Production Practices for an Environmentally Friendly Nursery Industry

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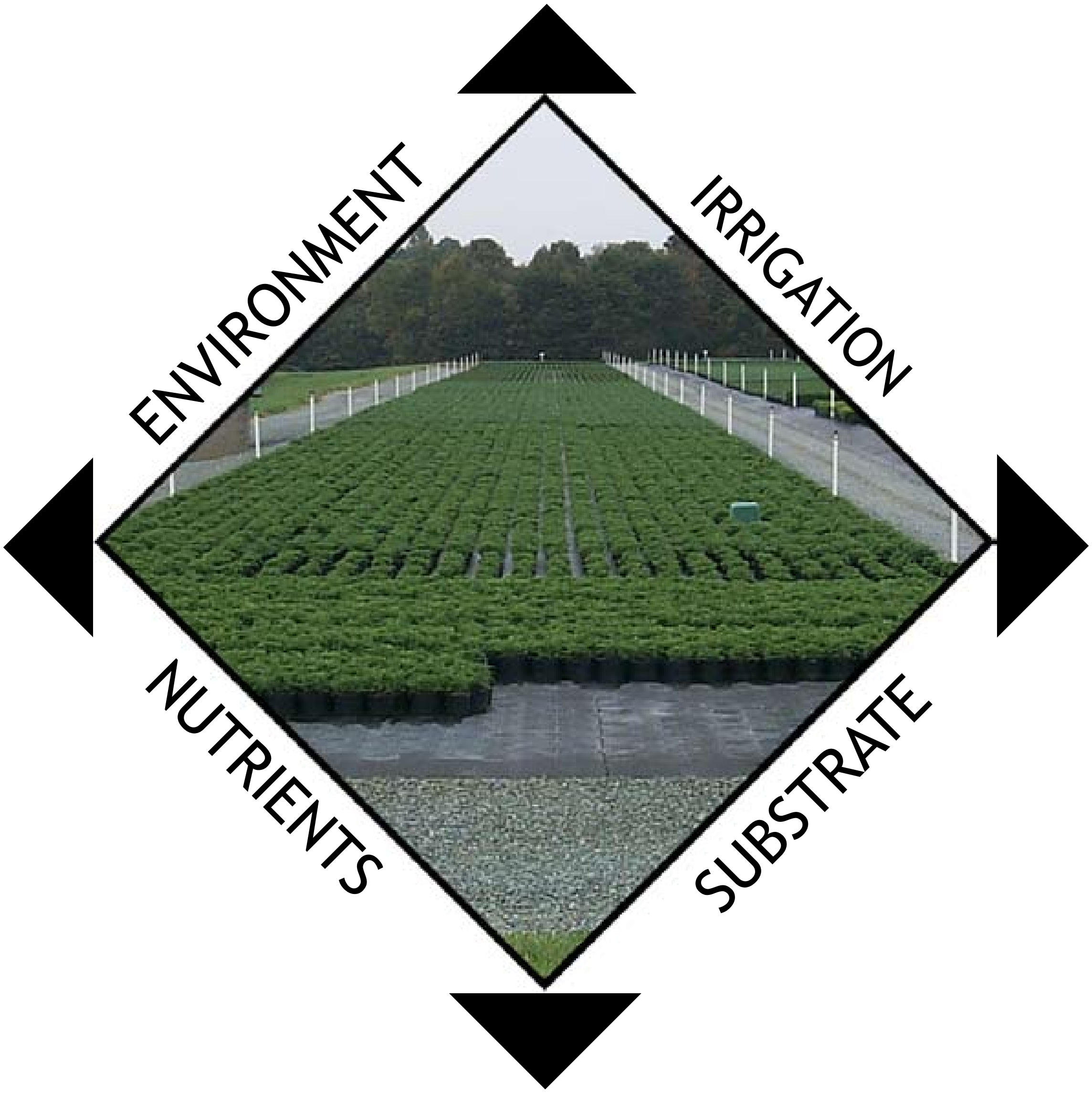

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Production Practices for an Environmentally Friendly Nursery Industry

Nursery crop production is among the fastest growing agricultural sectors. Currently, about 60% of US nursery acreage is in container production. This industry represents a widely diverse set of production practices and plants: over 390 genera and more than 2000 species of ornamentals are grown in the U.S.

With the emphasis on sustainability in businesses and communities, the nursery industry has a natural role in this movement that involves greater efficiency of resource use balanced with the environmental stewardship. By using water and nutrients efficiently and by controlling their movement both onsite and offsite, nurseries can become sustainable operations and be a part of the larger movement that stresses the importance of *"meeting the needs of the present without compromising the needs of future generations*."

