood, NJ 08884, or use a fogger. Place the smoke or fog behind one of the fans after the air flow has stabilized. Watch its movement. Short circuiting is easy to observe. Incense sticks also work well, especially for detecting turbulence in the air flow.

During early fall or late spring operation, the HAF system should be shut off when exhaust fans or vents are needed to cool the greenhouse. A power relay can be wired into the circuit so that either one or the other is activated at one time. Maintenance is also important for efficient operation. Clean dust and dirt from the fans to increase air flow and reduce motor temperature.

Fungicides

Too often it is assumed that disease control is synonymous with fungicide use. Fungicides can provide excellent control of some diseases, but for others they may be ineffective, unavailable or illegal. In general, use broad-spectrum fungicides (or a combination of several materials) on a preventive basis to control root diseases. For most foliage diseases, fungicides should be applied when disease is first evident. For valuable crops or when conditions are known to be favorable for disease development, apply fungicides on a preventive basis.

Thorough coverage is important. In the case of soil drenches, it may be necessary to apply additional water to push the fungicide deeper into the growing media. Most foliar fungicides act as protectants on the surface of the plant and kill spores after they germinate and absorb the toxicant. Thus it is important to have thorough coverage of the foliage before spores land on the surface. Additional applications are usually needed to protect new growth.

Biofungicides

Biofungicides are fungicides that contain living organisms such as fungi and bacteria. They must be used preventatively as they will not cure diseased plants. Biofungicides may suppress plant diseases by competition, attacking or feeding on the pathogen, or by producing secondary toxins that can inhibit the growth of pathogens. Many different types of biofungicides are being used with variable results by growers. These variable results may be due to differences in the particular crop or plant, the soil mix used, the soil pH, the fertilizer program and the level of disease pressure.

Advantages of using biological fungicides include: lower re-entry interval (REI) than traditional fungicides, may be on the Organic Materials Review Institute (OMRI) list and may be less phytotoxic to plants.

Soil Treatment

Soil disinfection (i.e., sterilization) is an important part of soil-borne disease control when raising vegetables by the ground culture method or when soil-based potting mixes are used. Soil-borne diseases include damping-off (*Pythium* and *Rhizoctonia*), black root rot (*Thielaviopsis*), and several other root rots and wilts caused by *Fusarium* and *Phytophthera*. Potting mixes based on compost, peat moss, vermiculite, perlite, and bark are typically pathogen-free and do not require prior sterilization. Steam treatment will also eliminate insects and weed seeds. After the soil has been treated, take care to avoid reinfestation. Soil can be fumigated with a chemical registered for that purpose. It is best, however, to avoid the use of field soil in greenhouse production of container crops.

Steam

Treatment with steam is preferred over fumigants because it is faster, very effective and safe. Proper steam treatment kills all pathogens, and nearly all weed seeds. The soil moisture content prior to steaming is important. Proper soil moisture is approximately the same as for good planting conditions: soil squeezed in the hand should crumble easily. The temperature of the entire soil mass should be raised to 160–180ºF for 30 minutes. It is important to use several accurate thermometers placed in one or more corners and the center of the soil. If it is difficult to obtain uniform steam throughout the soil, sample the soil with several thermometers to find the coolest area, wait for it to reach 160ºF, and then start timing the 30-minute steam treatment.

Steaming soil can result in some undesirable effects such as overkill of beneficial soil microorganisms and accumulation of ammonium nitrogen and toxic forms of manganese. Test soil that is high in organic matter for ammonium after steaming. Several weeks may be necessary to allow for the dissipation or conversion of ammonium. This time also allows beneficial microorganisms to reestablish.

The use of aerated steam at 140–160ºF reduces the undesirable effects produced by higher temperatures. In addition to being biologically efficient, aerated steam saves energy.

Causes of Plant Diseases

Bacteria

Bacteria are very small microorganisms. Under the high power (1,000 X) of a compound microscope they appear as tiny rods. To put their size into perspective, approximately 600 bacteria lined up end-to-end would measure 1/16″. Bacteria can multiply very rapidly, doubling their populations every 30–60 minutes.

With few exceptions, plant pathogenic bacteria cause disease by colonizing the internal tissues of plants, thereby interrupting normal growth and function. Bacteria cause a variety of symptoms including leaf spot, bud rot, canker, vascular wilt, soft rot and galls. Symptoms caused by bacteria are often indistinguishable from those caused by fungi. Soft rot bacteria like *Erwinia chrysanthemi* invade the space between cells and dissolve the cementing material (pectin), resulting in the characteristic symptoms of soft rot. On the same host, *Pseudomonas cichorii*, which is unable to produce pectic enzymes, causes a dry lesion as opposed to a soft rot.

Bacteria that colonize the vascular system cause systemic disease. When bacteria become systemic, they are transported relatively rapidly throughout the vascular system. The plant wilts due to the plugging of the water-conducting cells. Some systemic bacteria, such as *Xanthomonas campestris pv. pelargonii*, also produce pectic enzymes that cause rot in later stages of disease.

Management Practices for Bacterial Diseases: Copper products are very toxic to bacteria as well as many fungi. However, pesticides are only marginally effective unless coupled with sound cultural practices. Since bacteria are spread by water splash, insects, handling and pesticide applications, diseased plants should be promptly isolated from healthy plants or discarded.

Space plants adequately to allow for quick drying after watering. Discontinue overhead watering when bacterial diseases are evident. Reduce relative humidity and avoid prolonged periods of leaf wetness. When propagating geraniums, snap cuttings from the plant or, if a knife is used, disinfest it at least when moving from one stock plant to the next. Wholesale propagators of geraniums should culture-index stock plants.

Viruses

Viruses are ultra-microscopic, infectious particles composed of nucleic acid surrounded by a protein coat. Virus particles multiply only within living host plant cells where they disrupt normal cell functions. Viruses can spread systemically throughout the host plant, and plants may be infected even when symptoms of disease are not apparent. Many different viruses can infect floricultural crops. Some, like cymbidium mosaic virus, have a narrow host range. Others, like cucumber mosaic virus and impatiens necrotic spot virus, can infect a wide variety of greenhouse plants as well as vegetable crops and weeds.

Symptoms of virus infection are most evident on foliage. Mosaic, which is a variable pattern of chlorotic and healthy tissue on the same leaf, is a common symptom. Other foliar symptoms include leaf crinkle or distortion, chlorotic streaking (especially in monocots), ringspots, line patterns and distinct yellowing of veins. Flowers of virus-infected plants may be deformed, or show streaks or flecks of abnormal petal color. A more subtle but very common symptom of virus disease is stunting of the plant. Symptoms may be masked under certain environmental conditions or at particular times of the year, making their diagnosis more difficult.

The spread of viruses in greenhouses occurs in a variety of ways, depending on the virus. Mechanical transmission through handling of plants or use of infested tools is an efficient means of spreading tobacco mosaic virus. However, most viruses are not easily spread in this manner. Some, such as tomato ringspot virus, can be transmitted through infected seed. The most efficient way to spread viruses in floriculture crops is by vegetative propagation of infected stock plants. In this manner, viruses are passed on through successive crops. Insects such as aphids, thrips, mites, and leafhoppers are the most important vectors of viruses.

Management Practices for Virus Diseases: It is of primary importance to have the virus disease accurately identified. Casual on-site diagnosis is often inaccurate due to confusion of symptoms with other viruses, nutritional disorders, chemical injury, insect feeding and other problems. Serological techniques are currently available to accurately identify a wide range of viruses. Once identified, more specific control strategies can be developed.

There are no chemical control measures for virus diseases other than those directed at the vectors. Management practices include starting crops with virus-free seed or cuttings, eradicating weed hosts, reducing insect vectors and destroying diseased plants. Some propagation specialists provide virus-indexed plant material. In the virus-indexing process, stock plants are evaluated for the presence of specific viruses through the use of indicator plants or serology and molecular techniques. Virus-indexed plants are not immune or resistant to subsequent virus infection. Proper sanitation practices are necessary to prevent virus infection. Weed control and removal of crop debris can eliminate possible reservoirs of virus infected material.

Insect control may help to inhibit the spread of certain viruses. Reduction or elimination of thrips is essential for controlling the spread of the tospoviruses INSV and TSWV (see below). Reduced handling of plants can minimize the mechanical transmission of tobacco mosaic virus. Destroy virus-infected plants.

Management Practices for Tospovirus: Tospovirus is a virus family that includes impatiens necrotic spot virus (INSV) and tomato spotted wilt virus (TSWV). Tospoviruses, particularly INSV, are the most important viruses in the floriculture industry. These viruses are spread by the Western flower thrips. The virus is not seedborne but is brought into the greenhouse on plants that have been exposed to the virus. Once the thrips in the greenhouse pick up the virus they can transmit it to weeds and crops. To manage tospoviruses, it is necessary to get rid of all infected plant material, eliminate thrips and eradicate all weeds. Do not grow vegetable transplants in the same greenhouse as ornamental bedding plants. Inspect plants carefully for symptoms of virus and thrips before bringing new plants into the greenhouse.

INSV on Impatiens
Photo: Tina Smith, UMass Extension

Nematodes

With a few exceptions, nematodes are not an important problem in the floriculture industry in New England. There are several reasons for this. Soilless media are devoid of plant parasitic nematodes and subsequent contamination is not likely. Also, the relatively short length of time most crops are grown limits the ability of nematodes to build up to damaging levels.

Nematodes are small (1/32–¼″ long) roundworms that are common inhabitants of field soil. Most nematodes are not parasitic to plants but prey on microorganisms, insects and other nematodes. Plant parasitic nematodes are specialized to parasitize plants. Depending on the genus of nematode and the host involved, roots, stems or leaves may be colonized. With regard to root-colonizing species, root-knot nematodes (*Meloidogyne* spp.) are among the most important in outdoor crops such as herbaceous perennials. As the common name implies, symptoms appear as galls of various sizes (up to ¼″ diameter) on the roots. Root-knot nematodes have a fairly wide host range that includes many greenhouse plants. The bulb and stem nematodes (*Ditylenchus* spp.) occur in hyacinth, narcissus, tulip, mountain and annual phlox and iris, as well as other plants. Colonized bulbs may display necrotic areas, and leaves may produce swellings and distorted growth. Foliar nematodes (*Aphelenchoides* spp.) occur on *Anemone*, Indian rubber plant, birds nest fern, African violet, gloxinia, Rieger begonia, chrysanthemum, *Monarda*, *Phlox subulata*, Boston fern, Easter lily, *Lamium* and *Peperomia*. Symptoms may be mistaken for those of fungal or bacterial infections.

Root-knot nematodes occur primarily as contaminants of field soil but they may also be brought in on plant material. The bulb and stem nematode may occur in field soil or as a bulb inhabitant. Foliar nematodes are brought into the greenhouse on plant material.

Management Practices for Nematodes: Nematode problems can be avoided by using a soilless medium, purchasing plant material from a reputable source, and inspecting plants known to be commonly infected. When the bulb and stem nematode or foliar nematode appears, destroy infected plants and do not reuse media. When root-knot nematodes occur in beds, steam or fumigate the soil prior to the next crop.

Fungi

The majority of plant diseases are caused by fungi. Fungi are not plants and are distinct from plants in their inability to photosynthesize. Fungi are filamentous, highly branched microorganisms that grow over or through the substrate that provides them with nutrients. Those fungi that have evolved into plant pathogens attack living plants, and in horticultural crops, cause loss of yield or aesthetic value. Fungi are extremely diverse in their ecology, growth habits, form and pathogenicity. Symptoms of fungal diseases are also highly variable. Fungi that survive and reproduce in the soil are termed soil-borne. They are the principal cause of damping-off, and root and crown rot. Soil-borne fungi generally do not produce air-borne spores but are easily transported from contaminated soil to pathogen-free soil by tools, hose ends, transplants, water-splash and hands. Fungi that cause disease of stems, foliage and flowers usually produce spores that are easily disseminated by air currents, splashing water or insects.

