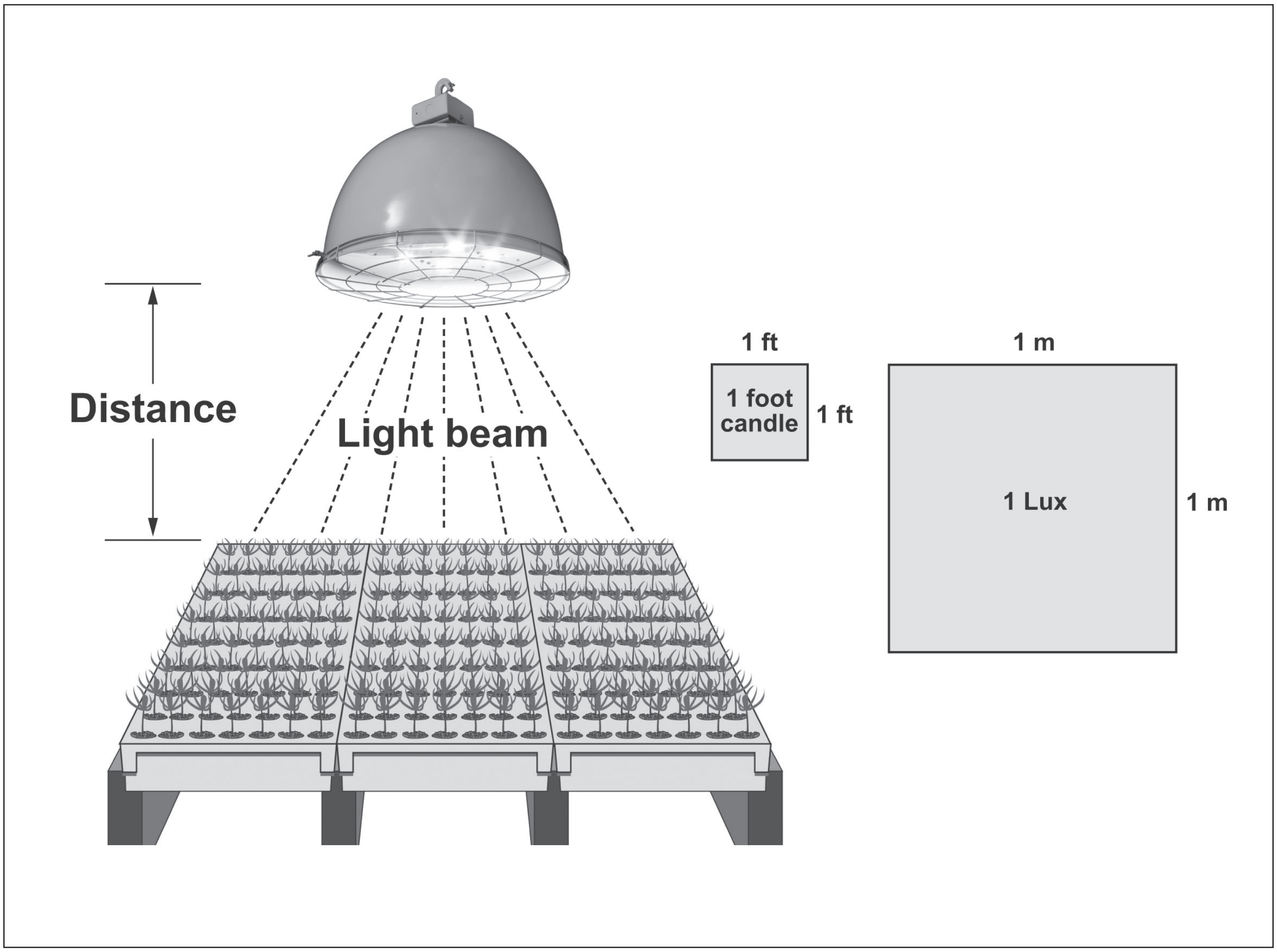
United States
Department of
Agriculture
Forest Service

Volume 33 • Issue 2

Forest Nursery Notes

Summer 2013



Cover Photo:
Artificial light is measured in illumination units of foot-candles or lux at a fixed distance from the light source.

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This international technology transfer service is printed by the U.S. Department of Agriculture, Forest Service, Natural Resources Conservation Service, National Agroforestry Center (Lincoln, Nebraska), with funding from the Forest Service, State and Private Forestry, through the Center for Reforestation, Nurseries, and Genetics Resources.

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Nursery Meetings

Note: Because FNN is only printed twice a year, the following information is necessarily dated. For the most up-to-date information on meetings about nurseries, reforestation, and restoration, visit the RNGR Website: www.rngr.net

The **combined Northeastern and Southern Forest Nursery Association meeting** will be held on **July 22 to 25, 2013** at the Holiday Inn City Centre in Lafayette, IN. The agenda will include technical presentations and exhibits as well as tours of the Purdue University Hardwood Tree Improvement and Regeneration Center, Arbor America, and Vallonia Nursery.

This year's **Western Forest and Conservation Nursery Association meeting** will be held on **August 6 to 7, 2013** at the Red Lion Hotel in Olympia, WA. This year's theme will be "Life in the Underground: management of soils, growing media, and roots in the production of forest and conservation seedlings". The agenda will consist of technical presentations as well as a nursery tour of the Washington Department of Natural Resources Webster Nursery.

To register or just get more information on
either of the above meetings, contact:

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Website: http://www.westernforestry.org/

The **33rd Annual General Meeting of the Forest Nursery Association of British Columbia (FNABC)** will be held on **September 30 to October 2, 2013** at the Best Western Plus Vernon Lodge in Vernon, BC, CANADA. The meeting theme is "Simplification - Efficiencies - Outlooks" and the schedule includes technical presentations, field tours, and commercial exhibits.

To register, or to preview the conference agenda,
go to the FNABC website at
www.fnabc.com

Western Forest & Conservation
Nursery Association

The **Western Region of the International Plant Propagators' meeting** will be held on **October 2 to 4, 2013** will be held at the Embassy Suites at the Portland, OR airport. Besides the wide ranging technical presentations during the meeting, there will be extensive pretours of local nurseries and scenic attractions in the Oregon and Washington area.

For more information, contact:

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The **Sixth Western Native Plant Conference** will be hold on **December 9 to 11, 2013** at the Heathman Lodge in Vancouver, WA. The agenda will focus on Current Topics in Propagation, Conservation, Restoration, and Policy concerning all types of native plants.

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Light Emitting Diodes (LED) – Applications in Forest and Native Plant Nurseries

by Thomas D. Landis , Jeremiah R. Pinto, and R. Kasten Dumroese

> *"LED lighting has a bright future in the world of horticultural lighting. —When applied in a well-designed system, no other light source can match the capabilities that LEDs have to offer"*
>
> — Bourget 2008

It was quotes like this that made us want to learn more about light emitting diodes (LED). Other than knowing that LEDs were the latest innovation in artificial lighting, we knew that we had a lot to learn. So we started by reviewing some of the basics. The following review is a brief synopsis of how light affects plants and some discussion about LED lighting. If you want more detailed information about the effects of light on plant growth, read Chapter 3 in Volume Three: Atmospheric Environment of the Container Tree Nursery Manual (Landis and others 1992).

1. The complicated nature of light

If you follow quantum mechanics, you are familiar with the relatively recent discovery that electromagnetic radiation, commonly referred to as "light", has a dual nature - properties of both waves and particles. Although scientists and philosophers as far back as Aristotle had developed theories about light, it was not until 1905 that Albert Einstein described the photoelectric effect that explained the relationship of wavelength and photons (individual particles of energy). This was just one of his most famous insights and earned him the Nobel Prize in Physics in 1921 (Nobel Media AB 2013).

Light is the most complex and variable of the limiting factors affecting plant growth, and for our purposes, there are two types: natural light (sunlight) and artificial light. Sunlight is the common name for electromagnetic radiation that originates from our sun, which is approximately 93 million miles away. The quantity and quality of sunlight differs significantly from the artificially produced light that we use in our homes and greenhouses. Managing light is particularly challenging due to its subjective nature. The sunlight that your crops "see" is much different in terms of wavelength (color) and intensity that what we humans perceive. In fact, the term "light" only refers to one small part of the electromagnetic spectrum that is visible to the human eye (Figure 1). And, to make matters even more complicated, our iris controls the diameter of the pupil of our eye and thus regulates the amount of light that we perceive from one location to another.

