H o r t i c u l t u r a l   E n g i n e e r i n g
Volume 16 No. 6, November 2001

Website: http://aesop.rutgers.edu/~horteng

September 11, 2001

The tragedies of September 11 have made a lasting impact on our society and our way of life. Our hearts go out to all the people immediately affected by these horrible events, and particularly to those who lost loved ones. The total impact of the attacks will not be known for some time, but it is clear that almost everyone will experience some degree of impact on his/her daily routine.

As a result of September 11, people have felt more connected with their friends, neighbors, co-workers, colleagues and family members. It is as if we rediscovered that we need one another to live a meaningful and fulfilling life, and that our well-being is the result of the well-being of others. Because of the tragedies, we were forced to re-examine our lives and how we interact with our fellow citizens. Let us hope that we never have to live through another "September 11" and that we are able to build on our renewed feelings of compassion.

New book about Supplemental Lighting

A new book about supplemental lighting (Supplemental Lighting For Greenhouse Crops, J.J. Spaargaren, 2001, Published by P.L. Light Systems, Inc., 1-800-263-0213) was released last month. The book was originally written in Dutch and translated by Willem van Winden, Theo Blom, and A.J. Both). The book contains useful information about both plant and technical aspects of supplemental lighting for both the European and North American markets. Lighting regimes (intensity, duration, and photoperiod) for many different crops (pot plants, cut flowers, and vegetables) are discussed in the book, which provides an excellent resource for anyone interested in using or evaluating supplemental lighting for greenhouse crop production.

New film material installed

One of the two Bioresource Engineering greenhouses (top picture, foreground) was recently outfitted with a two layers of a new material (F-Clean) provided by the Japanese ASAHI Glass Company, while the other greenhouse (top picture, background) was outfitted with a standard double polyethylene film. The F-Clean film material is an EthyleneTetraFluoroEthylene copolymer with a 10-year life expectancy and a high transmissivity (bottom picture). Additional data about this new film material will be published in a future issue of this Newsletter. Light sensors in both greenhouses, as well as an outside sensor, were installed and will help evaluate the light transmission over time.

Subirrigation for Greenhouse Crops

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Subirrigation is becoming an increasingly common way of watering and fertilizing greenhouse crops. This article is for growers considering a subirrigation system or just starting out with a new system.

Advantages to Subirrigation

There are three major economic advantages to subirrigation. The most commonly cited advantage is the savings in labor needed for watering the plants: a single person can water thousands of plants by operating the flooding system manually or with the help of a computer;. Additionally, there is a potential savings in water and fertilizer with subirrigation since both are recirculated and not lost by leaching or runoff. Also, depending on the system and how it is installed, a grower can expect an increase in greenhouse space efficiency (percentage of total floor area in use for growing plants.)

Many growers report more uniform plant growth and less foliar disease with subirrigation. The increase in plant uniformity may be the result of more even and complete moistening of the growth medium and better distribution of nutrients adsorbed by capillary flow. The absence of water on the leaves with subirrigation probably results in less foliar disease.

The elimination of fertilizer and pesticide leaching and runoff from the greenhouse is a very important reason for using subirrigation. In order to achieve the goal of reduced leaching and runoff the system must be maintained as a truly closed system. The immediate practical value of preventing irrigation effluent from escaping the greenhouse is not always apparent, but protection of water, used for drinking and recreating, from contamination is probably the most important long-term benefit of subirrigation.

Challenges to Using Subirrigation

Like any other new way of growing greenhouse crops there are a number of challenges to overcome to use subirrigation successfully. The two greatest challenges for most growers is the initial cost of the system and the ability to retrofit the system in an existing greenhouse. A conservative estimate of payback time is 5-10 years, but the period could be as short as 2-3 years depending on the system chosen, whether existing bench frames can be retrofitted and whether productivity of the system is maintained at a high level.

An excellent economic analysis of subirrigation systems was recently published by Wen-fei Uva and her colleagues of Cornell University (Uva, W.L. et al., 2001). Her article is very detailed, but concise, and would help growers in choosing a subirrigation system. Single copies are available from Douglas Cox at the University of Massachusetts.