***Botrytis* spores (fungi) on greenhouse tomato.**
Photo: Leanne Pundt, UConn

Fungicides: Fungicides play an important role in Integrated Pest Management (IPM). Sometimes they are the most effective component, but in other cases, their use may be ineffective, inappropriate, or illegal. To maximize the usefulness of fungicide treatments, use them in an informed and intelligent manner. An accurate diagnosis of disease (the cause of the symptoms) is necessary for the development of an effective IPM program. It is important to identify the pathogen, its host range, know the optimum conditions for its development, and its sensitivity to specific fungicides. A pesticide's effectiveness is not related to the number of crops on its label. Factors to consider are formulation (wettable powder, flowable, etc.), residue, spectrum of activity, resistance management, and safety. Pesticide users are responsible for making sure products are registered for use on specific crops in Massachusetts, and for using products according to label directions.

Resistance Management

It is important to use fungicides intelligently to prevent them from losing effectiveness. Resistance may result in poor or no disease control. Fungicides are classified as systemic (penetrant) or protectant (contact). Systemic chemicals are absorbed into plant tissues. Protectant materials act as a barrier to fungal infection, and do not penetrate plant tissue. In addition, fungicides are grouped by their mode of action (MoA), and each MoA group is assigned a Fungicide Resistance Action Committee Group number (FRAC code). Most systemic fungicides are specific in their mode of action; thus, it requires very little genetic change in fungus populations for resistance to develop. Protectant fungicides are less likely to develop resistance problems, as they have multi-site modes of action (FRAC codes preceded by "M"). Cross resistance can also occur among members within a chemical group.

To prevent the development of resistance, alternate applications among different MoA groups, or mix or rotate systemic/protectant fungicides. A list of fungicide names, companies, REI, EPA registration numbers and FRAC Codes is provided in Table C–8 on page. You can find more information about FRAC codes at: www.frac.info/frac/index.htm.

Grafting for Disease Management

Increasingly greenhouse tomato growers are using grafting to both decrease susceptibility to root diseases and to increase fruit production through increased plant vigor. Grafting involves splicing the fruit-producing shoot (called the 'scion') of a desirable cultivar onto the disease resistant rootstock from of another cultivar. The two cultivars most widely used for rootstock in the greenhouse are 'Maxifort' and 'Beaufort'. Both cultivars offer enhanced disease resistance to *Pyrenochaeta lycopersici* (Corky Root), most common species of nematodes, *Verticillium* sp, *Fusarium oxysporum* races 1 and 2, and *Fusarium oxysporum* fsp and *Radicis-lycopersici* (crown rot). In addition, 'Maxifort' confers a very vigorous growth habit while 'Beaufort' confers moderate plant vigor. For information on grafting tomatoes see the fact sheet: Grafting Techniques for Greenhouse Tomatoes at:
http://www.hort.uconn.edu/ipm/greenhs/htms/Tomgraft.htm

References

Bartok, J.W. 2005. *Horizontal Air Flow is Best for Greenhouse Air Circulation*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_haf.htm

McAvoy R. *Techniques for Greenhouse Tomatoes*, University of Connecticut:
http://www.hort.uconn.edu/ipm/greenhs/htms/Tomgraft.htm

Stack, L. Editor. *2009-2010 New England Greenhouse Floriculture Guide; A Management Guide for Insects, Diseases, Weeds and Growth Regulators*. Northeast Greenhouse Conference:
http://www.negreenhouse.org/index.html

PLANT PROBLEM DIAGNOSTIC SERVICE

The University of Massachusetts Extension Plant Diagnostic Laboratory serves farmers, horticulturists, landscape contractors, turf managers, arborists, nurseries, and others in agriculture and the green industries. The laboratory also assesses ticks for Lyme disease as a service to the public.

The UMass Extension Plant Diagnostic Laboratory is located at UMass Amherst. Each diagnosis performed by the laboratory includes a written report with pest management strategies that are research based, economically sound, and environmentally appropriate for the situation.

Diagnostic Sample Submission

A completed Diagnostic Form is required for each specimen (or particular problem). Diagnostic forms for various types of samples, along with instructions, can be accessed by following the links below. Remember that accurate diagnosis requires both a representative sample and sufficient information about the cultural practices and environmental conditions associated with the problem. The information you record on the form can be more important to the diagnosis than the sample itself! Photos of the problem are also extremely helpful. S*amples will not be diagnosed without a completed submission form*.

There is a fee per specimen (or particular problem) payable to the University of Massachusetts, and the appropriate fee must accompany each sample. For a list of fees and to obtain a submission form see http://www.umass.edu/agland/diagnostics. The UMass Extension Plant Diagnostic Laboratory will call and/or send a written report when a conclusion has been reached on the diagnosis or identification. Detailed management recommendations are included with pest diagnoses.

Preparing Samples to Submit to the Diagnostic Laboratory

Submit as much of the plant as possible

The accuracy of a disease diagnosis can only be as good as the sample provided. To provide a good sample, be sure that the sample contains the right part of the plant. Symptoms may appear in parts of the plant that are not infected with the pathogen. For this reason, if possible, submit as much of the plant as possible. Ideally, this would be an intact plant.

Send several plants with a range of symptoms

Secondly, the samples must be fresh and in good condition. Dead plants tell no tales. Due to secondary infections in extremely decayed plants, it is difficult to determine which organism may have created the problem in the first place. If possible, send in several plants with a range of symptoms from moderate to severe.

Keep leaves dry and free of soil

Wet samples with soil on the leaves promote the growth of secondary pathogens and create problems that did not exist when the sample was originally collected. Do not ever add water to your sample.

Send detailed information and payment with the sample

Complete the required form to be sent with the sample or make sure to include detailed information including: host plant, date collected, plant history (planting date, approximate age, cultural practices), when symptoms occurred, description of the problem, pesticide treatments, and your contact information. Keep accompanying paperwork separate and do not include in the bags with the sample. Ideally, paperwork could be placed in its own Ziploc bag. Download the form: http://www.umass.edu/umext/floriculture/pdf/veg_flor_form_new.pdf
The cost for diagnosis is $50 per sample (price in 2010). Include a check payable to: *University of Massachusetts* with the sample.

Hand deliver or ship overnight

Rapid delivery may be critical for an accurate diagnosis. Samples that take a long time to get to the diagnostic lab have a greater chance of decaying or drying up making diagnosis difficult. You may want to hand deliver the sample to the lab. If you are too far away from the lab, then ship the sample overnight. The diagnostic laboratory is closed over the weekend and you may not want to ship the sample on Friday or during a holiday. Call the UMass diagnostic lab prior to shipping to make arrangements for receiving the package.

How to select samples from plants with the following symptoms:

Leaf spots and Blights

Select leaves which show a range of symptom development. Place leaves between paper towels or sheets of paper to keep leaves dry. Place the package in a plastic bag, and then into the envelope for mailing. Never wrap leaves in wet paper towels.

Stem Cankers

When a canker occurs on a large plant, cut a section of the stem with the symptoms, wrap in newspaper and place in a plastic bag for mailing. If the plants are small (1 foot or less), shake the soil from the roots, wrap in newspaper and put into a plastic bag for mailing.

Wilt, Crown rot or Root rot

If the plants are 1 foot or less, include the entire plant. Include the root system with the plant, leaving the growing media on the roots. Place the root ball into a plastic bag and tie off at the crown to keep the media off the foliage. If the plants are large, send a portion of the plant that includes the infected tissue. For wilt diseases, include the lower stem tissue and roots.

Poor growth, Defoliation, Scorch

These symptoms are usually caused by nutritional or environmental factors. They may also be the result of root rot or vascular disease. Collect a specimen as for wilt (see above); be sure to also submit a soil sample to a soil test laboratory.

Contact Information

University of Massachusetts Extension Plant Diagnostic Laboratory

Phone: 413-545-3209
Fax: 413-545-4385
Email: mbdicklo@umext.umass.edu

CHECKLIST
WEED MANAGEMENT

- ✓ Develop a weed management program.
- ✓ Monitor inside and outside of greenhouses, potting and propagation areas, holding areas, and areas adjacent to these locations for the presence of weeds on a regular basis.
- ✓ When scouting, identify the type of weeds (broadleaf, or grass), life cycle (annual, biennial or perennial) and location. It is critical to remove weeds from greenhouse pots, benches and floors before they flower and produce seed.
- ✓ Keep weed seeds, and rhizomes out of the greenhouse by using sterile media," clean " plant materials, and controlling weeds outside the greenhouse.
- ✓ Prevent weeds from going to seed in all areas of the greenhouse. Control measures include mowing outdoors, hand-pulling, and selected herbicides.
- ✓ Optimize the production cycle and minimize the duration in which perennials remain.
- ✓ Maintain weed-free areas around and between greenhouses and hoophouses.
- ✓ Use a physical barrier such as a weed block fabric helps to limit weed establishment on greenhouse floors. Leave the weed fabric bare so it can be easily swept and repair tears as they appear.
- ✓ Clean container media that has spilled or has fallen and all plant debris from container area.
- ✓ Use growing media that is weed-free.
- ✓ Use liners and transplants that are weed-free. Routinely monitor newly potted plants. Newly planted containers can be very prone to weed growth.
- ✓ Thoroughly wash containers that are going to be reused. Washing should be done in a manner that removes all leftover growing media and weed seeds.
- ✓ Use container surface covers or weed-mulch materials as container surface covers for perennials.
- ✓ To control existing weeds: 1) hand pull or 2) using a postemergence herbicide. These measures do not prevent reseeding of weeds.

Herbicides and Herbicide Applications

- ✓ Consider all characteristics of a particular herbicide when selecting an herbicide.

- ✓ Always be sure the herbicide selected is labeled for use in the greenhouse. Carefully follow all label instructions and precautions. It is the applicator’s responsibility to read and follow all label directions.

- ✓ Read and understand the product labels of all herbicide products before application.

- ✓ Use a dedicated sprayer that is clearly labeled for herbicide use *only*.

- ✓ Keep accurate records of all herbicide applications on file.

- ✓ Clean herbicide application equipment after application.

- ✓ When applying herbicides outside of the greenhouse, close the greenhouse vents and openings during herbicide applications to prevent drift inside to sensitive crops.

WEED MANAGEMENT

Weed Management Inside the Greenhouse

Maintaining weed-free growing conditions is necessary to produce high quality greenhouse crops while reducing pesticide use. Insects and diseases can be kept to a minimum only if proper weed control practices are carried out regularly, along with appropriate control measures.

Weeds may compete with desirable crop plants for light, water and nutrients. Weeds are also a primary source of insects such as aphids, whiteflies, thrips, and other pests such as mites, slugs and diseases. Many common greenhouse weeds such as chickweed, oxalis, bittercress, jewelweed, dandelion and ground ivy can become infected with tospoviruses including impatiens necrotic spot virus (INSV) and tomato spotted wilt virus (TSWV) while showing few, if any visible symptoms. Thrips can then vector the virus to susceptible greenhouse crops. Weeds can also carry other plant damaging viruses that are vectored by aphids.

An integrated weed management program will help to effectively manage weed populations. This approach includes preventive measures, sanitation, physical barriers, handweeding and the selective use of postemergence herbicides.