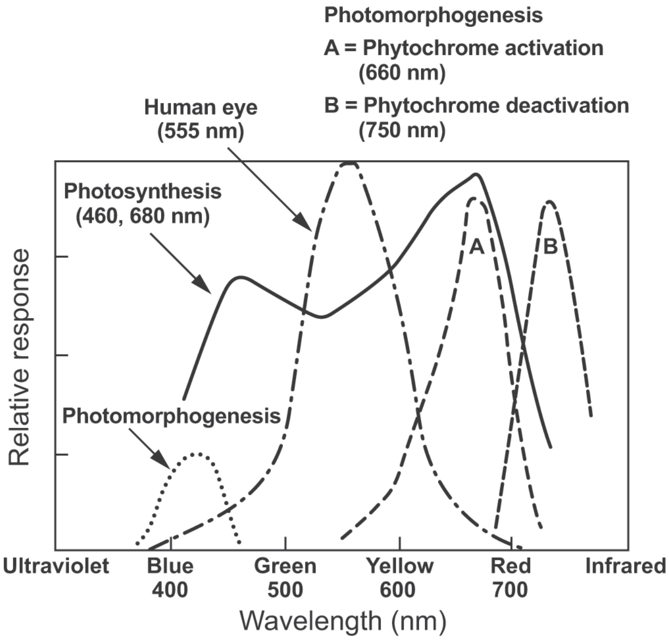

Figure 1 - Plants absorb certain wavelengths of light. Photosynthesis is fueled by blue or red light (peaking at 460 and 680 nm), whereas phytochrome is activated by red light (660 nm) and deactivated by far red light (750 nm). Phototropism and cell expansion are promoted by blue wavelengths. Contrast these responses to those of the human eye which peak in the yellow-green wavelengths (555 nm).

2. Measuring light

While the dual nature of light can be complicated in and of itself, the measurement and unit description of light only adds to the complexity and confusion. Sunlight can be measured by 3 different systems each with its own units. The unit of micromoles (µmols) per second per square meter measures the sun's energy as photon flux density per unit area, and for natural sunlight this is about 2000 µmols/s/m^2. These units are commonly used in measuring photosynthesis light energy, as described in Figure 1. In this article, we focus on artificial light that, for horticultural purposes, should be measured in terms of intensity (energy) and quality (wavelength).

Engineers measure light intensity using illumination units that reflect the sensitivity of the human eye within the

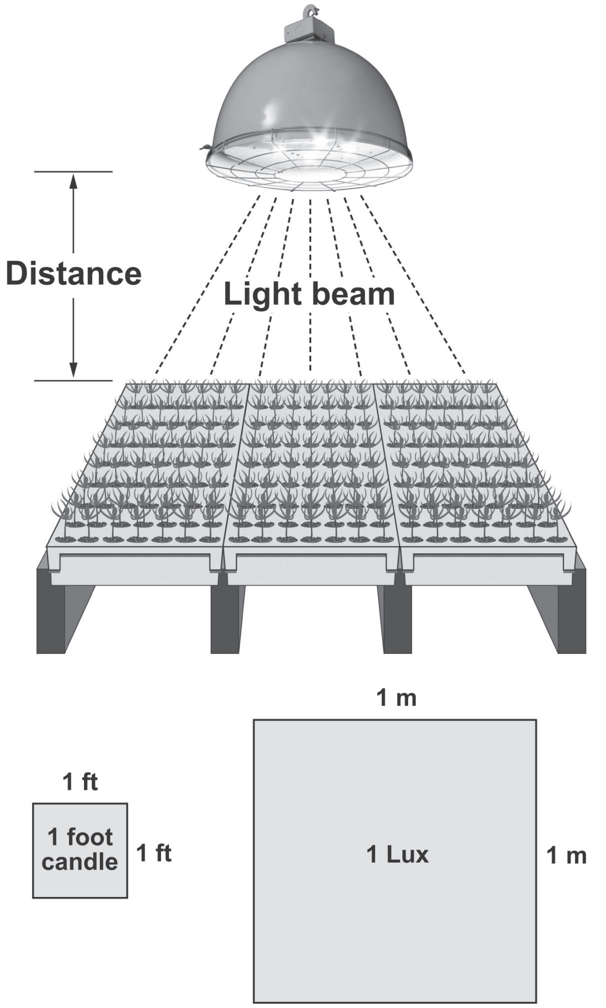

Figure 2 - Artificial lighting is measured in illumination units: the metric lux and the English foot-candle. It is critical to measure light at the crop level because illumination decreases with distance from the light source (modified from Bickford and Dunn 1972).

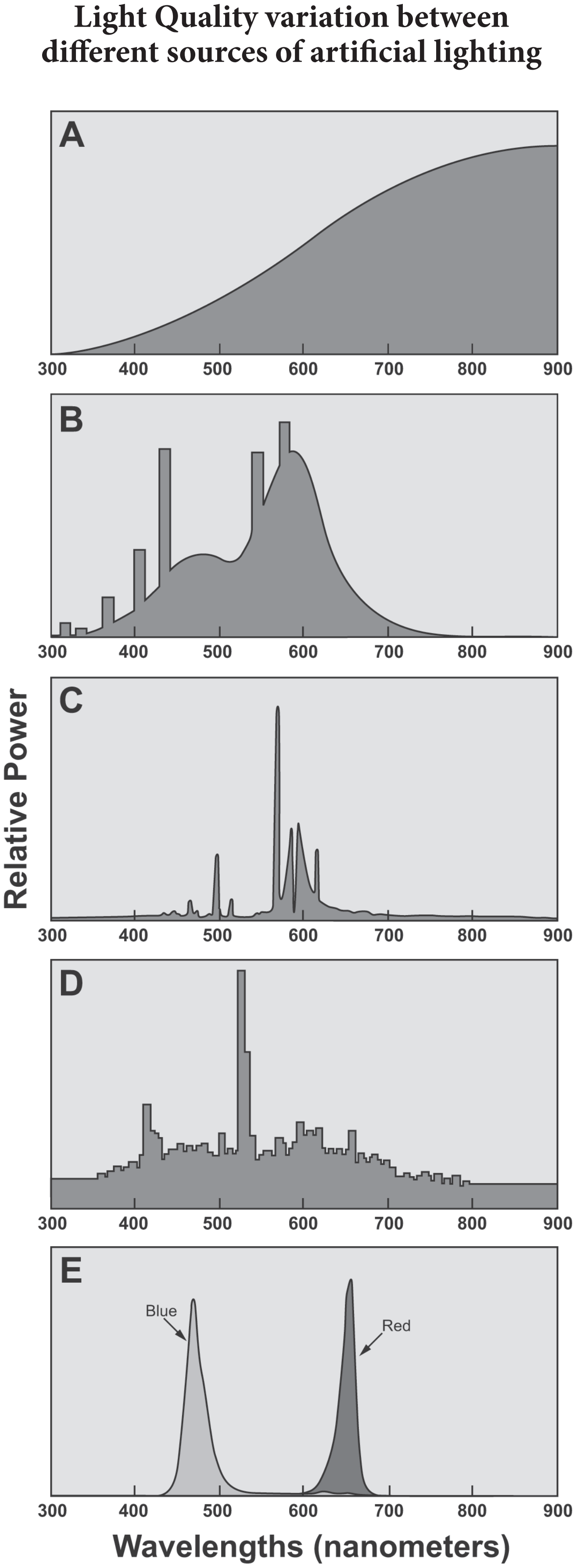

Figure 3 - These spectral energy distribution curves show the different quality of light produced by different lighting sources. Incandescent lamps produce most of their light in the red and infrared wavelengths (A), compared to fluorescent lamps that produce a more balanced output (B). Infrared wavelengths are perceived as heat, which is not only a waste of energy but requires compensatory cooling. High pressure sodium lamps produce most of their light in the yellow wavelengths (C) whereas metal halide lamps generate a more balanced "white" light (D). Light emitting diodes (LED) are unique in that each produces just one specific wavelength, such as blue and red (E) (A-D from Kaufman and Christensen 1984; E modified from Seelye and Mullan 2010).

visual spectrum (Figure 1). The standard unit of illumination is the lumen. A lumen that is evenly distributed over an area of 1 square meter is defined as 1 Lux (lx); for English units, a lumen distributed over 1 square foot is 1 foot-candle (Figure 2). An inexpensive light meter ($35+) can provide basic information on light intensity by measuring these units; because most growers of native plants rely on natural daylight for photosynthesis and usually use photoperiod lighting to extend daylength, this is adequate. The spectral quality (wavelengths) of artificial lighting varies significantly between different sources (Figure 3) and is usually measured in nanometers (nm). Fortunately, for photoperiod control, most artificial lights generate enough light to be effective (see the next section for more details). However, the light quantity and quality needed to increase photosynthesis differs considerably from that needed for photoperiod extension. If growers may want to measure the photosynthetically active wavelengths actually reaching their crops, a higher quality light meter is required ($1000+).