A grower beginning to use subirrigation will have to learn some new ways of irrigating and fertilizing to use the system successfully. Growth medium and irrigation solution testing for pH and EC is one important skill to acquire. Since the growth medium tends to accumulate salts with subirrigation it is critical to be able to test for EC on a regular basis without having to wait for results from a commercial lab. Also, growers who maintain nutrient and pH levels in the irrigation solution by adding fertilizer or water to stock tanks manually rather than with automatic equipment need to carefully monitor EC and pH to maintain the proper ranges.

Successful use of subirrigation requires extra attention to cleanliness to avoid disease and insect problems. The use of pesticides and other chemicals, particularly as drenches, can be problematic with subirrigation so adoption of IPM techniques, especially pest population monitoring, is very important. Cleanliness will be discussed later in this article.

Subirrigation Systems

There are three basic closed, recirculating subirrigation systems currently in use: ebb-and-flow benches, trough benches and and flooded floor systems. Capillary mats and collection trays are also a form of subirrigation, but they are not normally closed systems.

Ebb and Flow. The ebb and flow system is very common and is quite familiar to most growers. The system consists of a shallow, molded plastic bench top which is flooded to water and fertilize plants. When the irrigation cycle is complete the remaining solution drains from the bench and is pumped back to a storage tank.

Ebb-and-flow is very versatile because the bench tops can accommodate all sizes of pots and bedding plant flats (although not on the same bench or irrigation zone at the same time because of the differences in water absorption rates between container sizes). The bench tops can be installed on existing frames and, with the rolling feature, ebb-and-flow benches are easy to retrofit in clearspan greenhouses, but not in greenhouses with many internal supports. This system has the highest initial cost, $4 to $6 per square foot, installed on existing bench frames and including tanks, delivery and return pumps, plumbing and installation. A major portion of the cost comes from the specially molded plastic bench tops which cost about $2.50 per square foot.

Troughs. This system works by running a film of irrigation solution down a slightly inclined, shallow trough holding the plants. The empty troughs empty in a return channel for recirculation. The pots or flats in the trough have plenty of opportunity to absorb water and nutrients as they run past.

The trough system is very easy to retrofit on existing bench frames. The troughs can be obtained in various lengths and widths from a commercial manufacturer or they can be fabricated by a local metalworking firm to the growers specs. A trough system is about 70-80% space efficient, less than ebb-and-flow, because normally spaces are left between the troughs. Most growers use this system mainly for potted crops, but it is possible to do bedding plant flats if the open mesh style of tray is used to hold the packs. However, because of the trough spacing it isn't possible to space flat-to-flat except in an individual trough.

The initial cost of the trough system is about $2-$6 per square foot. The cost of this system can be fairly low if the troughs are made locally or if they are installed on existing benches. Most of the plumbing is simple to put together and inexpensive.

Flooded Floor. In this system the entire floor of the greenhouse is covered with a concrete carefully designed and installed to pitch toward openings in the floor. Through these openings the irrigation solution enters to flood the floor and, following flooding, the excess drains back to the storage tank. The floors can be installed with bottom heating and divided into zones for separate flooding and bottom heating.

Flooded floors can be used to grow plants in all container types and sizes as long as separate irrigation zones are provided for each type. Space efficiency is about 85-90%. Most greenhouses with flooded floors were built with them rather than retrofitted later. The bottom heating option is an efficient way of providing the proper growing temperature for the plants because the air close to the plants is heated and the larger air volume of the greenhouse does not have to be heated as much.

Some growers complain that in a flooded floor, plants close to he flood/drain openings tend to be overwatered, especially bedding plants. Also as in the case of any floor growing system, all the bending and squatting needed to work with the plants can be tiring for workers.

Initial cost for a flooded floor is $3-$5 per square foot, but costs can vary significantly depending on the amount of excavation required for the storage tanks and piping whether or not bottom heat is installed, and whether the floor is divided into zones for separate irrigation. A very skilled concrete contractor is needed to get the pitch of the floor right to encourage proper drainage and to prevent puddling. (*Editor's note. We don't recommend to install an ebb-and-flood floor watering system without a floor heating system.)*

Fertilizing Subirrigated Plants

Since there is little or no nutrient leaching with subirrigation, less fertilizer is needed compared to traditional overhead watering systems. The general rule for fertilizing subirrigated plants is to use one-half the rate (ppm) normally applied by overhead irrigation.