Prevention

Weed seeds are easily blown into the greenhouse through vents and other openings. Weeds and their seeds can be brought into the greenhouse on infected plant material, tools, and equipment. Seeds can be moved in soil, by the wind, irrigation water, animals and people. Creeping wood sorrel, (*Oxalis corniculata*), hairy bitter cress *(Cardamine hirsuta)*, prostrate spurge *(Euphorbia humistrata*), common chickweed (*Stellaria media)* and other weeds are persistent problems in greenhouses. These annual weeds reproduce primarily by seed, with several generations occurring per year. Prevention and sanitation are the grower’s first line of defense.

Sanitation

Keep weed seeds, and rhizomes out of the greenhouse by using sterile media," clean " plant materials, and controlling weeds outside the greenhouse. Screening vents and other openings will help to limit the entry of wind blown seed, as well as insects.

When scouting, identify the type of weeds (broadleaf, or grass), life cycle (annual, biennial or perennial) and location. It is critical to remove weeds from greenhouse pots, benches and floors before they flower and produce seed. For example, a single plant of bittercress can produce 5000 seeds, that germinate in as little as 5 days and can propel the seeds over 9 feet from the plant. Yellow woodsorrel and creeping woodsorrel also expel seeds by force throughout a greenhouse.

Physical Barriers

The use of a physical barrier such as a weed block fabric helps to limit weed establishment on greenhouse floors. Leave the weed fabric bare so it can be easily swept. Covering the weed fabric with gravel makes it difficult to remove any spilled potting media providing an ideal environment for weed growth. Regularly handpull any escaped weeds before they go to seed. Repair any tears in the weed block fabric.

Oxalis is growing on the edge of weed barrier in a greenhouse.
Photo: Tina Smith, UMass Extension

Controlling Existing Weed
To control existing weeds, the following methods may be used: 1) hand pulling or 2) using a postemergence herbicide. These measures do not prevent reseeding of weeds.

Precautions on the Use of Herbicides
Few herbicides are labeled for use in a greenhouse due to the potential for severe crop injury or death to desirable plants. This injury may occur in a number of ways including: 1) spray drift occurs if fans are operating at the time of application, and 2) volatilization (changing from a liquid to a gas). Herbicide vapors are then easily trapped within an enclosed greenhouse and injure desirable plant foliage. Always be sure the herbicide selected is labeled for use in the greenhouse. Carefully follow all label instructions and precautions. It is the applicator's responsibility to read and follow all label directions. Use a dedicated sprayer that is clearly labeled for herbicide use *only*.

Symptoms of Herbicide Injury
Some of the symptoms of herbicide injury include discolored, thickened, or stunted leaves. Sometimes, the growing point of young seedlings is injured, severely stunting their growth. Symptoms may be similar to those caused by nutritional imbalances, viral diseases or air pollution injury. Proper diagnosis is needed to determine the causal agent. In many cases, symptoms are so severe, that the injured plants cannot be sold.

Types of Herbicides
Herbicides are generally classified according to their mechanism of action (contact or systemic) and how they are used (preemergence and postemergence) Avoid use of preemergence herbicides in the greenhouse; preemergence herbicides are applied before weeds emerge. They provide residual control of weed seedlings and can persist for many months, and in some cases, over a year. Preemergence herbicides can continue to vaporize, causing crop damage. Currently, there are no preemergence herbicides labeled for greenhouse use.

Selective use of postemergence herbicides
Postemergence herbicides are applied after the weeds have emerged. In the greenhouse, several postemergence herbicides can be used under greenhouse benches and on the floors. See New England Recommendation Guide for details.

There are of two different types of postemergence herbicides: contact and systemic. Contact herbicides kill only the portion of the plant that the herbicide contacts, so good spray coverage is generally needed.

Systemic herbicides are absorbed and move through the plant. The target weeds must be actively growing for the herbicide to be effective. Systemic herbicides are best applied to actively growing weeds when temperatures are above 50° F.

Systemics should not come in contact with desirable crop foliage. Irrigating crops too soon after applying an herbicide can wash it off the target weeds under the benches and reduce its effectiveness.

Algae Management

Algae are primitive plants lacking true roots, leaves and stems that contain chlorophyll. The greenhouse provides an ideal environment for the growth of algae. Algae growth on walkways, under benches, and in pots or plugs is a problem for many growers. Algae compete with desirable plants for nutrients and form an impermeable layer on the media surface that can interfere with water penetration. During plug production, slower-growing plants can be especially sensitive to algae buildup. Algae are a food source for both shore flies and fungus gnats. Excessive growth on walkways can be a safety hazard to workers. Growth of algae on greenhouse coverings can also reduce light levels in the greenhouse. Prevention measures include sanitation, environmental modification, and frequent use of disinfectants.

Algae growth in a greenhouse
Photo: Tina Smith, UMass Extension

Prevention

Sanitation

All surfaces should be kept free of plant debris and weeds that can be a nutrient source for the growth of algae. A physical weed mat barrier helps to prevent both weed and algae growth.

Environmental Modification

Proper ventilation reduces the amount of moisture in the greenhouse. Horizontal airflow fans help regulate greenhouse temperatures and reduce excess condensation. Retractable roof or open roof greenhouses provide superior ventilation benefits.

Proper Watering Practices

Overwatering crops frequently leads to algae and liverwort buildup on the surface of the growing media. Avoid overwatering crops, especially early in the crop cycle, to allow the upper surface of media to dry out between waterings. Select a growing media with the proper drainage for your crops. Water the growing containers only as needed, to prevent excess puddling on the floor. Avoid excessive fertilization, runoff and puddling on floors, benches, and greenhouse surfaces to discourage algae growth. The use of porous concrete floors limits the development of excessive moisture in the greenhouse. The greenhouse floor should be level and drain properly to prevent pooling of water.

Disinfectants and Algicides

A number of disinfectants and algidices are registered for algae control in greenhouses. Disinfectants should be used on a routine basis as part of a precrop clean-up program and during the cropping cycle.

Liverwort Management

Liverworts *(Marchantia polymorpha)* are branching, ribbon-like plants lacking distinct roots, stems and leaves. The reproduce vegetatively and by spores. Stalked, umbrella-like structures release spores. Small, bud-like branches produced in cup-like structures on the surface of the plant also help spread liverworts from pot to pot by water droplets during irrigation. Liverworts thrive in conditions of high fertility, moisture and humidity.

Liverworts
Photo: Leanne Pundt, UConn

Incoming plants should be inspected for signs of liverworts and isolate infested plants. If the growing media stays moist, small infestations of liverwort can quickly spread through an entire greenhouse. Empty greenhouses should be cleaned and disinfested to remove spores. Growing media should be stored properly to prevent contamination by spores.

Avoid overwatering crops and water according to plant need. Use course textured mulch to reduce surface moisture levels. Topdressing with a slow release fertilizer contributes to increased fertility levels on the media surface and to the growth of liverworts. Proper plant spacing helps to reduce humidity levels. Liverworts lack true roots, so allowing the media to dry between watering helps reduce their vigor.

Weed Management Outside the Greenhouse

Managing weeds outside the greenhouse is important to: 1) prevent weed seeds from being blown into the greenhouse; 2) prevent perennial weeds such as bindweed, quackgrass, etc., from growing under the foundation of the greenhouse; and 3) help reduce the unwanted entry of winged insects into the greenhouse.

Prevention

Maintain a 10 to 20-foot weed free barrier around the greenhouse. A geotextile fabric can be used outside the greenhouse to prevent weed growth. Mow beyond this area to help limit the blow in of weed seeds. Or maintain a boundary of grasses, such as a mix of chewings, hard and creeping fescues. Thrips tend to not reproduce well on these grasses. Fescues are also not yet known to be hosts of tospovirsues.

Precautions on the Use of Herbicides

Herbicides may also be used outside the greenhouse. The label should state if use near greenhouses is permitted. Close the greenhouse vents and openings during herbicide applications to prevent drift inside to sensitive crops. Soil residual and post emergence herbicides may be carefully used surrounding the greenhouse. Herbicides should be chosen with low volatility that will control target weeds. Do not use any auxin type herbicides such as those labeled for broadleaf weed control in turf, near greenhouses. Their volatility and the extreme sensitivity of greenhouse crops to these herbicides can result in severe injury.

Flame Weeding

Flame weeding is thermal weed control that uses propane gas burners to produce a carefully controlled and directed flame that briefly passes over weeds, searing the leaves and causing the weed to wilt and die. Killing weeds can be achieved by heating without actually burning the weeds. Weeds are most susceptible to flaming when they are seedlings, 1 or 2 inches tall. Broadleaf weeds are more susceptible to lethal flaming than grasses.

Extreme care must be taken when using a flame weeder in or around a greenhouse. The most obvious concern is the chance of catching something on fire. Another, less obvious concern is the possibility that the heat may cause pollutants in the soil to volatilize.

Reference:

Stack, L. Editor. *2009-2010 New England Greenhouse Floriculture Guide; A Management Guide for Insects, Diseases, Weeds and Growth Regulators*. Northeast Greenhouse Conference: http://www.negreenhouse.org/index.html

A physical barrier such as a weed block fabric helps to limit weed establishment on greenhouse floors. Leave the weed fabric bare so it can be easily swept.

Photo: Tina Smith, UMass Extension

CHECKLIST
ANIMAL DAMAGE MANAGEMENT

Managing Animal Damage in Greenhouses

- ✓ Make overwintering greenhouses rodent tight.

- ✓ Mow and clean up the natural vegetation close around the greenhouses to eliminate protected areas for rodents.

- ✓ Trapping is not effective for controlling large vole populations, but can be used to control small populations. Place mouse snap traps containing bait perpendicular to the runways.

- ✓ Chemical repellents are available that can be used on plants. Some repel by giving off an offensive odor and others are taste repellents. Some of these products may not be persistent and some are easily washed off and need to be reapplied.

ANIMAL DAMAGE MANAGEMENT

Small animals may occasionally invade a greenhouse and are commonly a problem in overwintering structures. They cause damage by girdling stems, and burrowing into pots if given the chance. The most likely critter to cause havoc is the meadow vole. Meadow voles construct many tunnels and surface runways with numerous burrow entrances. These surface runways are the most easily identifiable sign of voles. By the time the runways are noticed, damage is usually done.

The first step to prevent damage caused by rodents is to deny them access to greenhouses or overwintering greenhouses. Make them rodent tight by using fine mesh screen wire such as hardware cloth around the perimeter of the greenhouse. Bury it under ground and bend it outward at a 90° angle leaving it at least 6 inches deep.

Next, mow and clean up the natural vegetation close around the greenhouses to eliminate protected areas for rodents. Most of our wildlife animals will not venture across a wide-open space because they are much more vulnerable to natural predators.

Trapping is not effective for controlling large vole populations, but can be used to control small populations. Place mouse snap traps containing bait perpendicular to the runways.

Chemical repellents are available that can be used on plants. Some repel by giving off an offensive odor and others are taste repellents. These products reportedly work for a number of animal pests. Some of these products may not be persistent and some are easily washed off and need to be reapplied.

Finally, when all else fails, there are toxic baits that are effective for reducing the population. One of the most effective and common baits is zinc phosphide treated cracked corn or oats. It is a single-dose toxicant available in pelleted and grain bait formulations and as a concentrate. Anti-coagulant baits are also effective in controlling voles. Anticoagulants are slow acting toxicants requiring from 5 to 15 days to take effect. Multiple feedings are needed for most anti-coagulants to be effective. Toxic baits can be harmful to children, pets and wildlife and should be used with utmost caution. Read and carefully follow the directions and safety precautions on the label of any of these products.