3. Plant responses to light

Plants respond to visible light by 2 general mechanisms that are keyed to specific wavelengths: photosynthesis that has a higher-energy requirement and photomorphogenesis that has a lower-energy requirement.

3.1 Photosynthesis

Visible light is captured by the carotene and chlorophyll pigments in leaves and, using carbon dioxide and water as raw materials, is converted into the chemical energy needed for plant growth and metabolism. Photosynthetic rates are highest in 2 bands: red light, with some activity in the blue-green wavelengths (Figure 1); these wavelengths are collectively known as photosynthetically active radiation (PAR). Conceptually, photosynthesis can be thought of as a tachometer (Figure 4A) because photosynthetic rates increase with more light up to a point that is species dependent. In forestry, this response to light levels is known as shade tolerance. Shade tolerant plants, such as dogwood, reach their maximum photosynthetic rate at 35 kilolux (klx) of illumination compared to shade intolerant (sun loving plants, such as ponderosa pine) that may continue to photosynthesize up to 120 klx.

3.2 Photomorphogenesis

The pigment phytochrome is sensitive to the ratio of red to far-red light (Figure 1) and acts as an environmental sensor to measure daylength. The phytochrome system controls several aspects of seedling phenology, such as seed germination and bud set. Although all plants in the temperate zones and higher latitudes are sensitive, tropical and subtropical species have not adapted to these changes in daylength. Blue light is important to normal morphological development, particularly in regard to branching and shoot sturdiness. Conceptually, the phytochrome system can be viewed as a light switch. Under predominantly red light, the switch is "on" and cell growth occurs as fast as the light intensity permits. However, when far-red light predominates the switch is turned "off" and growth stops as plants transition into dormancy (Figure 4B).

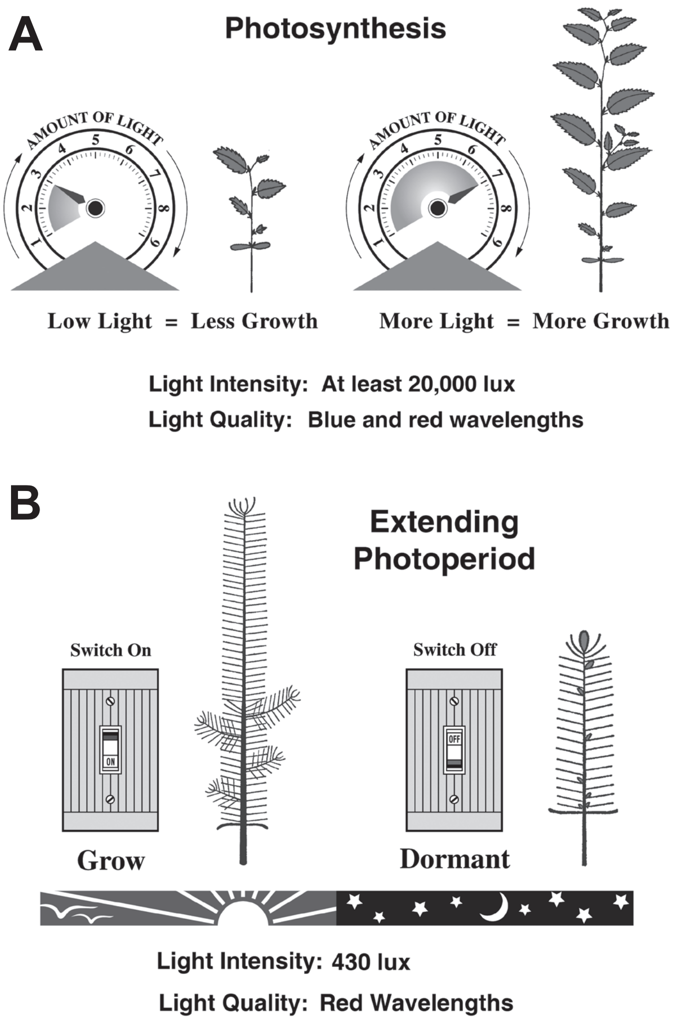

Figure 4 - Analogies are helpful in understanding the effects of light on plant growth. Shoot growth can be viewed as a tachometer - the higher the light intensity, the higher the photosynthetic rate (A). Using low intensities of red light to extend daylength is like a switch that triggers the phytochrome receptor and tricks plants into thinking it is still summer (B).

4. Types of artificial lighting used in horticulture

As we just discussed, artificial lighting is used in greenhouses to either increase photosynthesis or control photoperiod (extend daylength), but the required light intensity and quality for each are very different. A wide variety of artificial lights have been used in horticulture including incandescent, fluorescent, and high intensity discharge (HID) lights. Incandescent lighting is typically high in the red and infrared wavelengths (Figure 3A). Fluorescent lights produce more white light (Figure 3B) but the fixtures must be located very close to the crop. High intensity discharge (HID) lights, such as high pressure sodium (Figure 3C) and metal halide (Figure 3D), are more energy efficient choices. Light emitting diodes (LED) are the newest light source and can be developed to produce specific wavelengths, such as blue and red (Figure 3E). Because no semiconductors emit pure white light, most white LEDs consist of a blue light-emitting chip coated with phosphor, which causes yellow light to be emitted. This mixture of blue and yellow light is perceived as white light by the human eye. White light can also be produced by combining semiconductors of red, green and blue (RGB) into a single LED lamp (Seelye and Mullan 2010).

It is critical to note that illumination units are always measured at a standard distance from the source. We have found that the engineering specifications for artificial lighting systems are not always accurate. It is therefore important that growers make their own measurements under each bulb as well as between bulbs to make sure that the entire crop receives at least the minimum intensity. Remember, always measure light intensity at crop height (Figure 2).

4.1 Lighting to increase photosynthesis

Traditionally, HIDs, including high pressure sodium and metal halide lamps, have been used in growth chambers to supplement natural sunlight and increase photosynthetic rates (Figure 5A). Because of the large amount of electrical energy required, adding lights to increase photosynthesis is, for most reforestation and native plant nurseries, economically impractical. This conclusion, however, may need to be revisited with the advent of LED lighting that has been developed for horticulture.

Required light intensity and quality. If artificial lights are the only source of illumination, as in a growth chamber, the minimum requirement for commercial plant production is considered to be about 250 umol/s/m^2 (20

Figure 5 - High intensity discharge lights, such as these metal halide lamps, must be grouped close to the crop to produce enough light intensity for photosynthesis (A). Due to the low intensity of light required, a wide variety of different lighting systems have been used to extend photoperiod, including these incandescent flood lamps (B) (Photos from Landis and others 1992).

klx), which is about one-eighth the intensity of normal sunshine. Photosynthetic lights must also be kept on for at least 12 hours per day to generate reasonable rates of growth. Supplemental lighting is sometimes needed to compensate for cloudy weather, shading from greenhouse structures or equipment, or during the winter at higher latitudes. When 122 umol/s/m^2 (10 klx) of PAR light is added for 8 to 16 hours per day, growth rates can approach those obtained in growth chambers (ASHRAE 1989).

Because not all wavelengths are equally effective for photosynthesis, artificial lighting should be high in the PAR wavelengths bands (Figure 1): blue (460 nm) and red (680 nm) wavelengths are ideal.