Through the matrix of the USDA Floriculture and Nursery Research Initiative and the American Nursery and Landscape Association, a research team representing four universities and two USDA-ARS locations was formed to address issues of water quality and water conservation on nursery operations in the southeast.The broad objectives of the Southeast Water Project are to develop economically feasible production systems and management practices that promote water conservation and protect water quality while sustaining or improving crop quality, production and profitability. Specific objectives include: improving water and nutrient use efficiency, capturing and recycling runoff, and remediation of runoff containing excess nutrients and residual pesticides prior to offsite discharge. Together, the project takes a whole-systems approach to environmental resource management as the "dots" are connected from the fertilizer that leaves the grower's hand, to runoff that leaves the nursery.

Figure 1. Better control of on- and off-site water and nutrient movement can increase both the profitability and sustainability of nursery production operations.

The following set of technical transfer papers is offered as a guide to improved practices for the nursery industry. Here you will find practices to reduce environmental impacts from nursery production and improve your bottom line.

- ***Decision Tool for Container Plant Production: Optimizing the Bottom Line*** details a web-based computer model that container production managers can use as a decision-making tool. The model uses weather data and production information to determine water and nutrient use for container crops. Using this model, managers, can test "what-if" situations, in order to maximize plant growth, water and nutrient efficiency, and profits.
- ***Industrial Clay Mineral Aggregate: A New Component for Bark-Based Container Mixes*** summarizes research results which point to a solution to the nitrogen and phosphorus problem right at its source. Here, you can learn how to adjust soilless container mixes to retain both nutrients and water in the container. This holds promise for container nurseries of any size.
- ***Small Scale Systems to Treat Nursery Runoff for Nitrate*** details a space-saving method to reduce nitrate loading in irrigation runoff. It is similar in its science to the constructed wetland, but treats runoff very near the area from which it is lost. This technique is appropriate for nurseries of any size.
- ***Nitrogen and Phosphorus in Irrigation Runoff*** summarizes the potential for environmental impacts from irrigated container nursery production. It reviews the biochemistry of nitrogen and phosphorus cycling, and describes the role of constructed wetlands in addressing these problems. This solution is most suitable for large operations with sufficient land to dedicate to irrigation water treatment.

The members of the Nursery Research Initiative team offer this set of innovative practices to the container nursery industry as a pro-active response to the current call for more environmentally friendly practices for this high-value sector of US agriculture.

Additional Reading

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Acknowledgements

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Decision Tool for Container Plant Production: Optimizing the Bottom Line

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Because infrastructure, nutrients and water demands for container production are great, successful container production requires thoughtful management. Nursery managers can modify production practices to ensure that operations remain profitable and environmental impacts are minimized.

Cultural practices vary from nursery to nursery. The decision to use a specific practice is usually based on experience and good judgment. Here we describe a computer-based decision-making tool for irrigation, fertilization and spacing in container nurseries. The tool, which includes a crop simulation model and a user friendly, web-based interface to run it, estimates outcomes based on production inputs and weather data. Some examples of model outcomes are described below. A nursery manager can use the model to evaluate "what if" scenarios based on historical weather data to select inputs that support optimal growth with minimal environmental impacts. By importing real-time weather data, the program can also aid in day-to-day management decisions such as irrigation scheduling. To date, the computer programs of the model enable simulations for production of trade one gallon container plants of *Viburnum odoratissimum*, the plant chosen to research the mathematical relationships of the model. Additional research with other crops is being conducted so that the applicability of the model will extend to other types of nursery crops.

In the language of computer-modeling, inputs are the things going into a system and outputs are the results. Production inputs for a container nursery include planting date, container size, container spacing, irrigation schedule, and fertilization. Outputs include plant growth, runoff volume and nutrients in runoff. Figures 2 through 5 are the result of computer simulations based on 40 years of weather data for a central Florida location. They illustrate how the model can be used to evaluate common management decisions for container production.

Optimize irrigation water use

Soilless container substrates provide a good environment for root growth, but container volume is limited. For this reason, container-grown plants must be irrigated frequently. For greatest water savings, irrigation systems of all types should be routinely maintained and calibrated.

Figure 1. Numerous experiments were conducted to obtain data for crop simulation model.

Figure 2 shows the response of *V. odoratissimum* grown in one gallon containers to various rates of overhead irrigation. The graph shows the percentage of optimal growth achieved as it varies with the rate of water applied. The graph reaches its peak (100% optimal growth) at about 0.3 inches of water daily, indicating optimal growth at this rate of irrigation for plants planted in March.