CHECKLIST
ORGANIC WASTE MANAGEMENT - COMPOSTING

- ✓ Follow all state and local regulations regarding composting. Contact Massachusetts Department of Agricultural Resources Composting Program for more information http://www.mass.gov/agr/programs/compost/index.htm.
- ✓ Most organic waste materials generated by a greenhouse can be composted.
- ✓ Avoid composting grass clippings that has been treated with herbicides.
- ✓ Compost piles should always be distant and downwind from sensitive neighbors and not sited close to residential property.
- ✓ Piles should be protected from surface water and storm water runoff.
- ✓ Proportions of carbon to nitrogen are critical to successful composting. The materials being composted will determine the exact recipe for any given operation. Materials with high carbon to nitrogen ratios, such as 100:1, should be balanced with materials having low carbon to nitrogen ratios, e.g. 15:1.
- ✓ Regular turning of the pile will mix the nutrients and re-establish pile structure.
- ✓ Moisture content can be adjusted during turning.
- ✓ After the compost has gone through several heating and cooling cycles and the original waste has decomposed, the compost process should slowly finish in a curing pile.
- ✓ Activities that tend to release odors should be scheduled to minimize negative impacts.
- ✓ Consider wind conditions before opening compost piles. Stronger winds can disperse odors but also create dust concerns. Care should be taken to control dust when grinding and turning piles.
- ✓ Most odor problems can be avoided, controlled, or minimized by keeping the compost pile aerobic, porous, well aerated, and well mixed. Odor problems are most likely when anaerobic decomposition is occurring.

ORGANIC WASTE MANAGEMENT

University of Massachusettts

Composting is a managed process which utilizes microorganisms naturally present in organic matter and soil to decompose organic material. These microorganisms require basic nutrients, oxygen, and water in order for decomposition to occur at an accelerated pace. The end-product, compost, is a dark brown, humus-like material which can be easily and safely handled, stored, and used as a valuable soil conditioner. The composting process is dependent upon several factors, including: the population of microorganisms, carbon to nitrogen ratio, oxygen level, temperature, moisture, surface area, pH, and time.

Aerobic Composting

The composting process involves microorganisms feeding on organic material and consuming oxygen. The process generates heat, drives off moisture, and reduces bulky organic waste into a beneficial soil-like material containing nutrients, humus and microorganisms in just a few months. Material in an unmanaged pile of organic debris will eventually break down but the process will take a long time and may result in odor or other nuisance problems due to poor aeration.

Regulations

With a few, specific exceptions, solid waste facilities require a “site assignment” from the Massachusetts Department of Environmental Protection (“MassDEP”). At issue in past years has been whether farms, when undertaking the time-honored agricultural practice of composting “wastes” from their own operations and other sources, have been engaging in solid waste management activities and are, thus, subject to the regulatory control of MassDEP. In order to recognize the legitimate agricultural nature of such on-farm composting operations, and avoid unnecessary regulatory control, MassDEP and MDAR have undertaken the joint responsibility for agricultural composting registration oversight. Specifically, MassDEP has granted conditional exemptions under the Solid Waste regulations (310 CMR 16.00) for agricultural composting operations, and MDAR has established an Agricultural Composting Registration process.

Any agricultural operation which is only composting its own on-site generated waste materials does not need to register with MDAR. An agricultural operation only needs to register with MDAR if it is planning to bring waste materials on to its property from off-site to compost with waste materials which are generated on-site. Persons composting organic materials without a registration are subject to the Department of Environmental Protection's site assignment requirements. The registration application should be completed and mailed to The Department of Agricultural Resources. Yearly Annual Reports will be required in order for a composter to remain registered with the Department. For more information, contact the Massachusetts Department of Agricultural Resources at (617) 626-1700, Agricultural Composting Program at (617) 626-1709 http://www.mass.gov/agr/programs/compost/index.htm or the Massachusetts Department of Environmental Protection at (617) 292-5500.

The Massachusetts Department of Agriculture Resources may register agricultural composting operations if the Department determines that:
1) the compost operation is located on agricultural unit;
2) the applicant has submitted a completed application;
3) the applicant agrees to a site visit; and
4) the applicant demonstrates knowledge and capability to conduct the agricultural composting operation to produce a stabilized compost product.
Details on agricultural composting are available from "The Guide to Agricultural Composting" which was updated in 2010 and is available from:
http://www.mass.gov/agr/programs/compost/docs/Guide_to_Ag_Composting2010.pdf

What to Compost
Most organic waste materials generated by a greenhouse can be composted. Large material will need to be shredded before it is added to a carefully-constructed compost pile. Some material may begin to decompose in a storage pile but full composting will not occur until the material is mixed and managed in the correct proportions of carbon to nitrogen (C:N ratio), with adequate airflow and moisture.

Composting is an excellent method of recycling grass clippings. However, do not compost grass clippings or any other plant residues that have been treated with herbicides. If carried out properly, it can reduce the potential weed seeds and diseases from being reintroduced into the fields. The finished compost is a stable organic material which is a useful soil conditioner or nutrient source. Due to the characteristics of fresh grass clippings (high-moisture, high-nitrogen content and small particle size), co-composting with a high-carbon bulking agent is essential.

Unacceptable Materials for Composting
Chemically treated wood products
Plastic, e.g. pots, bags, and sheet film
Unprocessed sod and chunks of soil
Large and bulky items, (e.g. stumps, pallets, concrete, and asphalt)

Acceptable Materials for Composting
Green and woody plants
Clippings and trimmings
Soil and planting media
Untreated wood and uncoated paper scraps

Site Selection for Compost Piles

Proper site selection is a prerequisite to the establishment of safe and effective composting operations. The location of a composting operation directly impacts the amount of site preparation required and the measures needed to satisfy environmental and regulatory requirements.

Protection of Water Resources

Sites need to be evaluated for their potential impact on water resources. Of primary concern are proximity to public water supplies, wetlands, floodplains, surface waters, and depth to groundwater. Below are guidelines from the "Guide to Agricultural Composting"

1) Sites must not be located within 400 feet (Zone I) of a public drinking water supply well or within 250 feet of a private well. For sites located within a Zone II or interim wellhead protection area (½ mile radius), MassDEP may require that extra precautions be taken in the design or operations depending on the quantities and types of material to be composted. Sites within Zone II may not be allowed under certain circumstances.

2) Operations must be sited in accordance with the Massachusetts Wetlands Protection Act. Under the wetlands regulations, siting of composting and storage areas is considered to be "normal improvement of land in agricultural use" when it occurs on land in agricultural use when it is directly related to the production or raising of certain agricultural commodities, and when it is undertaken in such a manner as to prevent erosion and siltation of adjacent water bodies and wetlands.

3) Sites should be located at such a distance to ensure that there will not be any potential adverse impacts from compost site runoff into surface waters.

4) Soils should be permeable enough to minimize runoff, yet capable of filtering drainage water. Excessively drained soils (e.g., sand) should be avoided if possible, as they may lack the physical properties necessary for effective filtering of potential contaminants. Highly impermeable soils (e.g., clay) should also be avoided if possible, as this may lead to poor site drainage and excessive runoff or erosion.

5) Sites should be avoided where groundwater rises closer than 4 feet or where bedrock is closer than 5 feet from the surface. Such conditions may lead to an operating surface that is too wet, and it increases the potential for nutrients to leach into groundwater.

Buffer to Sensitive Land Uses

Buffers, in the way of distance and/or visual screens, can go a long way toward reducing the real or perceived aggravations of noise, odor, litter, and aesthetic objections often associated with composting operations. Compost piles should always be distant and downwind from sensitive neighbors and not sited close to residential property. A distance of at least 250 feet from the nearest residence to the composting area is recommended, and the composting site should be at least 50 feet from the property line. More importantly, the buffer must be adequate to satisfy reasonable neighbor concerns. Keep the activities as far away from the property line as possible.

Available sites should be analyzed for conditions potentially detrimental to production and access. There needs to be enough space to store and process waste, operate and turn active windrows or piles, and store and cure finished compost. A facility that is short on space will eventually experience problems. Composting can have off-site impacts.

Composting can also create water quality problems. Piles should be protected from surface water and storm water runoff. Piles may need to be protected from rain. This is because a compost pile can get saturated, stop working and, become anaerobic. This will create odor problems. Saturated piles will need to be remixed and rebuilt. Runoff from an active compost pile or stored compost can also create water pollution problems. Standing water can cause odor problems. Compost piles should always be sited so that runoff is minimized. Any runoff should be collected and used rather than allowed to leave the property.

State and Local regulations regarding composting facilities should be thoroughly investigated. Contact Massachusetts Department of Agricultural Resources Composting Program for more information http://www.mass.gov/agr/programs/compost/index.htm.

The Basic Composting Process

The general steps in the biological process which creates compost are the same regardless of the raw materials being composted or the size and complexity of the production facility. A compost must pass through all of the steps outlined here in order for it to be considered of high enough quality for use in organic potting mixes.

The progress of organic matter decomposition during composting can be followed by monitoring the temperature of the compost pile. During the initial phase of composting the temperature of the pile increases rapidly as the population and activity of decay microorganisms increases in response to the readily decomposable carbon in the raw materials. The goals are to reach a temperature between 131°F or more and to maintain this temperature range until the microorganisms begin to exhaust the readily available carbon. During composting the pile is turned and remixed several times to ensure complete heating and decomposition.

To comply with the National Organic Program standards compost piles must maintain 131-170ºF for at least 3 days (static pile) or at least 15 days (windrow, turned at least 5 times). High temperatures are necessary to kill any human pathogens especially if farm manure is a component. Also, weed seeds and plant diseases are most successfully killed at high temperatures. Most weed seeds are destroyed at 145°F.

Following the high temperature phase there is an extended period of gradual temperature decline until the pile reaches ambient air temperature. Now, if the pile is turned, reheating will not occur. At this point the compost is said to be "near maturity", but to ensure that the compost is stable and ready to use, most producers allow some extra time for the compost to "cure". How long composting lasts varies with the method. It could take about 1-2 years in a static unturned pile, 6-9 months if the pile is turned occasionally, or only 1-4 months the pile is turned frequently.

Many types of raw materials can be used for making compost; some common materials are listed in the following table. Pay close attention to the comments in the table.

Compost Material	Comments
Farm animal manure	Must be composted
Straw and bedding	
Crop residues	Must be pesticide free
Fruit & vegetable wastes	Must be pesticide free
Food processing wastes	
Seafood processing waste	
Grass clippings	Must be pesticide free
Sawdust & other wood wastes	Use in moderation, low nutrient value.
Newspaper	Black ink only, shredded, <25%
Leaves	Shredded

It is important that the raw materials be properly prepared prior to mixing and the start of composting. Most organic materials must be shredded or ground to reduce particle size and help make them less resistant to decay.

During composting, oxygen and moisture levels are critical factors in determining the degree of decomposition which takes place and the length of time it takes to reach a stable product. Oxygen levels below 5% and moisture levels above or below the range of 40-65% inhibit the composting process. Most composting operations aerate the piles (turn) and irrigate them if conditions favor excessive drying. Too little moisture will inhibit microbial activity and slow down the composting process, while too much moisture will restrict the flow of oxygen because all pore space is taken up by water instead of air, and anaerobic conditions will begin to develop. The volume of the finished compost is smaller than the volume of raw materials because of the breakdown of organic matter and the evaporation of water.