Several years ago the author subirrigated poinsettias with solutions of 100, 175, 250, or 325 ppm N from peat-lite 20-10-20 fertilizer (Cox, 1998). The plants finished about the same size with nearly as large bracts as plants watered from overhead. Leaf analysis revealed normal levels of most nutrients at all fertilizer rates and no evidence of a serious nutrient deficiency or excess. EC (soluble salts) levels were higher with subirrigation than overhead watering. EC was highest near the top of the growth medium because of surface evaporation and deposition of nutrient residues. None of the treatments developed an excess EC.

The results of this study demonstrated that poinsettias grow well over a wide range of fertilizer concentrations using subirrigation or traditional overhead watering. In fact, most growers the author has visited in New England who sub irrigate poinsettias on a large scale use fertilizer rates in the range of 200-250 ppm N. Use of fertilizer rates above 250 for subirrigated poinsettias increases the risk of excess EC leading to growth inhibition and plant injury. Learning to use an EC meter to monitor soluble salts on a regular basis is very important with subirrigation.

Chemicals and Subirrigation

Many insects and disease problems can be prevented by adopting a new standard of greenhouse cleanliness and through the use of simple IPM practices to prevent infestations and infections from getting out of control.

To the author's knowledge, no pesticides are currently labeled specifically for application through a subirrigation system. This means that for now growers must apply pesticides as they would to overhead watered plants only more carefully. Heavy or frequent foliar spraying, or use of growth medium drench treatments, are risky practices because enough chemical may enter the irrigation solution to cause undesirable effects to the plants in the long term. To avoid this problem, some growers divert irrigation water from their subirrigation system for conventional disposal following a pesticide application rather than letting it return to the tank for recirculation. In the absence of definitive information on the extent of buildup and effects of recirculated chemicals, growers should try to limit pesticide treatments as much as possible especially growth medium drenches.

Zero Tolerance™ disinfectant is one chemical that can be recirculated in subirrigation with beneficial effects. Zero Tolerance™ can control algae and a wide variety of root disease organisms. The product label has specific directions on its use in subirrigation systems.

Interestingly, there is some interest in applying growth regulators (PGRS) through subirrigation. Currently, A-Rest™ and Bonzi® are labeled for use in 'chemigation' systems including subirrigation by ebb-and-flow and from saucers. Labels for both PGRS have detailed instructions on how to apply the chemicals as not to cause plant injury and to protect water supplies. In the author's opinion, it is too early to draw conclusions about the efficacy and safety of PGR application this way but it is being studied in Florida (Barrett, 1999) and results will be reported soon.

Finally, cleanliness is very important. As a routine practice dead plant material and other large 'stuff' should be removed from growing areas, inside tanks, and plumbing after each crop. Then the system should be disinfected with Zero Tolerance™ or Green-Shield. These sort of cleaning practices are not common in traditional growing (although they should be) but they are essential for successful growing in subirrigation.

This article appeared in Volume 13, No 6 of Floral Notes, UMASS Extension Floriculture Newsletter.

ENERGY CONSERVATION OPPORTUNITIES

There are several ways in which growers can reduce the energy required to heat their greenhouse. Higher energy prices have caused an increased interest in energy conservation. The most effective way to save energy is through the use of a shade screen that also serves as a thermal curtain. These screens can be used for summer cooling as well if the proper material is chosen. Generally, the use of special thermal curtain can save approximately 30-40% in heating cost compared to a standard double-clad polyethylene greenhouse. Using a typical shade screen for summer shading, with a shading factor of approximately 50%, will result in an energy saving of 25-30%. Some growers use both shade screens and energy curtains; others use only the screens (e.g., the woven double-knit summer shade cloth or the stripped aluminum shade material), and realize less energy savings. Growers who do not use the system for summer shading select the material that provides the best energy savings.

Other conservation methods include the use of transportable or movable bench systems that reduce the heating energy required per unit of product. However, it is advisable to have an excellent heating system which provides uniform conditions when a transportable or movable bench system is planned. Since the crop is handled in large units on benches, the environmental control system must create uniform growing conditions or uneven development will occur. This can cause severe problems when handling crops in large quantities.

Some growers are able to switch their fuel source and take advantage of lower unit prices of fuels at different times of the year. When making these changes information is needed to make the correct decision. In general No. 2 fuel oil has a heating value of 140,000 Btu/gallon. Natural gas has 100,000 Btu/therm (1,000 Btu/ft^3) and propane delivers approximately 85,000 Btu/gallon. If you apply an efficiency percentage to each heating system and know the unit price of the fuel you can determine the BTU received per dollar.