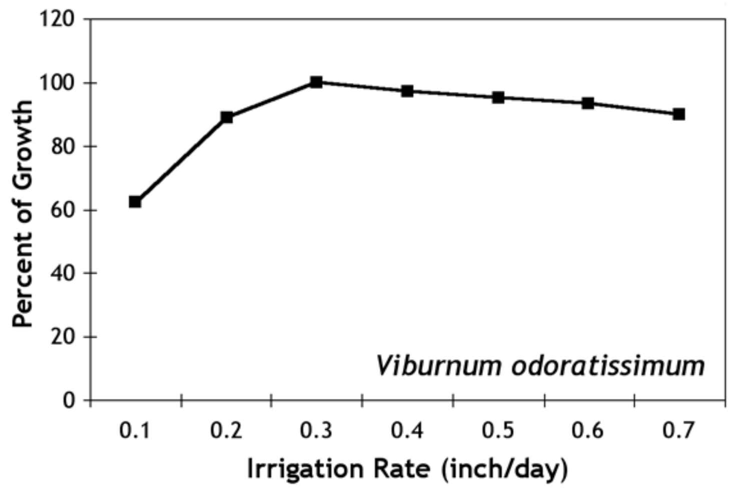

Figure 2. Irrigation and optimal growth.

Optimize plant nutrients

Most soilless container substrates have a very limited capacity to retain nutrients. Combined with high rates of irrigation, nutrient leaching from containers can be significant. Most nursery managers are aware of these facts associated with fertilizing containers:

- Controlled-release fertilizers result in less nutrient loss than water soluble fertilizers.
- Plants may take up as little as 30-50% of the nutrients applied as controlled-release fertilizers.
- Fertilizers leach more rapidly from container substrates than from native soils.

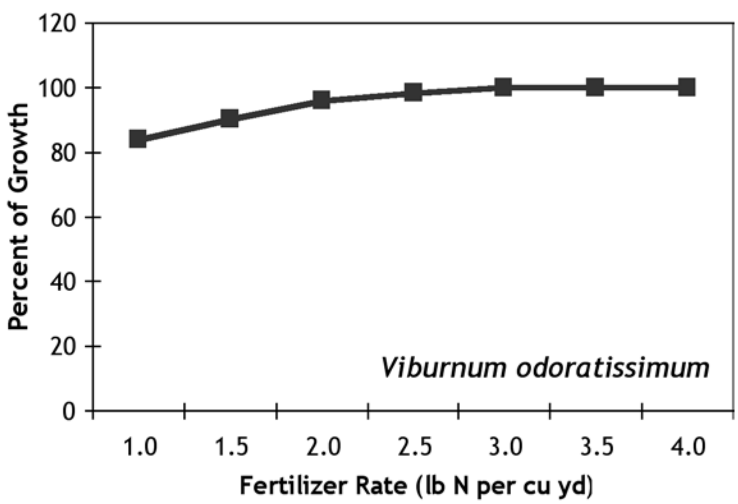

Figure 3. Nitrogen and optimal growth.

Figure 3 shows the percentage of optimal growth achieved by *V. odoratissimum* as a function of the rate of nitrogen applied. The graph shows that 2 pounds of nitrogen per cubic yard of container substrate supports optimal growth for this species planted in March and grown in one gallon containers.

Optimize runoff volumes

Whether the irrigation system is controlled manually or automatically, consideration of the plant's actual water use ensures quality plants and efficient irrigation: preset delivery times and amounts may not.

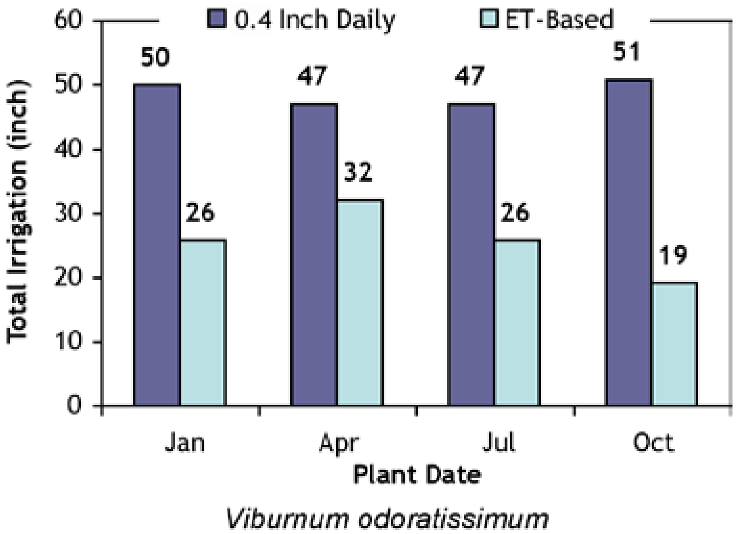

Figure 4. Irrigation strategy and water savings.