When is the compost ready for use? Currently there is no single widely accepted criterion to determine when compost is "done". Measurements of temperature, respiration, ammonia production, pH, and carbon to nitrogen ratio (C:N) are among the potential indicators of compost maturity, but no one factor is completely reliable. Generally, at the end of active composting (heating period) producers allow a “curing” period of about 1-2 months to make sure the compost is stable before it’s used.

Frequenty Asked Questions About Composts

What are the indicators of a good compost?
Much research and some controversy surrounds this question. Here are the major quality indicators that help answer this question:

- Producer can give details of the composting process.
- Raw materials should not be recognizable.
- No unpleasant odor.
- Compost temperature should not be more than 20ºF above air temperature after delivery.
- C:N ratio should be 15-20:1.
- pH should be no more than 8.0 (ideal 6.5) before mixing.
- EC (soluble salts) <6.0 mmho/cm before mixing with other components. The EC of the final potting mix should be <1.0.
- Ammonium level should be low.

The UMass Soil Testing Lab has a specific test for composts.

Can I use my cull pile as compost?
The answer is "yes" if you have treated your cull pile like a compost pile - turning it frequently to encourage heating and thus complete decomposition and killing of weed seeds and plant pathogens. Compost made from a cull pile should meet the standards of a good compost in Question 1.

Most of the time the answer to this question is "no" because the cull piles at most greenhouses have not been turned and allowed to heated and therefore the plant material is probably not completely decomposed and weed seeds and disease organisms are probably still alive. A static cull pile is not a compost pile, it's just a trash pile!

Can a compost medium supply all the nutrients for bedding plants and potted plants?
Often composts are described as being "nutrient rich". For the purpose of increasing the long term fertility of soil for outdoor field crops regular application of compost is effective. When used as a component in a potting mix, most of the time, the compost cannot supply enough nutrients and additional fertilizer must be applied.

Calibrachoa growing in Fafard 3B and 100% of two types of composted cranberry pomace. In some cases it may be possible to grow in 100% compost.

Photos: Douglas Cox, UMass

Marigolds (left) and tomatoes (right) were grown in Metro Mix (top) and wood products compost (bottom). No fertilizer has been applied to either flat since the seeds were sown about 4 weeks earlier. Low fertility accounts for the small plants growing in the compost.

Can I use 100% compost to grow bedding and potted plants?
It's possible, as the previous picture shows, but the commonly accepted guidelines suggest using compost at about 30-40% by volume. Most composts are too heavy, hold too much water or drain too much, or have too high a starting EC to be used 100%.

Other Components for Organic Media

Many materials used to make growing media in “traditional” greenhouses can be used for organic production. However, to be certain, check with your organic certifier. Consider the comments in the table when you choose a component.

Material	Comments
Field soil	No chemicals. Obtain from a certified organic source.
Sand	Clean coarse or “sharp” sand.
Sphagnum peat moss	No fertilizer or wetting agent.
Shredded newspaper	No color ink. No more than 25% by volume.
Alfalfa	Dried and screened, moistened, composted 20 days, and dried again.
Perlite or vermiculite	Use perlite for drainage and aeration. Use vermiculite for increasing water-holding capacity. Asbestos in vermiculite?
Coir dust or fiber	Salt content?

References

The Guide to Agricultural Composting
http://www.mass.gov/agr/programs/compost/docs/Guide_to_Ag_Composting2010.pdf

Cox, D.A. 2008. *Organic Growing Media and Fertilizers for Greenhouses.*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/dc_organic_fert.html

INORGANIC WASTE CHECKLIST

Options for Pesticide Disposal

- ✓ If a pesticide is not able to be used according the label because it is too old and/or no longer legal to use the pesticide, it is considered hazardous waste and must be disposed of accordingly.

- ✓ Contact the Massachusetts Department of Agricultural Resources for possible planned collection events http://www.mass.gov/agr/pesticides/waste/index.htm.

- ✓ Contact your town administration for possible pesticide disposal collection programs occurring at the local or regional level.

- ✓ Contact a Licensed Hazardous Waste Hauler.

Options for Disposal of Agricultural Plastics

- ✓ In Massachusetts, the Department of Environmental Protection open burning regulations do not allow for the burning of agricultural plastics.

- ✓ Check with your local municipal recycling center.

- ✓ Contact a plastic recycler company.

- ✓ Hire a commercial waste hauler.

INORGANIC WASTE MANAGEMENT

Pesticide Disposal

Many pesticide labels will have instructions for proper disposal. If you are not able to use the pesticide according the label because it is too old and/or no longer legal to use, the pesticide is considered hazardous waste. The Massachusetts Department of Agricultural Resources has held many subsidized collection events in the past. Also, individual communities throughout Massachusetts have annual household hazardous waste collection events. If you are not able to participate in these types of events, then you will have to contact a licensed hazardous waste hauler company.

Contact the Massachusetts Department of Agricultural Resources http://www.mass.gov/agr/pesticides/waste/index.htm and your town administration to find out if there are pesticide disposal collection programs happening at the local or regional level

OR

Contact a Licensed Hazardous Waste Hauler. The Massachusetts Statewide Contract for Hazardous Materials Collection lists the following vendors:

- Clean Harbors
- Enviro-Safe Corporation
- Medical Waste Disposal Company
- Triumvirate Environmental Services
- Stericycle, Inc.
- Veolia Environmental Services Technical Solutions, LLC (formerly Onyx Environmental)

Agricultural Plastics

The term "agricultural plastics covers a wide variety of products and plastic types. These include:

- Low density polyethylene (LDPE) and low linear density polyethylene (LLDPE) film used to make silage and haylage bags, bunker silo covers, greenhouse covers, bale wrap, mulch film, and other flexible products.
- High density polyethylene (HDPE), a more rigid plastic used in pesticide containers and nursery pots.
- Polystyrene (PS), another rigid plastic used in nursery containers and flats.
- Polypropylene (PP), used in nursery pots, row covers and woven tarps.

Recycling

Recycled plastics are typically chopped and washed to remove contaminants. They are then dried, melted, and formed into pellets that serve as the raw material to make garbage bags, pilings, fencing, road signs, roofing materials, and many other products.

For a successful plastic recycling program, nurseries must have an on-site system for:
• Collecting and storing plastics.
• Separating the plastics into different types.
• Ensuring the recycled plastics are dry and clean.

Contact a plastic recycler company for more information. For a list of companies in the Northeast see the fact sheet “Recycling Your Used Agricultural Plastics” at http://www.umassgreeninfo.org/fact_sheets/plant_culture/recycle_ag_plastic.pdf

Disposal
In Massachusetts, the Department of Environmental Protection open burning regulations does not allow for the burning agricultural plastics. Burning plastic can release toxic and potentially cancer-causing chemicals into the air, where they can be inhaled by humans and animals and deposited in soil and surface water.

If you have plastic waste for disposal, first check with your local municipal recycling center or a plastic recycler company. The second option for proper disposal is to hire a commercial waste hauler.

References
Massachusetts Department of Agricultural Resources Pesticide Storage and Disposal http://www.mass.gov/agr/pesticides/waste/index.htm

CHECKLIST
ENERGY CONSERVATION

New greenhouse designs, better glazing, improved heating and ventilating equipment and new management systems should be included when upgrading or adding on. With typical annual energy usage being 75% for heating, 15% for electricity, and 10% for vehicles, efforts and resources should be put where the greatest savings can be realized. Prices are at the time of publication.

Reduce Air Leaks

- ✓ **Keep doors closed** - use door closer or springs.

- ✓ **Weather-strip doors, vents, and fan openings.** For example, a 48-inch fan louver that fails to close properly leaving 1-inch gaps, allows 23,000 Btu/hr of heat to escape, costing $0.53 if you are burning $2.30 fuel oil (prices at time of publication).

- ✓ **Lubricate louvers** frequently so that they close tightly. A partially open louver may allow several air changes per hour. Additional fuel is needed to heat this air. Shut off some fans during the winter and cover openings with insulation or plastic to reduce infiltration of air.

- ✓ **Repair broken glass** or holes in the plastic covering.

Double Covering

- ✓ **Line sidewalls and endwalls** of greenhouse inside with poly or bubble wrap to achieve the thermopane effect. Install double wall polycarbonate structured sheets to get insulation effect and reduce recovering labor.

- ✓ **Use poly with an infrared inhibitor** on the inner layer for 15% savings. Payback is two to three months.

- ✓ **Add a single or double layer of plastic** over older glasshouses to reduce infiltration and heat loss by 50%.

Energy Conserving Blanket

- ✓ **Install a thermal blanket** for 20 to 50% savings. Cost is $1.50 to $2.50 per square foot. Payback is one to two years. Tight closures should be maintained where curtains meet sidewalls, framing or gutters. Use a U-shaped trap to prevent heat from escaping overhead. Heat and water lines should be insulated or located below the blanket.

Foundation and Sidewall Insulation

- ✓ **Insulate the foundation.** Place 1- to 2-inch polyurethane or polystyrene board to 18 inches below ground to reduce heat loss. This can increase the soil temperature near the sidewall as much as 10 °F during the winter.

- ✓ **Insulate the kneewall** or sidewall to bench height. Use 1- to 2-inch insulation board. Applying 2 inches of foam insulation to a 3-foot-high kneewall on a 28-foot by 100-foot greenhouse will save about 400 gallons of fuel oil per year.

- ✓ **Insulate behind sidewall heat pipes.** Use aluminum faced building paper or insulation board behind to radiant heat back into the growing area. Leave air space next to wall to prevent frost damage to the wall.

Site Location

- ✓ **Locate new greenhouses in sheltered areas** to reduce wind-induced heat loss, if this does not reduce light.

- ✓ **Install windbreaks** on the north and northwest sides of the greenhouse. The windbreak can be a double row of conifer trees or plastic snow fence.

Space Utilization

- ✓ **Increase space utilization** to 80 to 90% with peninsular or movable benches.

- ✓ **Install multi-level racks** for crops that don't require high light levels.

- ✓ **Grow a crop** of hanging baskets on overhead rails or truss-mounted conveyor system.

- ✓ **Roll-out bench system** can double growing space. Plants are moved outside during the day.

Efficient Heating System

- ✓ **Installation of floor or under-bench heat** will allow air temperature to be set 5 to 10 ºF lower.

- ✓ **Yearly maintenance** - Check boiler, burner and backup systems to make sure they are operating at peak efficiency. Have furnaces cleaned and adjusted and an efficiency test run before heating season. A 2% increase in efficiency for a 30-foot by 150-foot greenhouse will save about 200 gallons of fuel oil.

Under-bench heat system
Photo: Tina Smith, UMass Extension

- ✓ **Clean heating pipes** and other radiation surfaces frequently.

- ✓ **Check accuracy of thermostats** - correcting a reading that is 2 ºF high will save $100 to $200.

- ✓ **Install electronic thermostats** or controllers with a 1 °F accuracy. Potential yearly savings of 500 gallons of fuel oil in a 30 foot by 100 foot greenhouse when changing from a mechanical to electronic thermostat or controller.

- ✓ **Aspirate thermostats** or sensors for more uniform temperature control. Differential between on and off can be reduced as much as 6 ºF.

- ✓ **Install horizontal air flow** (HAF) fans to get more uniform temperature in growing area.

- ✓ **Insulate distribution pipes** in areas where heat is not required.

- ✓ **Check and repair** leaks in valves, steam traps, and pipes.

Efficient Cooling System

- ✓ **Build a new greenhouse** with open-roof design to eliminate the need for fans.

- ✓ **Install roll-up** or guillotine sides to reduce the need for fan ventilation.

- ✓ **Use shading** to reduce the need for mechanical cooling.