Monitoring photosynthetic lighting. For high value horticulture crops, growers monitor the Daily Light Integral (DLI), which is the amount of PAR calculated as a function of light intensity and duration. Calculating DLI requires special sensors and data recorders so that light intensity and quality can be simultaneously and continuously recorded. DLI values for floriculture have been well described (Torres and Lopez 2010), but for forestry and native plant crops, are most likely non-existent.

4.2 Lighting to increase daylength

Photoperiodic lighting is much more common than photosynthetic lighting in forest, conservation, and native plant nurseries. A variety of different lighting arrangements (Figure 5B) have been effective in triggering the phytochrome response and keeping plants actively growing in the spring or fall when natural daylength becomes limiting.

Required light intensity and quality. Very low light levels are needed for daylight extension. Research trials, validated in many operational nurseries, have determined photoperiodic lighting intensity should be at least 8 µmol/s/m^2 (~430 lux), and should be increased to 16 µmol/s/m^2 (~860 lux) when the crop has a greater light requirement (Landis and others 1992). Almost any of the standard lamps can be used because they all emit light in the red wavelengths (Figure 3). A complete discussion of the most common photoperiodic lighting systems can be found in Landis and others (1992).

Monitoring photoperiod lighting. Illumination intensity should be measured at crop height with a standard light meter after sunset; to ensure that all plants are receiving the proper light intensity, take measurements beneath and between lighting fixtures.

5. LED lighting

Light emitting diodes (LED) are the newest type of artificial illumination being used in greenhouse culture. An LED is a solid-state semiconductor device that is more closely related to a computer chip than a light bulb (Figure 6A). When electricity passes through a junction constructed of different materials, visible light is emitted in a narrow wavelength (Figure 2E). LED units by themselves are very small (0.2 in or 5 mm); consequently, they are often arranged in arrays that are sealed in plastic lenses protect the units and direct the light. LED units are available as traditional bulbs that will fit standard fixtures (Figure 6B) or in linear arrays (Figure 6C) that, because they radiate no heat, can be located within plant canopies (Figure 6D). As mentioned earlier, because LEDs produce light in narrow wavelengths, they can be used to generate colors across the visible spectrum from blue to red or combined or coated to produce a more all-inclusive white light (Lighting Design Lab 2013).

LED lighting has at least 5 advantages for use in horticulture, which are described below.

5.1 Energy efficiency

As measured by radiated power output (lumens) divided by electrical power input (watts), LED units are very efficient, especially when compared to traditional incandescent bulbs. The energy efficiency of LED lights continues to improve and is projected to exceed 200 lumens per watt in the near future (Clark 2013) (Table 1).

5.2 Lifespan

The useable life of LED units is significantly longer than traditional artificial light sources used in horticulture, from 2 to 3 times better than fluorescent or HID lamps, to a 50-fold increase over typical incandescent lamps (Table 1). Unlike traditional lamps, LEDs do not “burn out”; instead, they gradually dim and should be replaced once they dim to 70% (Bourget 2008).

5.3 Custom lighting

LEDs produce light in a very narrow wavelength range (Figure 3E), so units can be designed to produce light of desired wavelengths, or combined to generate white light (van Ieperen and Trouwborst 2008). LED arrays of blue and red light that increase photosynthesis can be positioned within crop canopies where these wavelengths do not normally reach due to absorption by the upper leaves (Figure 6D).

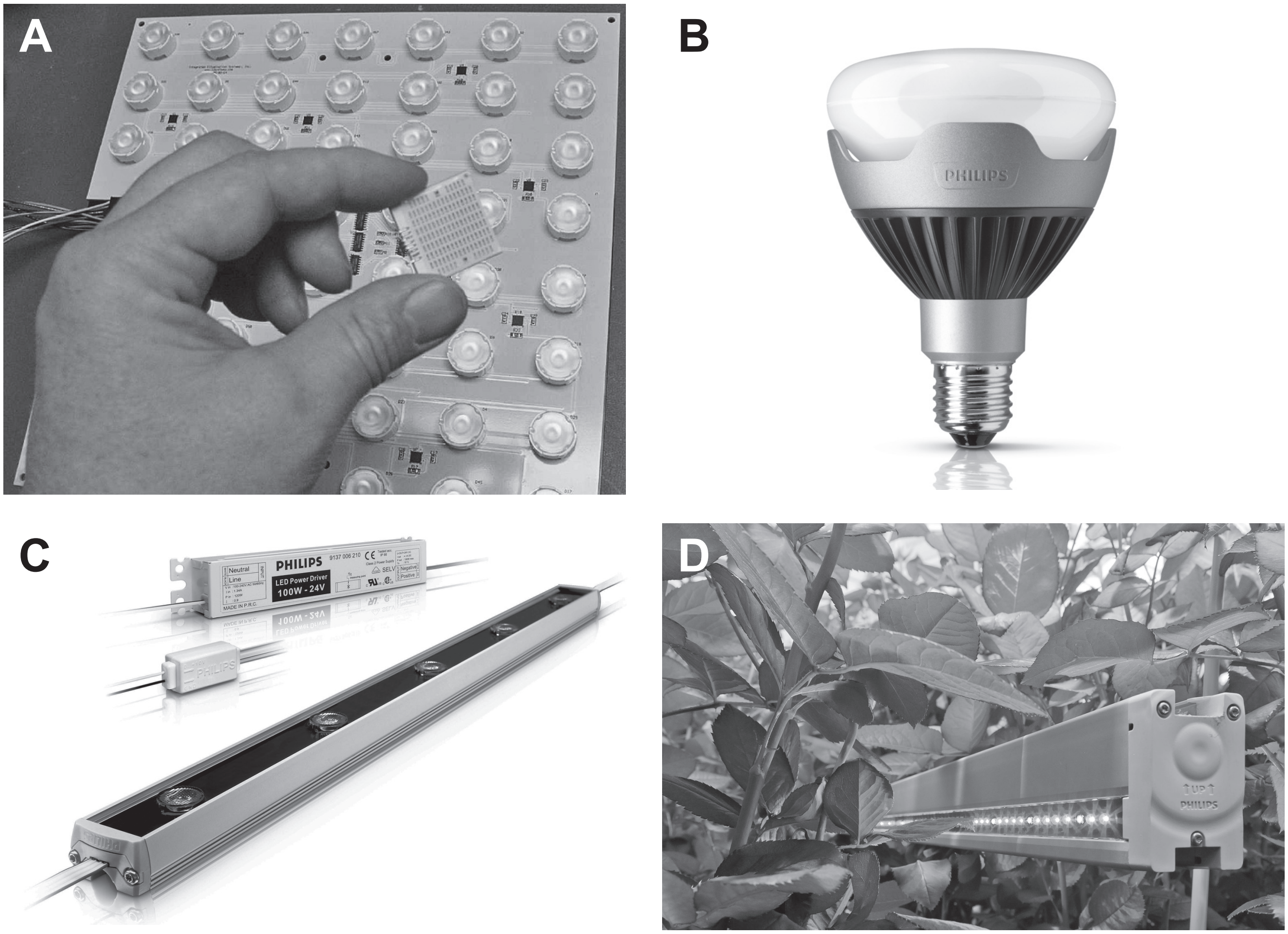

Figure 6 - Light emitting diodes (LED) are the newest form of artificial lighting used in horticulture and are more like computer chips than light bulbs (A). LED units can be housed in traditional bulbs that will fit standard fixtures (B) or arranged in arrays designed to produce light of specific wavelengths (C) that, because they do not radiate heat, can be located within plant canopies (D) (A from Morrow 2008; B-D courtesy of Philips Electronics 2012).

Table 1 - Energy efficiency and lifespan of common light bulbs compared to light emitting diode units (Bartok 2012).

Illumination source	Energy efficiency (Lumens per watt)	Average lifespan (hours)
Incandescent	15 to 18	1,000
Tungsten - halogen	15 to 20	2,000
Compact fluorescent	50 to 65	10,000
T-12 fluorescent	30 to 40	15,000
T-5 fluorescent	90 to 110	20,000
Metal halide	90 to 100	15,000
High pressure sodium	90 to 100	24,000
Light emitting diodes (LED)	60 to 90 *	50,000

* LED efficiencies continue to improve and are predicted to reach 260 to 300 lumens per watt in the coming decades (Clarke 2013).