Figure 4 shows the water savings possible when irrigation is based on evapotranspiration (ET) rather than a fixed daily application. ET is influenced primarily by weather and plant size. This practice replaces water that has evaporated from containers and through plant leaves since the last irrigation or rainfall so that only the amount of water needed is applied. Here, the grower saves 48% total irrigation water for one gallon *V. odoratissimum* planted in January, 32% for plants started in April, 45% for plants started in July and 63% for plants started in October by irrigating on the basis of evapotranspirative losses instead of a fixed rate of 0.4 inches per day. This method of irrigation leads to significant water savings; power savings associated with pumping and reduces the volume of nutrient-laden runoff.

Optimize container spacing

Container spacing is an important, but often overlooked cultural practice that improves overhead irrigation efficiency. Factors such as stage of growth and plant marketable size determine container spacing.

Figure 5 shows how the "irrigation interception factor" varies with plant growth. The interception factor is a measure of the plant canopy's ability to channel water into the container that would fall between containers if no plants were being grown. In this case, once plants were spaced at week 10, to 6 inches between containers, the interception factor increased during the second half of the season to 2 or more. This means that one-half inch of irrigation would result in the capture of 1 inch of water by the container. The model takes the interception factor into account when recommending irrigation rates based on resupplying water lost through evapotranspiration.

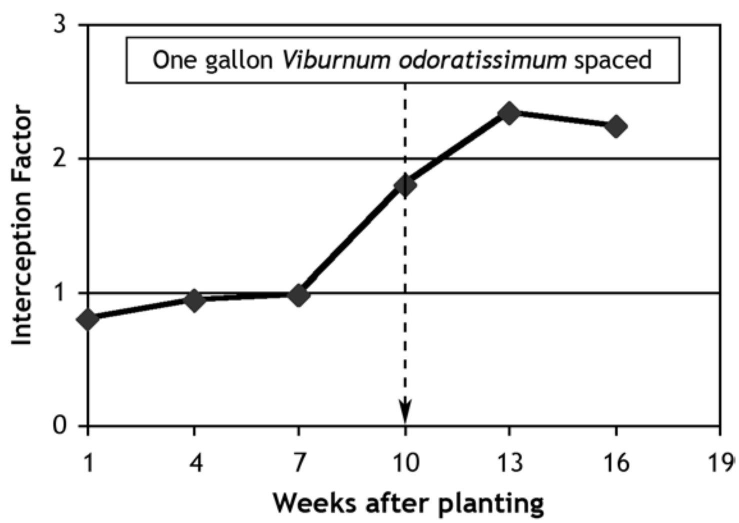

Figure 5. Irrigation interception factor.

Optimize your bottom line

This container plant production decision tool can be used by nursery managers to help decide which management practices will maximize their operation's bottom line. Although some were not discussed specifically, benefits to growers for using the decision tool to aid in management may include the following.

- Quantify irrigation and fertilizer inputs.
- Optimize fertilization and irrigation efficiency while producing quality plants.
- Estimate movement of nutrients and water within and away from the nursery.
- Space containers to maximize irrigation efficiency.
- Develop a nutrient management plan to minimize runoff quantity and runoff nutrient content.
- Create a production cost/benefit analysis in advance of the growing season which includes environmental considerations.
- Select plants best suited for specific geographic locations, based on historic weather data.
- Determine optimal planting dates and estimated production times.

The first version of the web-based decision tool will be available at http://hort.ufl.edu after grower verification tests are complete. Please contact the first author at the same website for additional information.

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Industrial Clay Mineral Aggregates:
A New Component for Bark-Based Container Mixes

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Pine bark amended with various rates of coarse sand is a widely used container mix in the Southeastern US nursery industry. Soilless substrate mixes containing pine bark provide excellent aeration and hold moderate amounts of water; however, they are less able to provide adequate water as the substrate dries. In addition, pine park is relatively inert therefore retaining little nutrients. Limited nutrient and water holding capacity lead to frequent irrigation and high fertilization rates. Increasingly, water conservation and water quality are major concerns for the nursery industry. An improved container mix that is able to retain water and nutrients would enhance the nursery industry's environmental stewardship efforts.

Calcined clays are minerals that have been fired at very high temperatures to yield an absorbent, stable granular material. Clay mineral aggregates promote good drainage and air space, stabilize pH levels, retain or supply phosphorus, and reduce phosphorus leaching. Clay aggregates could be adopted as alternatives to sand or other inorganic components in peat or bark based container mixes.