- ✓ **Install evaporative** cooling to get better temperature control during the summer.

- ✓ **Select fans** that meet AMCA standards and have a Ventilation Efficiency Ratio greater than 15.

- ✓ **Use the largest diameter fan** with the smallest motor that meets ventilation requirements.

- ✓ **Keep doors closed** when fans are operating. Locate intake louvers to give uniform cooling.

Conserve Electricity

- ✓ **Have wiring system inspected** for overloading, corroded parts, and faulty insulation.

- ✓ **Replace 3 hp or larger motors** with high efficiency ones to reduce electric consumption by 2 to 5%.

- ✓ **Check for proper belt** tension and alignment.

- ✓ **Replace incandescent bulbs** with low wattage fluorescent or HID bulbs. Save two-thirds on electricity.

- ✓ **Install motion detectors** to control security lights so they are not on all the time.

Trucks and Tractors

- ✓ **Regularly scheduled tune-ups** can save 10% on fuel usage. Keep tires properly inflated.
- ✓ **Avoid lengthy idling**. Idling can consume 15 to 20% of the fuel used.
- ✓ **Run equipment** in the proper gear for the load.

Water Systems

- ✓ **Locate hot water tanks** as close as possible to the largest and most frequent use. Insulate pipes.
- ✓ **Heat water to the lowest** temperature needed; usually 120 ºF is adequate.
- ✓ **Use pipe size large enough** to supply necessary water at minimum friction loss.
- ✓ **Eliminate water leaks.** A dripping faucet at 60 drops per minute will waste 113 gallons per month.

Management

- ✓ **Lower night temperature.** Fuel consumption is reduced 3% for each 1 ºF night temperature is lowered.
- ✓ **Delay starting the greenhouse** by a week or more. Build a germination/growth chamber to start seedlings.
- ✓ **Keep growing areas full** at all times.
- ✓ **Use root zone heating.**

Energy Resources

Booklet: "Energy Conservation for Commercial Greenhouses" - NRAES-3, 100 pages, $21.25 available from the Resource Center, Unit 4035, W.B. Young Building, Rm.2, Storrs, CT 06269-4035. Make check payable to UConn. Price includes postage and handling.

Fact Sheets: For details on energy use in greenhouses see the following **fact sheets** *by John Bartok* available from **University of Massachusetts Extension**: http://www.umass.edu/umext/floriculture/

- Corn - A Home Grown Heat Source
- Insulation-Know How
- Natural Ventilation in Hoophouses
- Combat Higher Fuel Prices with Efficient Heating Systems
- High Tunnels - Low Cost Seasonal Growing Space

Corn Burning Furnace in Greenhouse

- Greenhouse Energy Conservation Checklist
- Fuels and Alternate Heat Sources for Commercial Greenhouses
- Horizontal Air Flow is Best for Greenhouse Air Circulation
- Mechanization and Labor Saving for the Small Grower
- Retractable Roof Greenhouses and Shadehouses
- Root Zone Heating Systems
- Selecting and Building a Commercial Greenhouse
- Selecting an Energy/Shade Screen System
- Selecting and Maintaining Thermostats
- Will the Zoning Commission Approve Your Greenhouse?
- Greenhouse Ventilation
- Greenhouse Facilities Master Plan
- Problems With Using Unvented Heaters in Greenhouses
- Geothermal Heat for Greenhouses
- Wood Heat for Greenhouses

Wood chips are being used as a source of fuel to heat greenhouses.

Massachusetts Department of Agriculture (MDAR) Energy Program
http://www.mass.gov/agr/programs/energy/index.htm
The MDAR Energy Program's primary function is to promote energy knowledge and awareness and to facilitate the implementation of energy related projects for our agri-businesses through energy efficiency, energy conservation, and renewable energy applications, as a means to reduce both energy costs and environmental pollution. Information on grants and funding are also available on this website.

Energy Broker/Consultant
Large energy users often hire a consultant or broker to assist in reducing and managing their electricity and natural gas, fuel oil and other energy expenses. The consultant analyzes business energy use and helps negotiate contracts and rates.

Compare Fuel Efficiency
Consider the cost of different fuels in terms of energy value.
To determine the cost and value of a fuel, first consider the number of British Thermal Units (Btu) produced by the fuel (Table 1). To determine the Btu value per dollar, divide the fuel's Btu per unit by the unit price. Example: #2 Fuel Oil BTU/$ = $\frac{\text{138,500 BTU/gal}}{\textbf{\$2.50/gal}}$ = 55,400 BTU/dollar

Table 1. Approximate Heating Value of Common Fuels

Fuel type	**Heating value**	
Natural Gas	1,030 Btu/cu ft	100,000 Btu/therm
Propane	2,500 Btu/cu ft	92,500 Btu/gal
Methane	1,000 Btu/cu ft	
Landfill gas	500 Btu/cu ft	
Butane	3,200 Btu/cu ft	130,000 Btu/gal
Methanol		57,000 Btu/gal
Ethanol		76,000 Btu/gal
Fuel Oil		
Kerosene	135,000 Btu/gal	
#2	138,500 Btu/gal	
#4	145,000 Btu/gal	
#6	153,000 Btu/gal	
1 Barrel of oil = 42 gallons		
Waste oil	125,000 Btu/gal	
Biodiesel - Waste vegetable oil	120,000 Btu/gal	
Gasoline	125,000 Btu/gal	
Wood		
Softwood	2-3,000 lb/cord	10-15,000,000 Btu/cord
Hardwood	4-5,000 lb/cord	18-24,000,000 Btu/cord
Sawdust - green	10-13 lb/cu ft	8-10,000,000 Btu/ton
Sawdust - kiln dry	8-10 lb/cu ft	14-18,000,000 Btu/ton
Chips - 45% moisture	10-30 lb/cu ft	7,600,000 Btu/ton
Hogged	10-30 lb/cu ft	16-20,000,000 Btu/ton
Bark	10-20 lb/cu ft	9-10,500,000 Btu/ton
Wood pellets - 10% moisture	40-50 lb/cu ft	16,000,000 Btu/ton
Hard Coal (anthracite)	13,000 Btu/lb	26,000,000 Btu/ton
Soft Coal (bituminous)	12,000 Btu/lb	24,000,000 Btu/ton
Rubber - pelletized	16,000 Btu/lb	32-34,000,000 Btu/ton
Plastic	18-20,000 Btu/lb	
Corn - shelled	7,800-8,500 Btu/lb	15-17,000,000 Btu/ton
cobs	8,000-8,300 Btu/lb	16-17,000,000 Btu/ton
Electricity	3412 Btu/kilowatt hour	

Prepared by: John W. Bartok, Jr., Agricultural Engineer
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December 2004

GOOD AGRICULTURAL PRACTICES (GAP)

In October 1998 the U.S Department of Agriculture and the U.S Food & Drug Administration, in response to food safety concerns, issued guidance documents for the fresh fruit & vegetable industry that provide guidance for reducing the possibility of contamination of fresh produce by microbial organisms. Shortly thereafter, many wholesale produce companies began to seek assurances that fresh produce suppliers were following the Good Agricultural Practices that these documents recommended.

In January 2002, the USDA implemented the USDA GAP & GHP audit verification program.

This program is an audit based service. It is provided in order to assess a company's efforts to minimize the possibility of contamination of fresh fruits and vegetables by microbial contamination. Audits are intended to occur on a scheduled basis at a minimum of once a year. The responsibility for continuing product safety and the continued observance of practices leading to a minimized possibility of microbial contamination rests with the company.

Auditors for this program are licensed by the USDA Agricultural Marketing Service [AMS], Fresh Products Branch.

The mission of this program is to provide a uniformly applied national program for the U.S fresh produce industry for purposes of verification with GAP & GHP.

For details and an application form for GAP, contact Massachusetts Department of Agriculture:
http://www.mass.gov/agr/farmproducts/gap_ghp.htm

References

Agriculture Environmental Management (AEM), AEM Tier II Worksheet, Fertilizer Storage & Handling in the Greenhouse
http://www.agmkt.state.ny.us/SoilWater/aem/forms/Greenshouse%20Fertilizer%20Storage.pdf

Aldrich R.A. and J. Bartok, Jr. 1994. *Greenhouse Engineering*. NRAES-33.

Bartok, J.W., Jr. 2005. *Fuels and Alternative Heat Sources for Commercial Greenhouses*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_fuels.htm

Bartok, J.W. 2005. *Horizontal Air Flow is Best for Greenhouse Air Circulation*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_haf.htm

Bartok, J.W., Jr. 2009. *Rainwater Harvesting*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_rainwater_harvesting.pdf

Bartok, J.W., Jr. 2009. *Sizing the Greenhouse Water System*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_sizing_greenhouseirrigation.pdf

Bartok, J.W., Jr. 2005. *Selecting and Building a Commercial Greenhouse*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/jb_building_gh.htm

Bartok, J.W., Jr. 2010 *Stormwater and Wastewater Management for Greenhouses*
Fact Sheet

Biernbaum, J.A. 1995. *Water Quality. Tips on Growing Bedding Plants*. The Ohio Florists' Association.

Clean and Green, Water Quality Action Manual for Greenhouse and Nursery Growers, 1992
Horticultural Water Quality Alliance. Printed by Florists' Mutual Insurance Company

Cox, D.A Greenhouse *Irrigation Water Quality: pH and Alkalinity*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/waterph.html

Cox, D.A 1993 *Groundwater and Your Greenhouse*.
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/water.html

Cox D.A. 2001. *How to Prevent Iron Deficiency in Spring Greenhouse Crops*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/irondef.html

Cox, D.A. 1985. *Nitrogen recovery by seed geranium as influenced by nitrogen source*. HortScience 20:923-925.

Cox, D.A. 2008. *Organic Growing Media and Fertilizers for Greenhouses.*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/dc_organic_fert.html

Cox, D.A. 1993. *Reducing nitrogen leaching-losses from containerized plants: The effectiveness of controlled release fertilizers.* J. Plant Nutr. 16(3):533-545.

Cox D.A. *Current Methods of Greenhouse Media Testing and How They Differ*. University of Massachusetts Extension.
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/ghmedia_tests.htm

Cox D.A. *Use "BMPs" to Increase Fertilizer Efficiency and Reduce Runoff*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/bmp.html

Cox D.A. *Fertilizing Bedding Plants*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/bedfert.html

Cox D.A. *How to Use pH and EC "Pens" to Monitor Greenhouse Crop Nutrition*. University of Massachusetts Extension.
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/phecpens.html

Faust, J. E. and E. W. *Irrigation Water Quality for Greenhouse Production*, Agricultural Extension Service, University of Tennessee.
http://www.utextension.utk.edu/publications/pbfiles/pb1617.pdf.

Faust, J. E. and E. W. *Growing Media for Greenhouse Production,* University of Tennessee.
http://www.utextension.utk.edu/publications/pbfiles/PB1618.pdf

Jenkins J. and T. Smith. 1989. *Understanding Pesticide Persistence and Movement in Soils for Groundwater Protection.* Nursery Notes: 2(1)

Kuepper, G. and K. Everett. 2004. *Potting Mixes for Certified Organic Production*
http://attra.ncat.org/attra-pub/PDF/potmix.pdf

Lopes, M. and G. Walker. 1990. *You and Your Well: How to be responsible for your private water supply*. Issues in Water Quality. Fact Sheet, University of Massachusetts.