For example, if No. 2 fuel oil costs $1.75 per gallon and the heating system has a 75% efficiency, then you receive 60,000 Btu per dollar. If propane costs $1.50 per gallon and the heating system has an efficiency of 80%, then you receive 45,300 Btu per dollar. Similar calculations can be made for natural gas (average system efficiency is approximately 80%). Efficiencies vary among heating systems with older systems generally being less efficient. However, timely and proper maintenance can allow you to maintain maximum system efficiency. For those growers with the option to change fuels, these calculations throughout the heating season may provide avenues for further energy conservation.

In some cases, the installation of floor/bench heating systems can reduce the total energy requirement compared to when crops are grown on the floor. When growing on an unheated floor/bench, the greenhouse air temperature must be maintained much higher to provide good growing conditions on the floor. Installations of floor/bench heating systems create a micro environment at the crop level and allow the grower to use lower thermostat settings at the usual 6 feet above the floor/bench. **Soil Heating Systems for Greenhouse Production**, Rutgers Cooperative Extension Publication E208, provides engineering design information for floor heating systems and is available from your editor at a modest cost.

NRAES 3, **Energy Conservation for Commercial Greenhouses,** is also available from NRAES (http://www.nraes.org). It is an excellent publication describing various energy saving techniques for reducing heating costs. Another publication which contains helfpul environmental control information is **Environmental Control of Greenhouses**, RCE Publication E213, and is also available from your editor.

Energy Use and Potential Savings

The struggle between maximum light transmission and energy conservation is evident to every grower. Double glazing, as a method for energy conservation, reduces the available PAR (photosynthetically active radiation) to the crop. Double glazing on the walls does not affect lighting as much compared to when installed on the roof of the greenhouse. Thermal screens offer perhaps the best selection for energy conservation because they can be removed during the day when PAR is needed and replaced at night for thermal protection. The selection of a suitable thermal screen material allows for additional use as summer shading.

Table 1 attempts to show the amount of energy required and potential savings for a one acre facility having different construction features. The values were generated by a computer program developed by Bill Roberts to predict heating loss. The program calculates an average daily temperature by dividing the monthly degree day base by the number of days in a month and therefore determines the daily average degree-days. Adding this number to 65 gives the estimated daily average temperature. The model assumes that the difference between the desired set point and the daily average temperature is the average temperature difference for the 24 hour period. The model multiplies the thermal heat transfer coefficient times the surface area times the average temperature difference for 24 hours and determines a total number of BTU required in gallons of oil assuming an efficiency of the heating system of 71.5% for the combustion process. The solar input during the day is assumed to be 15% of the daily energy requirement and this is also credited in the model.

Examining a typical one acre installation gives the following results tabulated for easy comparison. The imaginary greenhouse is 192 by 210 feet with 12 foot sidewalls.

Table 1

Scenario A Single glass all around (roof and side walls)
Scenario B Single glass all around with an internal overhead thermal screen
Scenario C Double poly roof with polycarbonate side walls
Scenario D Double poly roof with polycarbonate side walls with overhead thermal screen
Scenario E Same as D but with floor heating added with a 5°F lower setpoint temperature

Scenario	Gallons of oil	Gallons/sq foot	Heating plant size	Savings in gallons (%)
A	69,000	1.71	187 HP	reference
B	48,810	1.24	135 HP	20,190 (29%)
C	46,000	1.14	124 HP	23,000 (33%)
D	31,615	0.78	86 HP	37,385 (54%)
E	24,651	0.61	86 HP	44,349 (65%)

Comparing A and B shows the value of a thermal screen for a single layer glass greenhouse.
Comparing A and C shows the difference in double glazing versus single glazing.
Comparing C and D shows the value of a thermal screen for a double poly house.
Comparing D and E shows the value of floor heating and a thermal screen for a double poly house.

For crops grown on the floor the value of floor heating in the program is accounted for by lowering the set point 5°F without any penalty on the crop in terms of time or performance. This has been verified for many floor-grown crops through years of experience.

Separated Combustion Units Safer

When unit heaters or furnaces are located within the greenhouse, a small primary delivery air duct should be provided to deliver combustion air directly to the combustion unit. Modern plastic greenhouses are so tight that it is possible to use up the oxygen in the greenhouse and create a dangerous condition for workers. This duct should provide 50 square inches of inlet opening per 100,000 Btu/hour capacity of the heating unit. This ensures good combustion and can reduce operating costs.