5.4 Radiant heat

LEDs produce almost no radiant heat and so can be positioned close to plants, ensuring maximum light interception (Seelye and Mullan 2010).

5.5 Plant productivity

The current literature contains very little research on using LEDs for forest or native plant crops. Recent preliminary research trials in Finnish conifer nurseries, however, show that LED lights (Vayola B100, spectra G2) performed similarly to high-pressure sodium lights and were sufficient to prevent bud formation in Norway spruce and Scots pine (Riikonen 2013). In horticulture, LED intracanopy lighting produced 75% more tomato fruit biomass compared to overhead high pressure sodium lighting (Gomez and others 2013).

5.6 Actual comparison of commercial LED lamps

We were curious to run our own tests on currently-available lamps, and purchased 3 different flood lamps with a 120 watt rating (Table 2). The first thing we noticed was "sticker shock" due to the much higher cost of the LED lamps — more than 4 times as much as the other bulbs. The price of LED lamps has continued to decrease. One report states that the top-rated LED lamp from Home Depot dropped about 50% in just a few months. Philips says it will introduce a $10 LED 60 watt rated light bulb by the end of the year (Janeway 2013). Based on the label information of estimated lifespan and yearly energy costs, annual operating cost for the compact fluorescent and LED lamps rated about the same, but the incandescent lamp was more than 3 times more costly to operate.

We decided to test the 3 lamps (Figure 7A) in the same fixture and immediately noticed that, although each had a 120 watt rating, the LED lamp was noticeably brighter. Illumination readings were taken 5-ft (1.5 m) directly under the lamps and our results confirmed our observations: the LED lamp produced 4,726 lx, the incandescent 561 lx, and the compact fluorescent 301 lx – an 8-fold and 15-fold difference, respectively. Another striking pattern we noticed was the horizontal light distribution perpendicular under each lamp. While the LED was brightest directly under the lamp, the light

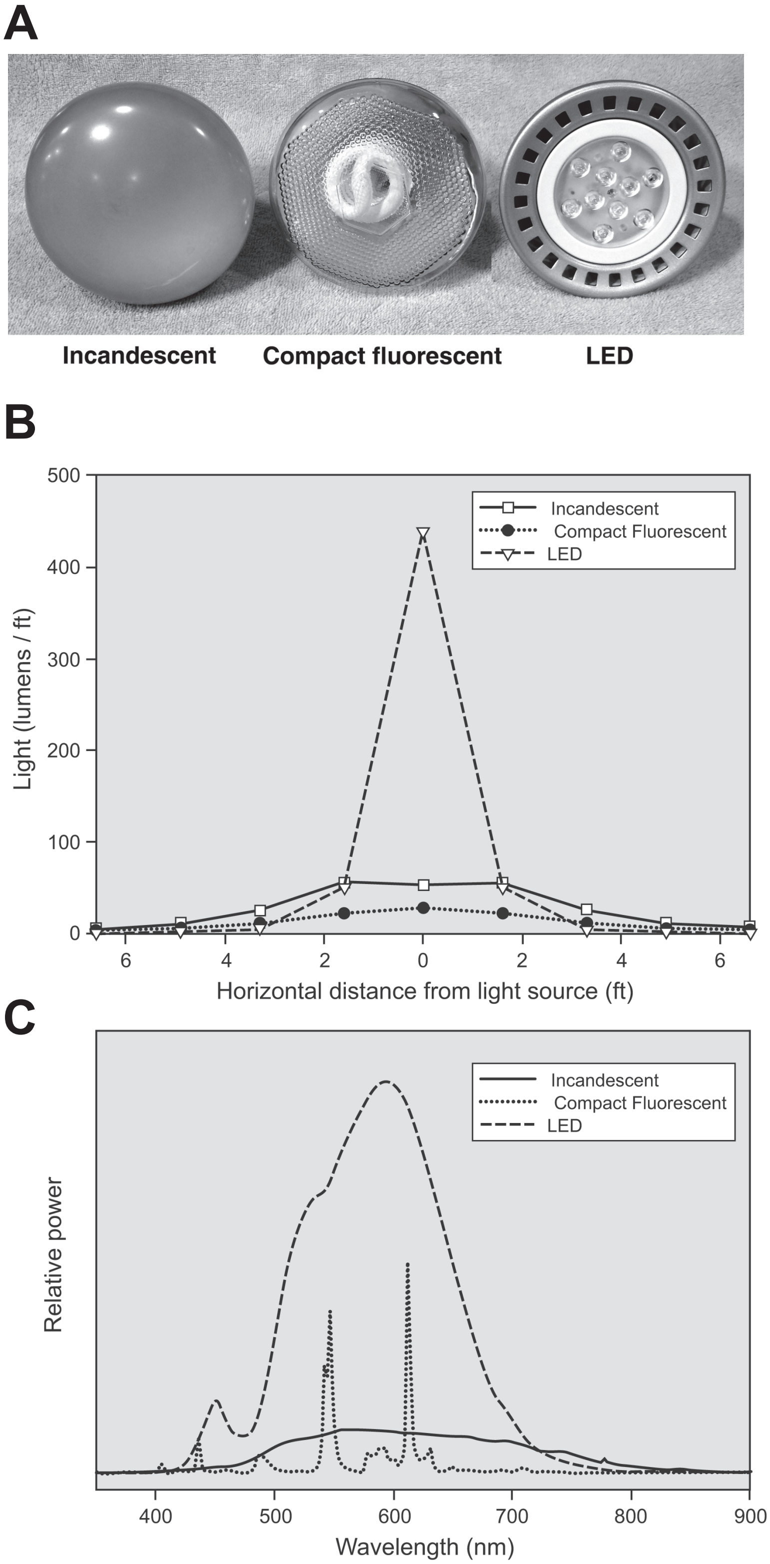

Figure 7 - Light intensity of 3 commercially available 120 watt-rated lamps (A: incandescent, compact fluorescent, and LED) measured 5 ft (1.5 m) directly below, and at 4 horizontal distances perpendicular from this point (B). Relative spectral energy distributions also differed among the three light sources (C).

Table 2 – Comparison of commercial 120 watt-rated flood lamps currently available.

	Incandescent	**Compact Fluorescent**	**LED**
Manufacturer	Philips	EcoSmart	Philips
Type	EcoVantage, Bright Light, Dimmable, Indoor BR40 [a] Flood	Soft White PAR38 [b] Flood	Soft White, Dimmable, PAR38 [b] Flood
Label Specifications			
Equivalent wattage	120	120	120
Actual wattage	70	23	19.5
Label Brightness (lumens) [c]	1225	1290	1100
Color temperature (K) [c]	2810	2700	2700
Estimated life (y) [c]	2.7	9.1	22.8
Estimated yearly energy cost [c]	$8.43	$2.77	$2.35
Purchase price [d]	$9.97	$10.27	$42.97
Annual operating cost [e]	$12.12	$3.90	$4.23
Toxicity	None	Mercury [f]	None
Disposal	Trash	Recyclable [g]	Recyclable [h]

[a] BR40: bulged reflector, 40/8ths of an inch wide, or 5 inch diameter.
[b] PAR38: parabolic aluminized reflector lamp, 38/8ths of an inch wide, or 4.75 inch diameter.
[c] Per manufacturer's package. Estimated life assumes 3 h use per day. Estimated yearly energy cost assumes 3 h use per day and $0.11 per kWh.
[d] Retail price for single bulbs at local "big box" home improvement store.
[e] Annual operating cost = (Purchase price/estimated life) + (estimated yearly energy cost).
[f] Contains mercury.
[g] See US EPA website for more information: http://www2.epa.gov/cfl/recycling-and-disposal-after-cfl-burns-out#cantrecycle (accessed 29 May 2013). Local options may be available.
[h] Varies: May be recycled where purchased (including online companies) and at some local recycle centers.

intensity diminished exponentially as distance increased horizontally from beneath the light source (Figure 7B). We also measured the spectral distribution of each light source to show relative differences in wavelength emittance, which demonstrates the high quality white light from the LED lamp (Figure 7C).