Understanding Industrial Clays

Clays are highly weathered soil minerals with particle size less than 0.002 millimeters in diameter. Because of their chemical and physical properties, clays store water and nutrients providing chemical and water buffering capacity to soils. These clay aggregates could offer buffering capacity to soilless substrates, making it a good component to be included in bark-based mixes. The "industrial" clay minerals are mined, heated or pasteurized and screened into various aggregates sizes that are physically uniform and reproducible. These industrial clay aggregates have a number of current agricultural uses such as chemical sorbents and pesticide carriers. The most popular size used in agriculture is between 0.85 and 0.25 mm (24/48 mesh). Industrial clay minerals dried at 250°F are the basis of products such as cat litter and garage absorbents. When further dried by heating this product is classified as 'calcined', and contains little or no water.

Figure 1. Top to bottom: 24/48 mesh calcined clay, bark, course sand. Because these have different relative sizes, they supply differing amounts of air and water to the root zone when used in potting mixes.clay material has a greater capacity to retain water and plant nutrients than the bark or sand.

This fact sheet summarizes studies conducted using using *Cotoneaster dammeri* C.K. Schneid. 'Skogholm' potted in trade 5 gallon (14 L) containers with a pine bark based substrate. All field trials were conducted in Raleigh, North Carolina. A 24/48 mesh Georgiana palygorskite-bentonite calcined clay amended pine bark was compared to industry representative substrate comprised of 8:1 pine bark: sand or pine bark only. Plant size, phosphorus retention, and water reduction was maximized at approximately 100 lbs 24/48 mesh calcined clay per cubic yard of potting mix. Plant growth increased with increasing clay addition to a maximum of about 8 parts pine bark to one part (11%) clay by volume.

The Big Picture: Improving Your Bottom Line

Pine bark amended with clay rather than sand can grow an equivalent plant with half the water and half the phosphorus inputs. For more details, and more benefits, read on.

- **Water savings you can count on.**

  An 8:1 pine bark: 24/48 mesh clay aggregate mix increased water storage in containerized plant production. Compared to an 8:1 pine bark:sand mix, the clay amended pine bark reduced water usage during the growing season by 6 gallons of water per 5 gallon container, or 200,000 gallons per acre per season.

  - Less is more with clay: Pine bark amended with clay increased available water in the container by 4% (by vol.) or 17 oz (500 mL).
  - Insurance: Established plants grown in a pine bark and clay aggregate mix when unwatered remained turgid without wilting for an additional 48 hours compared to plants in an 8:1 pine bark:sand soilless substrate mix.
  - Optimum use: An 8:1 pine bark:clay mix maximized water use efficiency and photosynthesis when compared to an unamended substrate.

- **Value added product: Improving fertility through nutrient retention and/or release:**

  Plant content of all macro-nutrients (P, K, Ca, and Mg) except N, increased when pine bark was amended with clay compared to sand. Growth increased for plants grown in pine bark clay mix rather than a pine bark sand mix.

  - *Crop phosphorus use efficiency:* Plants grown in clay amended mixes contained 100% more total plant P content compared to plants grown in sand amended mixes. This is a 20% to 60% increase in phosphorus use efficiency. In a follow-up study, plant growth was unaffected when phosphorus rate was decreased by 50% using a clay-pine bark mix.
  - *Substrate phosphorus retention:* Increased heating (pasteurized to calcined) of clay aggregates increased phosphorus sorption in the soilless substrate, thus decreasing phosphorus leaching. Phosphorus losses due to leaching were reduced by 60%, without sacrificing plant growth, when Pine bark was amended with calcined clay aggregates which do not contain phosphate minerals.
  - *Phosphorus supply:* Clay aggregates containing native calcium phosphate minerals provided adequate phosphorus to maximize plant growth throughout a growing season. A fertilizer analysis should be preformed on each clay lot or batch to determine its chemical content. Fertilizer rates can then be adjusted as needed.

- **Additional benefits.**
    - *Lighter containers:* The dry weight per unit volume of the soilless mix was 20% lighter than a 8:1 pine bark:sand amended mix, regardless of clay amendment rate.
    - *Cooler containers:* Temperatures on the south side of containers decreased with increasing clay content.

Clay can reduce water and phosphorus loss from containers and/or act as a slow release source of phosphorus. In addition, clay can reduce environmental impacts and assist in delivering sufficient water and nutrients for quality plant production. Incorporating clay aggregates into pine bark based container mixes is a simple practice which can reduce the environmental impacts associated with containerized nursery crop production while maximizing plant growth.

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Small-Scale Systems to Treat Nursery Runoff for Nitrate

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Constructed wetlands and retention ponds are effective nutrient removal and retention strategies for nurseries with the capacity to dedicate land area to non-production uses. However, this may not be practical , for smaller nurseries and those in areas where land is limited or too expensive. For those situations, the ideal water treatment system would be one that could be incorporated into the nursery production landscape without sacrificing production area. This system could collect and treat drainage water close to the individual production areas, rather than on a whole-nursery scale. It could be constructed beneath roadways, plant holding areas, or other areas used for production purposes.