Separated Combustion unit heaters use the concept of separated combustion to ensure that the primary air supply for combustion is always adequate and comes from outside the building. In this type of heater construction, no interior greenhouse air passes through the combustion side of the heat exchanger. There has been some evidence to suggest that pesticide traces and the high humidity of the greenhouse environment have contributed to shortening the life of the heat exchangers used in hanging gas combustion unit heaters. The separated combustion design has eliminated these potential problems and greatly increased the life of the heat exchangers in the combustion units..

Exhaust gases contain sulfur and traces of ethylene that can be damaging to plant growth. A wind directional draft device should be attached to the top of the exhaust stack to prevent down-drafting during heavy winds. The new separated combustion units, mentioned earlier, also eliminate this problem of back-drafting of exhaust gases into the greenhouse growing space. This can occur in windy conditions or when exhaust fans are being used for humidity control while the heating units are operating.

ALL COMBUSTION UNITS, including separated combustion designs, MUST BE VENTED to the outside with an approved exhaust stack that extends at least 24 inches above the ridge of the greenhouse or the highest adjacent building.

Air Movement Within the Canopy

Horizontal air flow, HAF, is a system utilizing fans to circulate air through the greenhouse canopy. Often, its greatest benefit is creating uniform temperatures within a greenhouse with a non-uniform heating system. However, it cannot remove moisture from the greenhouse.

Figure 1 indicates the microclimate around a typical potted plant on a greenhouse bench.

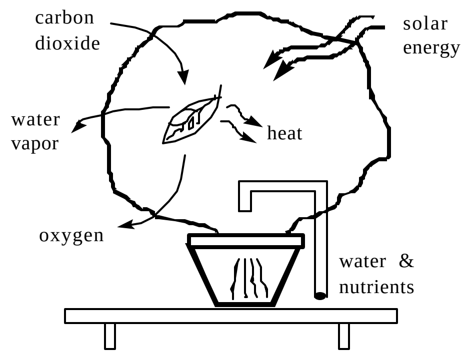

Figure 1. Plant processes affected by air movement (G.A. Giacomelli).

HAF can improve environmental uniformity throughout the plant production area by circulating the air within a greenhouse. The greenhouse air contains carbon dioxide, oxygen, water vapor and the capability for warming or cooling the plant. Air movement can transport and transfer these growth-limiting factors to and from the aerial part of the plant.

Horizontal air movement is created within the greenhouse by strategic placement of HAF fans. Total installed fan capacity in cfm is approximately 1/4 of the greenhouse volume each minute. If the greenhouse volume is 20,000 cubic feet, then HAF selection is based on a total capacity of 5,000 cfm. They are mounted overhead for safety in rows 20-50 feet apart, with row spacing as indicated in NRAES-33, “Greenhouse Engineering” by Aldrich and Bartok (http://www.nraes.org). The fans are arranged to move the air in a circular pattern further creating uniformity of temperature and plant gaseous environment.

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Horticultural Engineering on the Web

This issue of Horticultural Engineering, like previous ones, will soon be available on the internet at:

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We will send an e-mail announcing each Horticultural Engineering Newsletter as it is posted on our web site.
Thanks to those of you who have elected to receive this newsletter via the Web. We appreciate your help in saving the duplicating, postage, and handling costs.

Several useful Websites:
http://www.ag.ohio-state.edu/~vegnet
http://www.ces.ncsu.edu/depts/hort/greenhouse_veg
http://ag.arizona.edu/hydroponictomatoes
http://res2.agr.ca/harrow
http://www.rce.rutgers.edu

Important Dates
January 14 – 15, 2002
Greenhouse Engineering Short Course at Rutgers University

This 2-day course, coordinated by your editor, features timely topics for greenhouse operators and those interested in learning more about greenhouse engineering or perhaps thinking about getting started in the greenhouse business. Registration information is available for the Office of Continuing Professional Education at Cook College,
Phone: (732) 932-9271, or on the web: http://cook.rutgers.edu/~ocpe
It is not too early to plan to attend this program. Speakers include: Professor emeritus Bill Roberts, Professors George Wulster, David Mears, David Fleisher, your editor, and more!