McAvoy R.J. 2005. *Techniques for Greenhouse Tomatoes*, University of Connecticut:
http://www.hort.uconn.edu/ipm/greenhs/htms/Tomgraft.htm

McAvoy, R.J. 1995. *Managing nitrogen in greenhouse crops: Nitrogen sources, crop fertility, and water quality*. Conn. Grnhse. Newsletter 184:18-29.

Newman, J. 2008. *Greenhouse and Nursery Management Practices to Protect Water Quality.* University of California Agriculture and Natural Resources Publication 3508.

Pesticide Storage Mixing and Loading Guidelines for Applicators, Massachusetts Department of Agricultural Resources
http://www.mass.gov/agr/pesticides/waste/index.htm

Robbins, J.A. and M. R. Evans. *Growing Media for Container Production in a Greenhouse or Nursery*, University of Arkansas Division of Agriculture, Cooperative Extension Service
http://www.uaex.edu/Other_Areas/publications/PDF/FSA-6098.pdf

Smith, T.M. 2009. *Fertilizer Injectors for Greenhouses*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/fert_injector.html

Smith, T.M. 2004. *Effects of pH on Pesticides and Growth Regulators*
http://www.umass.edu/umext/floriculture/fact_sheets/greenhouse_management/ph_pesticides.htm

Stack, L. Editor. *2009-2010 New England Greenhouse Floriculture Guide; A Management Guide for Insects, Diseases, Weeds and Growth Regulators*. Northeast Greenhouse Conference:
http://www.negreenhouse.org/index.html

Strategic Recommendations for Managing Invasive Plants in Massachusetts
http://www.mass.gov/dfwele/dfw/nhesp/conservation/pdf/invasive_plant_strategicplan.pdf

United States Environmental Protection Agency, Pesticide and Fertilizer Storage
http://www.epa.gov/oecaagct/ag101/pestfertilizer.html

Whipker, B.E., Cavins, T.J. and W. C. Fonteno. *1, 2, 3's of PourThru*. North Carolina State University.
http://www.ces.ncsu.edu/depts/hort/floriculture/Florex/PourThru%20Handout%20123s.pdf

Resources

Organizations and Services

Massachusetts Department of Agricultural Resources (MDAR)
251 Causeway Street, Suite 500
Boston, MA 02114-2151
Phone: (617) 626-1700 Fax: (617) 626-1850
Division of Technical Assistance: (617) 626-1773
http://www.Mass.gov/agr
http://www.Mass.gov/Massgrown

Massachusetts Farm Bureau Federation Inc.
466 Chestnut Street.
Ashland, MA 01721
Phone: (508) 881-4766 Fax: (508) 881-4768
http://www.mfbf.net/

University of Massachusetts Extension
Greenhouse Crops and Floriculture Program
Resource for greenhouse crops in Massachusetts.
http://www.umass.edu/umext/floriculture/

UMass Extension Plant Diagnostic Lab (Plant disease diagnosis, weed ID, insect ID)
Contact: mbdicklo@umext.umass.edu Plant Diagnostic Laboratory 160 Holdsworth Way, Holdsworth Natural Resources Center, University of Massachusetts, Amherst, MA 01003
Phone: (413) 545-3208
http://www.umass.edu/umext/floriculture/grower_services/index.html

University of Massachusetts Soil & Tissue Testing Laboratory
West Experiment Station, 682 North Pleasant St. UMass, Amherst, MA 01003
Phone: (413) 545-2311
http://www.umass.edu/plsoils/soiltest/

USDA-Natural Resource Conservation Service (NRCS)
451 West Street, Amherst, MA 01002
Phone: (413) 253-4350
http://www.ma.nrcs.usda.gov
http://www.nrcs.usda.gov/technical/ENG/ (Conservation Engineering)
http://www.ma.nrcs.usda.gov/technical/soils/index.html (Massachusetts Soil Surveys)
The Natural Resources Conservation Service is the federal agency that shows farmers and landowners how to improve and protect their natural resources. NRCS is not a regulatory agency. Its mission is to introduce people to conservation practices and federal conservation programs that can improve water quality and maintain healthy and productive lands. Landowners and NRCS specialists work together on a voluntary basis.

Massachusetts Department of Environmental Protection (Mass DEP)
One Winter Street, Boston, MA 02108
Phone: (617) 292-5500 Fax: (617)556-1049
Wetland information
http://www.mass.gov/dep/water/waterres.htm
Composting information
http://www.mass.gov/dep/recycle/index.htm

Massachusetts Department of Environmental Protection Water Management Program
One Winter Street, Boston, MA 02108
Phone: (617) 292-5706
http://www.mass.gov/dep/water/approvals/wmgforms.htm

Massachusetts Division of Fisheries and Wildlife
251 Causeway St., Suite 400, Boston, MA 02114
Phone: (617) 626-1590
http://www.mass.gov/masswildlife

Greenhouse Production: Publications and On-line Resources

UMass Extension Greenhouse Crops and Floriculture Program
Greenhouse Crops Pest Message for Massachusetts
http://www.negreenhouseupdate.info/ (New England Greenhouse Update)
The greenhouse message is compiled from information gathered by Extension educators in Massachusetts and Connecticut and enables growers of greenhouse crops to be in touch with local pest activity and other problems that occur in greenhouses 24 hours a day. Contact: Tina Smith, tsmith@umext.umass.edu to be added to the email list.

New England Greenhouse Floriculture Guide; A Management Guide for Insects, Diseases, Weeds and Growth Regulators. Available through: UMass Extension Bookstore, 101 University Drive, Suite A4, Amherst, MA 01002. Phone: (413) 545-2717, on-line at: http://www.umassextensionbookstore.com or from the Northeast Greenhouse Conference: http://www.negreenhouse.org/index.html

Pest Identification
On-line Photo Library: Greenhouse Insects, Diseases, Mites, Weeds, Biological Control and Nutritional Disorders
http://www.negreenhouseupdate.info/index.php/photo-library

USDA Systematic Entomology Laboratory (SEL) provides specimen identification assistance as a free service. For information on sending samples see:
http://www.ars.usda.gov/Main/docs.htm?docid=9353&pf=1&cg_id=0

Massachusetts Prohibited Plants
List of plants: http://www.mass.gov/agr/farmproducts/Prohibited_Plant_Index2.htm.
Report: *Strategic Recommendations for Managing Invasive Plants in Massachusetts*
http://www.mass.gov/dfwele/dfw/nhesp/conservation/pdf/invasive_plant_strategicplan.pdf

Registration Status for Commercial Pesticide Products in Massachusetts
http://www.kellysolutions.com/MA/pesticideindex.htm

Pesticide Labels
Crop Data Management Systems, Inc.
http://www.cdms.net
This site lists nearly 100 pesticide companies that produce products for the turf and ornamentals (T&O) market (as well as ag products). The user of this site can obtain specimen labels of specific products along with the Material Safety Data Sheets (MSDS) that accompany the labels.

Greenbook
http://www.greenbook.net
This site lists a number of products and can be easily searched by company, active ingredient, and product trade name. Along with being able to obtain specimen labels and the MSDS, the user can usually also access a "product summary sheet," Department of Transportation (DOT) information, mode of action sheet, state registration information, supplemental label information, and other valuable information about each product.

Worker Protection Standards
http://www.epa.gov/oecaagct/htc.html

North Carolina State Nursery Crops Fact Sheets (Pour Thru, Production information)
http://www.ces.ncsu.edu/depts/hort/nursery/

Appropriate Technology Transfer for Rural Areas (ATTRA) http://www.attra.org/
National Sustainable Agriculture Information Service is managed by the National Center for Appropriate Technology (NCAT) and is funded under a grant from the United States Department of Agriculture's Rural Business-Cooperative Service. It provides information and other technical assistance to farmers, ranchers, Extension agents, educators, and others involved in sustainable agriculture in the United States.

Publication: Plants for Constructed Wetlands
Rain Gardens: A Household Way to Improve Water Quality in Your Community
http://www.umassgreeninfo.org/fact_sheets/plant_culture/rain_gardens_07.pdf

Publication: Water and Nutrient Management for Greenhouses NRAES-56, is available for $20 each from NRAES, Cooperative Extension, 152 Riley-Robb Hall, Ithaca, NY 14853-5701. For more information call (607)255-4080.

Grower's Guide to Water, Media, and Nutrition for Greenhouse Crops is $55 per copy and can be ordered from GrowerTalks Bookshelf, PO Box 9, 335 N. River St., Batavia, IL 60510. For more information call 1-800-456-5380.

Good Agricultural Practices (GAP) For details and an application form for GAP, contact Massachusetts Department of Agriculture: http://www.mass.gov/agr/farmproducts/gap_ghp.htm

Organic Information
The National Organic Program Guidelines
http://www.ams.usda.gov/nop/nop/nophome.html

Organic Materials Review Institute (OMRI) www.omri.org
The OMRI is a nonprofit organization that specializes in the review of pesticides and fertilizers for use in organic production, processing and handling. OMRI provides guidance on the suitability of material inputs under the USDA Organic Program standards

The Guide to Agricultural Composting
http://www.mass.gov/agr/programs/compost/docs/Guide_to_Ag_Composting2010.pdf

Commercial Greenhouse Water Testing Laboratories

- J.R. Peters Lab - Horticultural Testing, 866-522-5752
  www.jrpeterslab.com
- Harris Laboratories, 402-476-0300
  http://ag.agsource.com/
- SunGro Horticulture , 425-641-7577
  http://www.sungro.com/services_analytical.php

Energy Resources and Publications

Booklet: "Energy Conservation for Commercial Greenhouses" - NRAES-3, 100 pages, $21.25 available from the Resource Center, Unit 4035, W.B. Young Building, Rm.2, Storrs, CT 06269-4035. Make check payable to UConn. Price includes postage and handling.

Renewable Energy Resources for Massachusetts Farms and Greenhouses
University of Massachusetts Extension
http://www.umass.edu/agland/green_energy/index.html

Massachusetts Department of Agriculture Energy Program
http://www.mass.gov/agr/programs/energy/index.htm
The MDAR Energy Program's primary function is to promote energy knowledge and awareness and to facilitate the implementation of energy related projects for our agri-businesses through energy efficiency, energy conservation, and renewable energy applications, as a means to reduce both energy costs and environmental pollution.

Greenhouse Engineering. J.A. Aldrich and J. Bartok Jr. NRAES-33. 1994. Available from the Northeast Regional Agricultural Engineering Service
http://www.nraes.org/nra_order.taf?_function=detail&pr_booknum=nraes-33

Biomass Energy Crops: Potential for Massachusetts
http://www.mass.gov/doer/programs/renew/bio-ma-potential-crop.pdf

Recycling Your Used Agricultural Plastics Fact Sheet
List of companies in the Northeast
http://www.umassgreeninfo.org/fact_sheets/plant_culture/recycle_ag_plastic.pdf

Grower Membership Associations

- Massachusetts Flower Growers Association
  http://www.massflowergrowers.com/
- Massachusetts Nursery and Landscape Association (MNLA)
  http://www.mnla.com/
- New England Nursery Association Inc.
  http://www.nensyassn.org/
- American Nursery and Landscape Association (ANLA)
  http://www.anla.org/
- Northeast Organic Farmers Association
  http://www.nofa.org/index.php

Appendix A.

Massachusetts Prohibited Plant List

**Effective 1/1/06: The importation of the plants listed below are banned by the listed (importation ban) date. The one and three year propagation ban phase-out dates listed are allowed only on plants that have entered the state *prior to the listed importation ban date* and remain in the channels of trade within the Commonwealth.

NOTE: After the listed "propagation ban" date, the sale, trade, purchase, distribution and related activities for that plant are prohibited.