The technology that this system is based on is the same as that used in municipal and domestic wastewater treatment systems as well as natural wetlands. These systems rely on groups of specialized micro-organisms to convert nitrate nitrogen in the water to nitrogen gas which is vented to the atmosphere.

This type of nitrate removal system will require more intensive management, relative to constructed wetlands and retention ponds to optimize removal efficiencies. To ensure optimal nitrate removal by the system, nursery operators must accurately estimate:

- Expected nitrate loadings and concentrations from production areas
- Typical runoff flow rates and volumes to be accommodated

In addition, they must allocate system management resources (materials and labor) for optimal nitrate removal efficiency. These issues are discussed below. Ultimately a cost-benefit analysis will have to be used to determine whether such a system is feasible for a specific nursery.

Figure 1. Kaldness media inoculated with denitrifying microorganisms.

Ensuring Drainage

Since these denitrifying systems can conceptually be placed beneath roadways and production areas, adequate drainage is necessary to prevent flooding during normal use. To satisfy this requirement, trials were conducted using a commercially available polyethylene substrate, Kaldness media (Fig. 1), used by the aquaculture industry for the aerobic process of ammonia removal. This material is slightly buoyant and has a surface area of approximately 256 ft^2/ft^3 of media. Micro-organisms attach to the surfaces of the media. In reality, any substrate can be used for anchoring the nitrate-removing micro-organisms, as long as it is not toxic and provides sufficient drainage to prevent flooding. One advantage of Kaldness media is the tremendous surface area it provides the denitrifying system in comparison to the volume it occupies.

Figure 2. Conceptually treatment areas may be located beneath roadways or production areas.

The Science Behind the Technology

Nitrate removal in this system is based on the conversion of nitrate (NO_3) nitrogen into di-nitrogen gas (N_2), through a defined series of steps (Eq. 1). This process is called denitrification. Denitrification is a microbially driven chemical process that proceeds under low-oxygen conditions when an appropriate source of carbon is present in adequate amounts (Eq. 2). The carbon must be in an available form for the chemical reactions to occur. Research has shown that table sugar, molasses, grass clippings, and many other sources can support the denitrification reactions. At least three (3) carbons must be present for every two (2) nitrate-N atoms converted to N2 gas (Eq. 2).

$$NO_3 \Longrightarrow NO_2 \Longrightarrow NO \Longrightarrow N_2O \Longrightarrow N_2 \text{ (gas)} \qquad \text{Eq. 1}$$

$$C_6H_{12}O_6 + 4NO_3\text{-}\ 6CO_2 + 6H_2O + 2N_2 \qquad \text{Eq. 2}$$

Nitrate Design Criteria

Nitrate concentrations in the drainage water will determine the amount of carbon supply demanded by the system. Nitrate loading is the mass of nitrate present, and is the product of the volume of discharge times the concentration of nitrate in the discharge. Nitrate loading from production areas and concentrations within nursery water storage systems vary depending on the nutrient and water management strategies in place. Factors effecting nitrate loading include:

- Fertilizer formulation (liquid solution, dry blend, etc.)
- Percentage nitrogen in the formulation
- Frequency of application
- Rate of application, and
- Time of year

Irrigation rates and methods of application also influence nutrient loss from plant production areas. Over-application of irrigation water always increases flushing of dissolved nutrients through the containers. Even when fertilization and irrigation factors are optimized, some nutrient losses from the production area should be expected.

Nutrient loading and water discharge volumes from production areas can be measured using an inexpensive system such as that shown in Figure 3. A 90° elbow was fitted to the end of a drain pipe, and a PVC coupling attached to the top of the elbow. A V-shaped notch was cut into the top of the coupling. The size, depth and angle of the notch can vary depending on the range of flow expected. In general, the angle should be narrower and depth deeper for lower flow rates than for higher flow rates. For very high flow rates, shapes other than a v-notch may be more appropriate (i.e. rectangle, trapezoid, etc. The key is to select a combination that allows easy accurate flow and accurate measurement of the flow depth within the expected discharge volume rate range. Discharge volume from the production area is estimated based on the water depth in the notch. For accurate flow rate estimation, a system like this is calibrated by measuring the time

Figure 3. Water depth in notch estimates discharge rate from production area.

required to collect a set volume of water at a given water discharge depth in the notch. This process defines the ratio of flow depth in millimeters to discharge rate in liters per minute (L/min.), Calibration measurements should be taken throughout the range of expected flow depth within the v-notch.

To determine the total volume of water discharged during an interval of time,

1. Determine the discharge rate by comparing to the depth:rate calibration relationship.
2. Multiply the rate (L/min.) by the number of minutes (min.) in the time interval.
3. For an entire discharge event, add all of the interval discharge volumes together to determine the total volume discharge during the event.