6. Summary

So, what is the bottom line? Should you run right out and replace your existing lighting systems with LED lights? For the applications commonly used in forest and native plant container nurseries, we see some immediate applications. LED lights come in standard sizes and illumination units that can be easily substituted in existing lighting fixtures in offices and other workplaces. LED bulbs are available with screw bottoms or as long tubes to replace fluorescent bulbs. We have found a range of LED lights at our local home improvement stores.

For the high intensity lighting needed to increase photosynthesis, LED lights in the blue and red wavelengths would increase growth rates but, because they may have to be situated close to the crop, they could interfere with irrigation. For germination rooms, however, LED lighting would be much more efficient than standard fluorescent lights, would generate significantly less heat, and would not be subject to corrosion by the high humidity levels.

For the low intensity red light needed to extend photoperiods, LED lights would be as effective, use less energy, and last longer than traditional lamps. A major limitation as found by our rudimentary testing found that LED did have limitation in the area they illuminate (rapidly decreasing light intensity as the distance below the source increases). Before switching to LEDs, be sure that light coverage is adequate and confirmed with a light meter (at crop level). LED bulbs are available in screw bottom for traditional fixtures or as long tubes to replace fluorescent bulbs. Nurseries using high intensity discharge lamps would have to weigh the costs of replacing the fixtures as well as the lamps.

LED lighting is rapidly changing, with improving efficiencies improving and decreasing costs, so growers should keep an eye on this exciting new technology.

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Controlling Pests that are Spread in Irrigation Water

by Thomas D. Landis

The evidence that irrigation water can be a significant source of nursery pathogens has been accumulating for almost a century. In one of the first systematic testings of agricultural water sources, Bewley and Buddin (1921) isolated several pathogens including *Botrytis* spp. and *Phytophthora* spp. Although links between waterborne pests and nursery diseases have often been circumstantial, DNA analyses have now shown that specific isolates from diseased plants were identical to pests found in irrigation water (Hong and Moorman 2005).

Waterborne pests have been responsible for major losses in nurseries (Fisher and Smith 2007). *Phytophthora ramorum*, the cause of sudden oak death, spreads in water from plant-to-plant in nurseries and from nurseries to surrounding plant communties. Therefore, this waterborne pathogen is one of the most serious threats facing growers today (Chastagner and others 2010). Because *P. ramorum* not only causes shoot and leaf blights in a wide variety of nursery hosts but can also spread through runoff to plants in the surrounding forests, it is considered one of the most serious threats to forest, conservation, and native plant nurseries (Landis 2013).

It is critically important to have an overall plan. Two major approaches to phytosanitation can be employed. The systems approach is based on a hazard analysis of critical control points where waterborne pests could gain entry into your nursery. The comprehensive programs that have been developed for ornamental nurseries can easily be modified for forest, conservation, and native plant facilities (Parke and Grunwald 2012). Another option is based on target pests (Landis 2013): nurseries should learn as much as possible about potential waterborne pests and determine how, where, and when to check their irrigation water. So, the following discussion focuses on learning which pests can be spread in irrigation water, how to test irrigation water, and options for treating irrigation sources to eliminate any threats.

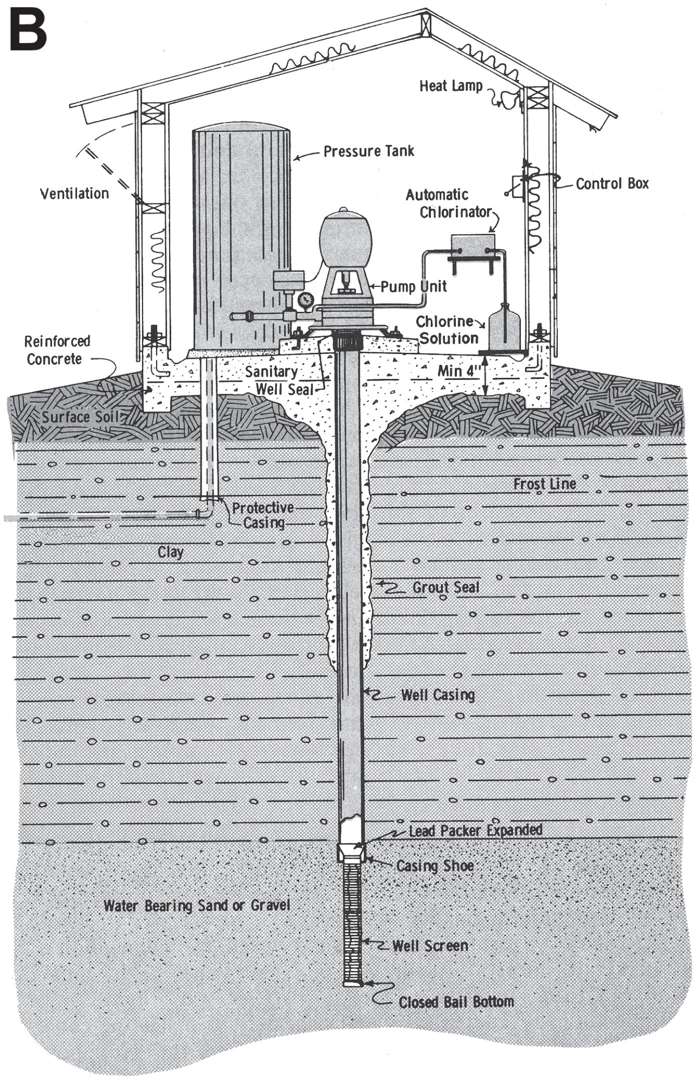


Figure 1 - Nurseries using irrigation water from surface water sources such as ponds, lakes, or rivers (A) may encounter problems with a variety of pests including weed seeds or spores of pathogenic fungi, moss, algae, or liverworts. Water from a well-designed well (B) has been shown to be free from waterborne pathogens (B modified from Whitsell and others 1982).

1. Pests in irrigation water

Water does not naturally contain organisms that can cause plant disease but irrigation sources often become contaminated, especially in agricultural areas. The source of your irrigation water is critical to determining whether it might contain pathogens and therefore require treatment. Water from ground wells can be considered pest-free (Fisher and Smith 2007), but ponds, ditches, rivers and other surface waters have been shown to contain propagules of almost every major pathogen group (Hong and Moorman 2005)(Figure 1). However, if well water is stored in unlined ponds, it can still become contaminated (Baker and Matkin 1978). Many nurseries are now recycling or are considering reusing runoff water and this makes the subject of waterborne pathogens even more important. Recycled water has been proven to contain several pathogens, and must be tested and treated before it can be reused (Black 2009).

1.1 Water molds

Pythium spp. and *Phytophthora* spp. are fungus-like pathogens that are uniquely suited for water transport because of their motile zoospore stage. In addition, they have 2 other resting spore stages called chlamydospores and oospores (Figure 2A) that allow them to survive in infected plant material for months or even years. One estimate is that an infected fragment only 1 mm long could contain 50 to 100 resting spores (Wick and others 2008), and organic wastes can be transmitted in nursery runoff. In a review of the literature, 17 species of *Phytophthora* and 26 species of *Pythium* have been identified from water samples (Hong and Moorman 2005). Therefore, control of water molds in irrigation and especially in recycled nursery water has been getting a lot of recent attention (Meador and others 2012).