Latin Name	Common Name	Importation Ban	Propagation Ban
Acer platanoides	Norway maple	7/1/06	1/1/09
Acer pseudoplatanus	Sycamore maple	7/1/06	1/1/09
Aeginetia		1/1/06	1/1/06
Aegopodium podagraria	Bishop's goutweed; bishop's weed; goutweed	7/1/06	1/1/09
Ageratina adenophora	Crofton weed	1/1/06	1/1/06
Ailanthus altissima	Tree of Heaven	1/1/06	1/1/06
Alectra Thunb.		1/1/06	1/1/06
Alliaria petiolata	Garlic mustard	1/1/06	1/1/06
Alternanthera sessilis	Sessile joyweed	1/1/06	1/1/06
Ampelopsis brevipedunculata	Porcelain-berry; Amur peppervine	1/1/06	1/1/06
Anthriscus sylvestris	Wild chervil	1/1/06	1/1/06
Arthraxon hispidus	Hairy joint grass; jointhead; small carpetgrass	1/1/06	1/1/06
Asphodelus fistulosus	Onion weed	1/1/06	1/1/06
Avena sterilis	Animated oat	1/1/06	1/1/06
Azolla pinnata	Mosquito fern	1/1/06	1/1/06
Berberis thunbergii	Japanese Barberry	7/1/06	1/1/09
Berberis vulgaris	Common barberry; European barberry	1/1/06	1/1/06
Cabomba caroliniana	Carolina Fanwort; fanwort	1/1/06	1/1/06
Cardamine impatiens	Bushy rock-cress; narrowleaf bittercress	1/1/06	1/1/06
Carex kobomugi	Japanese sedge; Asiatic sand sedge	1/1/06	1/1/06
Carthamus oxyacantha Bieb.	Wild safflower	1/1/06	1/1/06
Caulerpa taxifolia		1/1/06	1/1/06
Celastrus orbiculatus	Oriental bittersweet; Asian or Asiatic bittersweet	1/1/06	1/1/06
Centaurea biebersteinii	Spotted knapweed	1/1/06	1/1/06
Chrysopogon aciculatus	Pilipiliula	1/1/06	1/1/06
Commelina benghalensis	Benghal dayflower	1/1/06	1/1/06
Crupina vulgaris	Common crupina	1/1/06	1/1/06
Cuscuta	Dodder	1/1/06	1/1/06
Cynanchum louiseae	Black Swallow-wort; Louise's swallow-wart; Autumn olive	1/1/06	1/1/06
Cynanchum rossicum	European swallow-wort;	1/1/06	1/1/06
Digitaria abyssinica		1/1/06	1/1/06
Digitaria scalarum	African couch grass	1/1/06	1/1/06
Digitaria velutina	Velvet fingergrass	1/1/06	1/1/06

Latin Name	Common Name	Importation Ban	Propagation Ban
Drymaria arenarioides	Alfombrilla	1/1/06	1/1/06
Egeria densa	Brazilian waterweed; Brazilian eloda	1/1/06	1/1/06
Eichhornia azurea	Anchored waterhyacinth	1/1/06	1/1/06
Elaeagnus umbellata	Autumn Olive	1/1/06	1/1/06
Emex australis	Three-cornered jack	1/1/06	1/1/06
Emex spinosa	Devil's thorn	1/1/06	1/1/06
Epilobium hirsutum	Hairy willow-herb; Codlins and Cream	1/1/06	1/1/06
Euonymus alatus	Winged euonymus; Burning Bush	7/1/06	1/1/09
Euphorbia esula	Leafy Spurge; Wolf's Milk	1/1/06	1/1/06
Euphorbia cyparissias	Cypress spurge	1/1/06	1/1/06
Festuca filiformis	Hair fescue; fineleaf sheep fescue	1/1/06	1/1/06
Frangula alnus	European buckthorn; glossy buckthorn	1/1/06	1/1/06
Galega officinalis	Goatsrue	1/1/06	1/1/06
Glaucium flavum	Sea or horned poppy; yellow horn poppy	1/1/06	1/1/06
Glyceria maxima	Tall mannagrass; reed mannagrass	1/1/06	1/1/06
Heracleum mantegazzianum	Giant hogweed	1/1/06	1/1/06
Hesperis matronalis	Dames Rocket	1/1/06	1/1/06
Homeria	Cape tulip	1/1/06	1/1/06
Humulus japonicus	Japanese hops	1/1/06	1/1/06
Hydrilla verticillata	Hydrilla; water-thyme; Florida elodea	1/1/06	1/1/06
Hygrophila polysperma	Miramar weed	1/1/06	1/1/06
Imperata brasiliensis	Brazilian satintail	1/1/06	1/1/06
Ipomoea aquatica	Chinese waterspinach	*Permit required-contact Department	*Permit required-contact Department
Iris pseudacorus	Yellow iris	1/1/06	1/1/06
Ischaemum rugosum	Murain-grass	7/1/06	1/1/07
Lagarosiphon major	Oxygen weed	1/1/06	1/1/06
Lepidium latifolium	Broad-leafed pepperweed; tall pepperweed	1/1/06	1/1/06
Leptochloa chinensis	Asian sprangletop	1/1/06	1/1/06
Ligustrum obtusifolium	Border privet	1/1/06	1/1/06
Limnophila sessiliflora	Ambulia	1/1/06	1/1/06
Lonicera japonica	Japanese honeysuckle	7/1/06	1/1/09
Lonicera maackii	Amur honeysuckle	7/1/06	1/1/09
Lonicera morrowii	Morrow’s honeysuckle	7/1/06	1/1/09
Lonicera tatarica	Tatarian honeysuckle	7/1/06	1/1/09
Lonicera x bella [morrowii x tatarica]	Bell’s honeysuckle	7/1/06	1/1/09
Lycium ferrocissimum	African boxthorn	1/1/06	1/1/06
Lysimachia nummularia	Creeping jenny; moneywort	7/1/06	1/1/09
Lythrum salicaria	Purple loosestrife	1/1/06	1/1/06
Melaleuca quinquenervia	Melaleuca	1/1/06	1/1/06
Melastoma malabathricum		1/1/06	1/1/06
Microstegium vimineum	Japanese stilt grass; Nepalese browntop	1/1/06	1/1/06
Mikania cordata	Mile-a-minute	1/1/06	1/1/06
Mikania micrantha	Mile-a-minute	1/1/06	1/1/06

Latin Name	Common Name	Importation Ban	Propagation Ban
Mimosa diplotricha		1/1/06	1/1/06
Mimosa invisa	Giant sensitive plant	1/1/06	1/1/06
Mimosa pigra L.	Catclaw mimosa	1/1/06	1/1/06
Miscanthus sacchariflorus	Plume grass; Amur silvergrass	7/1/06	1/1/07
Monochoria hastata	Monochoria	1/1/06	1/1/06
Monochoria vaginalis	Pickerel weed	1/1/06	1/1/06
Myosotis scorpioides	Forget-me-not	7/1/06	1/1/07
Myriophyllum aquaticum	Parrot-feather; water-feather; Brazilian water-milfoil	1/1/06	1/1/06
Myriophyllum heterophyllum	Variable water-milfoil; Two-leaved water-milfoil	1/1/06	1/1/06
Myriophyllum spicatum	Eurasian or European water-milfoil; Spike water-milfoil	1/1/06	1/1/06
Najas minor	Brittle water-nymph; lesser naiad	1/1/06	1/1/06
Nassella trichotoma	Serrated tussock	1/1/06	1/1/06
Nymphoides peltata	Yellow floating heart	1/1/06	1/1/06
Opuntia aurantiaca	Jointed prickly pear	1/1/06	1/1/06
Orobanche L.	Broomrape	1/1/06	1/1/06
Oryza longistaminata	Red rice	1/1/06	1/1/06
Oryza punctata	Red rice	1/1/06	1/1/06
Oryza rufipogon Griffiths	Red rice	1/1/06	1/1/06
Ottelia alismoides	Duck-lettuce	1/1/06	1/1/06
Paspalum scrobiculatum	Kodo-millet	1/1/06	1/1/06
Pennisetum clandestinum	Kikuyugrass	1/1/06	1/1/06
Pennisetum macrourum Trin.	African feathergrass	1/1/06	1/1/06
Pennisetum pedicellatum Trin.	Kyasuma-grass	1/1/06	1/1/06
Pennisetum polystachyon	Missiongrass	1/1/06	1/1/06
Phalaris arundinacea	Reed canary-grass	1/1/06	1/1/06
Phellodendron amurense	Amur cork-tree	1/1/06	1/1/06
Phragmites australis	Common reed	1/1/06	1/1/06
Polygonum cuspidatum	Japanese knotweed; Japanese arrowroot	1/1/06	1/1/06
Polygonum perfoliatum	Mile-a-minute vine or weed; Asiatic Tearthumb	1/1/06	1/1/06
Potamogeton crispus	Crisped pondweed; curly pondweed	1/1/06	1/1/06
Prosopis pallida	Kiawe	1/1/06	1/1/06
Prosopis reptans	Tornillo	1/1/06	1/1/06
Prosopis strombulifera	Argentine screwbean	1/1/06	1/1/06
Prosopis velutina		1/1/06	1/1/06
Pueraria montana	Kudzu; Japanese arrowroot	1/1/06	1/1/06
Ranunculus ficaria	Lesser celandine; fig buttercup	1/1/06	1/1/06
Ranunculus repens	Creeping buttercup	1/1/06	1/1/06
Rhamnus cathartica	Common buckthorn	1/1/06	1/1/06
Robinia pseudoacacia	Black locust	1/1/06	1/1/06
Rorippa amphibia	Water yellowcress; great yellowcress	1/1/06	1/1/06
Rosa multiflora	Multiflora rose	1/1/06	1/1/06
Rottboellia cochinchinensis	Itchgrass	1/1/06	1/1/06
Rubus fruticosus	Wild blackberry complex	1/1/06	1/1/06
Rubus moluccanus	Wild blackberry	1/1/06	1/1/06
Rubus phoenicolasius	Wineberry; Japanese wineberry; wine raspberry	1/1/06	1/1/06

Latin Name	Common Name	Importation Ban	Propagation Ban
Saccharum spontaneum	Wild sugarcane	1/1/06	1/1/06
Sagittaria sagittifolia	Arrowhead	1/1/06	1/1/06
Salsola vermiculata	Wormleaf salsola	1/1/06	1/1/06
Salvinia auriculata	Giant salvinia	1/1/06	1/1/06
Salvinia biloba	Giant salvinia	1/1/06	1/1/06
Salvinia herzogii de la Sota	Giant salvinia	1/1/06	1/1/06
Salvinia molesta	Giant salvinia	1/1/06	1/1/06
Senecio jacobaea	Tansy ragwort; stinking Willie	1/1/06	1/1/06
Setaria pallidifusca	Cattail grass	1/1/06	1/1/06
Setaria pumila		1/1/06	1/1/06
Solanum tampicense	Wetland nightshade	1/1/06	1/1/06
Solanum torvum	Turkeyberry	1/1/06	1/1/06
Solanum viarum	Tropical soda apple	1/1/06	1/1/06
Sparganium erectum	Exotic bur-reed	1/1/06	1/1/06
Spermacoce alata	Borreria	1/1/06	1/1/06
Striga Lour.	Witchweed	1/1/06	1/1/06
Trapa natans	Water-chestnut	1/1/06	1/1/06
Tridax procumbens	Coat buttons	1/1/06	1/1/06
Tussilago farfara	Coltsfoot	1/1/06	1/1/06
Urochloa panicoides	Liverseed grass	1/1/06	1/1/06