To estimate nitrate loadings, multiple samples must be collected and the discharge rate must be measured at several intervals throughout a given discharge event. Single "grab" samples and depth measurements do not provide accurate loading estimates for an entire event. To determine interval loadings, multiply the nitrate-N concentration (mg/L) by the total volume (L) discharged during the sampled interval. All of the interval loadings are added together to give the total event loading.

Source of Microflora

Ideally, the microflora for the denitrification system are harvested on-site from the nursery's own drainage system. Field trials have shown that nitrate removal activity occurs naturally in almost all aquatic systems, including on-site drainage systems. However, environmental conditions may not always be sufficient to support large populations and high activity. Naturally occurring "seed" microbes were captured at several nurseries by submersing the microflora anchoring substrate (i.e. Kaldness media) in nursery retention ponds and drainage ditches for several months. This inoculated substrate then became the basis for the denitrifying system once the denitrifying microflora were selected by providing low oxygen conditions and consistent access to nitrate-N and available carbon.

Figure 4. Microflora for the denitrification system can be captured by anchoring substrate for microflora attachment in on-site drainage systems.

Figure 5. Small-scale bioreactor installed at an ornamental nursery.

Nitrogen and carbon management

Establishment and maintenance of an optimal community of denitrifying microflora requires a continuous supply of available carbon and nitrate. If either nitrate or carbon becomes limited, nitrate transformation activity will decrease and the amount of time for re-establishment will increase. The carbon can be obtained from many different sources including, but not limited to, sugar, molasses, and grass clippings.

Figure 5 shows an experimental, small-scale flow-through bioreactor installed at an ornamental nursery. A constant duty sump pump supplies production-area drainage water to the bio reactors. The carbon source injector (A) ensures adequate carbon supply, as shown in equation 2. Bioreactors (B) are filled with inoculated Kaldness media. In these bioreactors, microbes denitrify nursery runoff.

Performance Potential

Small-scale lab and field studies at a commercial foliage plant nursery indicates nitrate removal rates greater than 90% are possible in a flow-through system with a residence time less than 30 minutes and a flow rate of approximately 10 L/min. However, there are concerns about the potential impact of pesticides used in routine plant production on the microbial community. Despite these uncertainties, this system offers promise as an option for space-limited nurseries.

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Stricter Water Quality Standards:
What will They Mean for Nursery and Greenhouse Operators?

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Successful nursery and greenhouse production relies on fertilizers and other chemicals such as pesticides and growth regulators. In the near future, it is likely that state environmental agencies will enforce higher water quality standards. Currently, only the use and disposal of pesticides fall under regulatory direction. Horticultural producers will then have to consider not only pesticides, but fertilizer in runoff as well. How individual states will approach regulation is unknown, but new water quality goals will change how nurseries and greenhouses handle their irrigation runoff.

How nursery runoff impacts surface water

Algae are microscopic aquatic plants that benefit from the same nutrients nursery and greenhouse plants do. Eutrophication is the increase in plant and algae growth in streams, lakes, and estuaries, stimulated by a concurrent increase in nutrients. "Algal blooms" cloud the water, block sunlight and deplete oxygen in the water as they die and decompose. Of the major plant nutrients in fertilizers, two lead to algal blooms:

- Excess nitrogen (more than 0.4 ppm) in surface waters promotes eutrophication in freshwater and in estuarine systems and decline of native aquatic plant species.
- Excess phosphorus (more than 0.1 ppm) contributes to eutrophication in freshwater systems.

Figure 1. Common production practices may lead to runoff containing agrochemicals that degrade offsite water quality.

Nursery runoff frequently contains elevated levels of nitrogen and phosphorus. It's to the benefit of the nursery industry to consider how to reduce nutrients in their runoff to conserve costly fertilizer resources, and to fend off regulatory action.

The annual cycle of irrigation run-off

Levels of nitrogen in runoff vary by season:

- Lowest levels occur during winter months,
- Intermediate levels occur during summer and fall months,
- Highest levels occur during spring months.

Phosphorus shows less dramatic changes through the seasons:

- Minimum levels occur during winter months,
- Intermediate levels occur during spring months,
- Slightly higher levels occur during the summer and fall months.

Whatever the season, when nursery personnel take proactive steps to reduce nutrient levels in runoff, both nitrogen and phosphorus levels and production costs decline. Probably the best option for reducing nitrogen and phosphorus in runoff is to re-think irrigation practices management. Ensuring irrigation application is uniform, and watering to meet plant needs reduces nutrient leaching from soilless mixes, and reduces the overall volume of runoff.