1.2 Fungi

More than 25 fungal genera including *Botrytis* spp. and *Rhizoctonia* spp. have been found in nursery irrigation water (Baker and Matkin 1978), but their relationship to actual nursery diseases is sometimes hard to prove (Hong and Moorman 2005). *Fusarium* spp., on the other hand, has been confirmed to spread between plants in greenhouse water (Wick and others 2008). *Botrytis cinerea*, *Cylindrocladium candelabrum*, and *Ralstonia solanacearum* are the fungi most associated with diseases in Brazilian forest nurseries and have been shown to be transmitted through water (Machado and others 2013). Obviously, much depends on the type of irrigation system; spores from pathogenic root fungi would

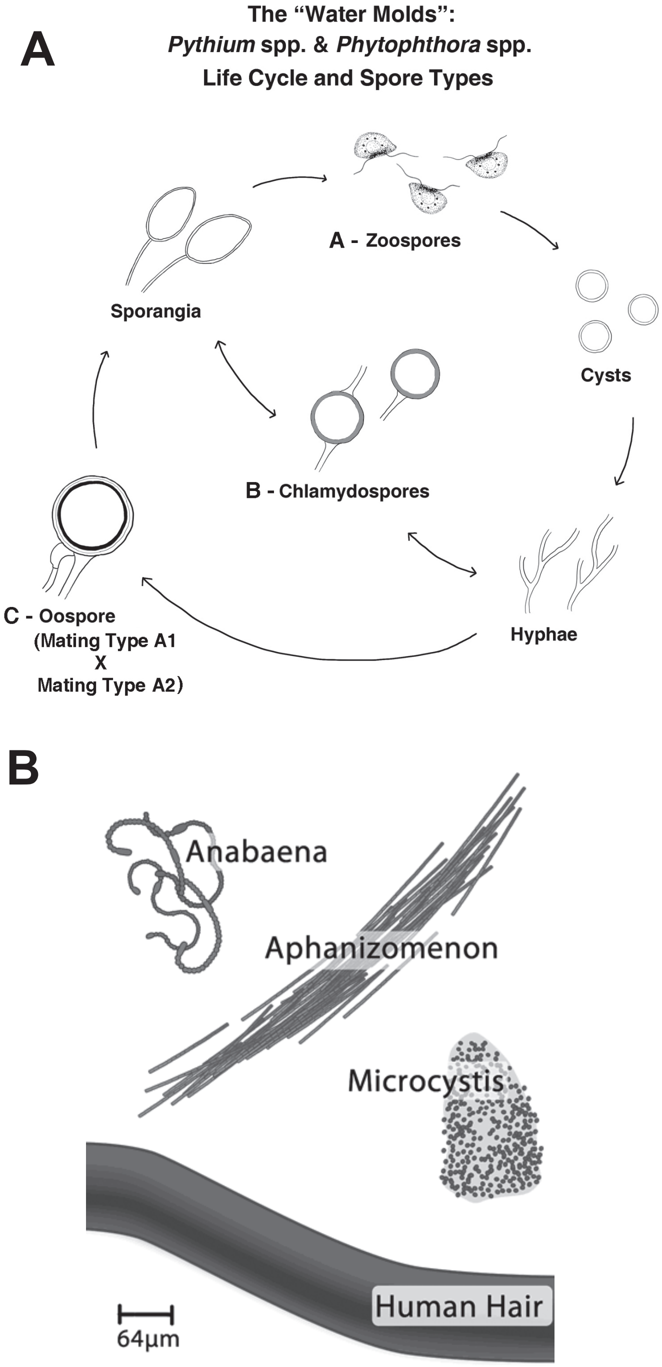


Figure 2 - The motile zoospores of Pythium *and* Phytophthora *are especially suited for water transport, and the resting oospores and chlamydospores can be transported in organic suspensions (A). Propagules of algae (B) and liverworts can also be introduced in irrigation water from surface sources (A modified from* Phytophthoras *of the World 2013; B courtesy Lakes of Missouri Volunteer Program 2013).*

be more likely to spread in recycled water or under subirrigation systems.

1.3 Bacteria

Although bacterial diseases are not common in most woody plants in forest, conservation and native plant nurseries, 8 different species of bacteria have been confirmed in nursery irrigation water. The pathogenic bacteria *Erwinia* spp. and *Xanthomonas* spp. have been shown to spread through water, and to cause disease in ornamental crops (Hong and Moorman 2005). *Xanthomonas axonopodis* is a pathogenic bacterium that is introduced in irrigation water in eucalyptus nurseries in Brazil (Machado and others 2013).

1.4 Nematodes

Plant parastic nematodes can be carried in muddy water but usually settle to the bottom of storage ponds (Baker and Matkin 1978). In a search of the literature, 13 species of plant parasitic nematodes were confirmed in nursery irrigation water. However, several nematode species identified in a water source did not survive when applied through a sprinkler irrigation system (Hong and Moorman 2005).

1.5 Algae, mosses, and liverworts

Although not widely appreciated, propagules of algae (Figure 2B), mosses, and liverworts are easily spread through irrigation water. Even though they are not considered classical pathogens, these primitive plants can cause serious problems in nurseries. Mosses and liverworts can become so thick on the top of container plants that they interfere with water absorption (Svenson and others 1998). In Oregon, liverworts were rated as the worst container nursery weed problem (Hester and others 2013). Harmful algal blooms can develop in irrigation storage ponds or ditches, especially when fed with surface waters high in nitrogen and phosphorus. Certain blue algae, such as *Microcystis aeruginosa* (Figure 2B), produce toxins when they die that can be harmful to humans and pets (Wikipedia 2013). Algal blooms have resulted in legal action in one forest nursery, and even nontoxic algae can plug irrigation nozzles (Haman 2013). Algal mats on the surfaces of container plants create ideal conditions for fungus gnats, which can become a serious plant pest (Landis 2007). Algal slime can create a safely hazard on walkways and create unsightly and unsanitary conditions that give nursery customers a bad impression (Merrill and Konjoian 2006).

1.6 Viruses

At least 10 plant pathogenic viruses have been documented in irrigation water (Hong and Moorman 2005) but none have been associated with diseases in forest, conservation, or native plant nurseries.

2. Detecting and monitoring waterborne nursery pests

As we have just discussed, water from wells is much less likely to contain pathogens than water from rivers, ponds, or other surface sources and recycled irrigation water is particularly suspect. So, how can you test your water source and determine if pest populations are present and are high enough to cause problems? A pathological evaluation of your irrigation water should determine whether the pathogen can be detected (the detection threshold) and whether populations are high enough and for sufficient time (the biological threshold) to pose a real threat to your crops (Hong and Moorman 2005).

It is important to obtain an accurate evaluation of your water quality because treating irrigation water can be an expensive operation. The first step is to determine what pests you are looking for because sampling and testing procedures can vary considerably. A recent national survey tested irrigation water quality at 5 points including the source, storage tanks, subirrigation, furthest outlet, and catchment basins. However, because the researchers only assayed the water samples for “aerobic bacteria” and “yeasts and molds” (Meador and others 2012), this general information really does not help detect which could be causing problems.

No single test will detect all potential waterborne pests, so irrigation water should be assayed by specific diagnostic techniques. Laboratory tests are available from some water treatment companies, university plant pathology laboratories, and private microbiology laboratories. For example, the Soil and Plant Testing Laboratory at the University of Missouri at Columbia will perform a basic water quality test for about $35 (Schultheis 2013).

2.1. Microscopic examination

Light microscopy is the classical method for detecting and enumerating algal species, and detection of nematodes requires direct examination and counting under a microscope (Baker and Matkin 1978). Identifying algal species and determining population levels requires specialized training and standard protocols, such as Standard Methods for the Examination of Water and Wastewater, must be followed. Although microscopic examinations provide important visual confirmation of which algal species are found in water samples and generates reasonably accurate population information, it is tedious and time-consuming (Sellner and others 2003). Therefore, laboratories specializing in algal analysis, such as Phyco Tec should be consulted if a problem exists; their website is a wealth of information on identifying and treating algae in irrigation systems (http://www.phycotech.com/).

2.2 Culturing on selective media

Water molds, fungi, and bacteria must be identified after culturing on selective agar or in liquid culture, and the number of colonies that grow from one milliliter of water can then be counted in terms of colony forming units per milliliter of water (cfu/ml) (Fisher and Smith 2007). One of the oldest tests for waterborne pathogens is the use of apples, pears, or other plant tissues as baits for water molds. The zoospores of both *Phytophthora* spp. and *Pythium* spp. are attracted to the baits, penetrate the tissue, and cause small circular decayed areas (Figure 3). Castor bean (*Ricinus communis*) leaf discs were used to bait *B. cinerea* and *C. candelabrum* from nursery irrigation water in Brazil (Machado and others 2013). The number of lesions per bait give a rough estimate of the pest population (Baker and Matkin 1978), but culturing on selective media is required for specific information. A wide variety of plant tissues or seedlings have been used as baits for *Phytophthora* spp, but leaves of rhododendron plants have proven to be the most effective (Orlikowski and Ptaszek 2010). Recent research into detecting and monitoring *Phytophthora ramorum* in and around nurseries has resulted in specific protocols for this important waterborne pest (USDA APHIS 2013).