Options for treating nitrogen in irrigation runoff

The option you choose to reduce nitrogen levels in runoff from your operation depends on several things: limited or excess rainfall, nutrient loading and availability, and irrigation management strategy. Holding ponds store runoff for reuse; this runoff is often mixed with fresh water and reapplied to the growing beds. However, success with this technique requires careful attention and strict management of the three "M's": managing salts, monitoring water quality, and managing disease organisms in the ponds. We will address water quality in this publication; for information on managing salts and managing disease organisms in ponds see the resource available at:
http://www.sna.org/publications/index.shtml

Figure 2. Retention/irrigation ponds can contain agrochemicals and pathogens; thus, monitoring and managing pond water quality is necessary.

Several factors influence which remediation system will work for best for managing runoff:

- Runoff volume,
- Runoff frequency,
- Continuous or intermittent runoff flow, and
- Nitrogen load/concentration in runoff.

The volume of run-off is key to choosing a run-off treatment system. Constructed wetlands work best for high to moderate volumes of runoff, and where land is both available and affordable. For moderate to low volumes of runoff, denitrification walls or vegetated ditches are recommended. Vegetated or turfgrass buffer strips may be sufficient for low volumes of runoff. See Best Management Practices at http://www.sna.org/publications/index.shtml

Figure 3. Constructed wetlands are low maintenance, treatment systems that can handle high to moderate runoff volumes.

Natural nutrient cycling

All plant nutrients undergo natural cycling processes, which change them from plant-available forms to non-plant-available forms and back again. The nitrogen cycle includes a non-polluting form of nitrogen, N_2 gas, which makes up 80% of the atmosphere. Nitrogen in nursery runoff is primarily in the plant-available nitrate form. Nitrate stimulates the growth of wetland plants and becomes "tied up" in plant tissue. Under the anaerobic conditions found in a constructed wetland, the remaining nitrate readily converts to N_2 gas before treated runoff is discharged into receiving waters.

Phosphorus poses a more difficult problem, because its natural cycle does not include a gaseous form. Constructed wetlands alone cannot reduce phosphorus levels enough to meet regulatory standards. Wetland plants do take up some phosphorus, but probably won't do the whole job.

Nitrogen reduction in constructed wetlands

- Constructed wetlands can be very efficient at removing nitrogen from runoff - above 90% during the warm months. Efficiency drops during winter months, though significant nitrogen conversion continues.
- Efficiency is related to the length of time runoff remains in the wetland. This, in turn, dictates the size of the wetland. Constructed wetlands should be large enough to retain runoff for 3 to 3½ days.
- Wetlands are well-suited to low, poorly drained sites, provide rich wildlife habitat and add to the property's aesthetic value.
- Wetland construction is a technical task, beyond the skills of many nursery crews. Permitting may be required in your area. Always consult your state water regulatory agency, and a civil engineer before constructing a wetland.

Figure 4. Nitrification structures (elevation changes where runoff is aerated) enhance conversion of ammonia to nitrate, the nitrogen form removed in constructed wetlands.

Phosphorus reduction in constructed wetlands

Phosphorus is more of a challenge to eliminate. Simply passing runoff through a wetland will not reduce phosphorus to acceptable levels. Additional action is required.

1. Attack the problem from the front end: reduce soil mix phosphorus levels, use low phosphorus fertilizers in liquid feeding programs, and use components such as fired clays to bind phosphorus in soilless mixes. Research demonstrates that container plants require less initial phosphorus than is currently recommended. This, in turn, reduces the amount available to leach from growing containers.

2. Plant phosphorus "hyper-accumulators" in the wetland. These species show some potential for removing excess phosphorus from runoff:

    - *Canna* 'Bengal Tiger',
    - *Pontederia cordata* 'Singapore Pink',
    - *Thalia geniculata* f. *rheumoides*.

3. Provide secondary treatments for phosphorus removal beyond primary treatment in constructed wetlands. Secondary treatments can be more than 80% efficient in reducing phosphorus concentrations.

    - In secondary treatment, water flows through fired clay nuggets and remains in contact with them for at least 1¼ days.
    - Phosphorus attaches to "binding sites" within the clay; phosphorus removal efficiency decreases as the clay becomes saturated with phosphorus.
    - Implement routine sampling and testing to monitor phosphorus levels in discharge. Replace fired clay when levels rise above acceptable limits.

Figure 5. Hyper-accumulator plant species show some potential for greater phosphorus uptake. (A) *Canna* **'King Humbert', (B)** *Pontederia cordata*, **and (C)** *Thalia geniculata* **f.** *rheumoides*.

A cooperative stance by the nursery industry will encourage regulators to seek input from industry leaders when new regulations are being drafted. Pro-active approaches within other agricultural sectors have resulted in solutions producers can live with, because producers had a hand in their crafting.

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