Vacuum filtration of irrigation is a new technique that was found to be more effective for detecting *Phytophthora* species in streams, and also provided information on inoculum density (Hwang and others 2008).

2.3 Serological tests

The enzyme-linked immunosorbent assay (ELISA) test uses antibodies and color change to identify a substance, and is basically the same as home pregnancy tests. However, due to cross reaction with other closely-related species, it can be difficult to positively confirm a specific pathogen. But, if large numbers of samples are to be processed, ELISA can be used as a low-cost prescreening to reduce the number of samples that will need to be processed for subsequent tests (Kliejunas 2010). In the Pacific Northwest, the recommended procedure for detecting water molds is to bait irrigation water sources with *Rhododendron* spp. leaves for one week and then test the leaves with ELISA kits (Parke and Fisher 2013):

Figure 3 - Fruits, leaves and other baits attract the zoospores of water molds, and then the lesions can be cultured to identify individual species.

> Phytophthora ImmunoStrip® is a dipstick on-site kit that can be used to detect *Phytophthora* spp. and *Pythium* spp. (Agdia 2013).
>
> Alert LF™ lateral flow devices can be used to detect the oomycete and fungal pathogens including *Phytophthora* spp., *Pythium* spp., *Rhizoctonia* spp. and *Botrytis* spp. (Neogen Europe 2013)

2.4 Molecular tests

Several different DNA-based molecular techniques have been used to detect *Phytophthora ramorum*, and new variations are continually being developed (Kliejunas 2020). Both real-time and nested polymerase chain reaction (PCR) based molecular diagnostic assays have proven useful for detecting *Phytophthora* spp. from leaf baits, and greatly reduce the turnaround time (Colburn and Jeffers 2011). PCR-based tests are being developed to detect algal species in irrigation water, and would represent a big improvement over the lower and more labor intensive light microscopy (Sellner and others 2003).

3. Treating water for pests

Any good water treatment system always begins with filtration, which not only removes suspended inorganic particles that can damage fertilizer injectors or plug irrigation nozzle but can also filter many waterborne pests from the irrigation water.

3.1 Filtration

Filtration is a prerequisite for all types of water treatment. Ultraviolet light requires clear water to to penetrate pathogen cell walls whereas oxidizing compounds like chlorine react with all types of suspended organic material (Fisher and others 2008a). One recommendation is that the total suspended solids should be less than 20 ppm (Parke and Fisher 2012). Any filtration system is a trade-off between removing suspended solids and waterborne pests while allowing enough water flow and pressure so that your irrigation system will operate properly. New nurseries should do a series of water tests before selecting on a filtration system, keeping in mind that the quality of surface sources may change during the year. For example, algae levels will increase during the summer so the filtration system must be able to handle the worst water quality (Bartok 2000).

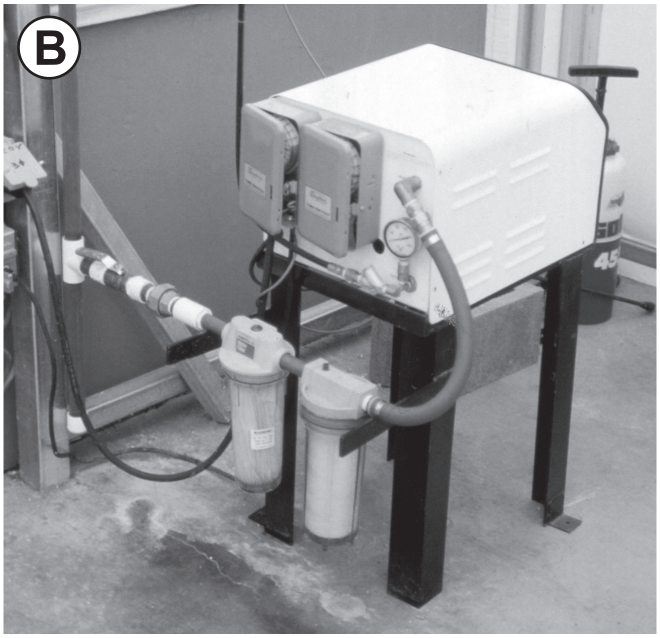
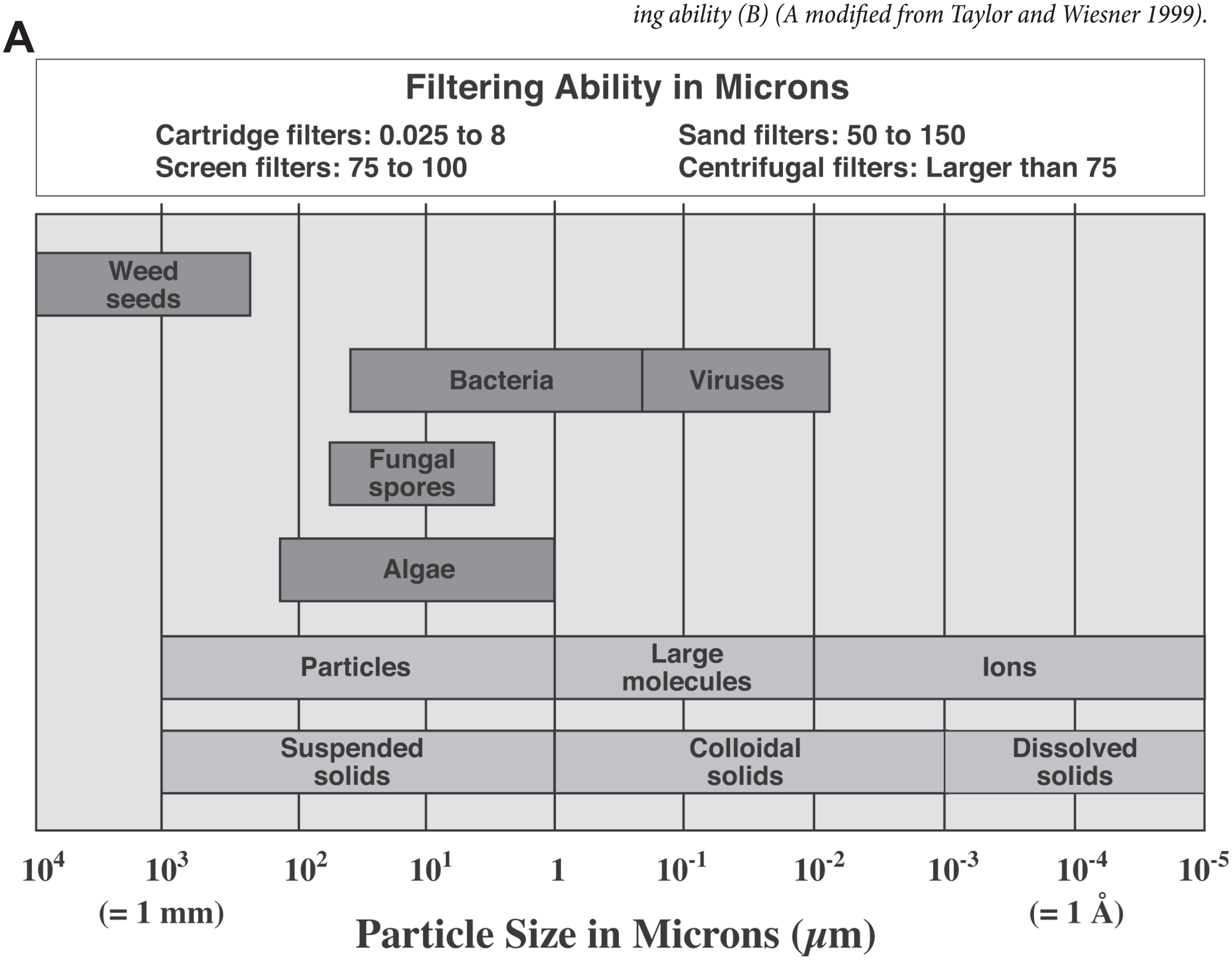


Figure 4 - The first step in any water treatment is filtration and several types of filters have been used (A). Cartridge filters are easy to use and are available in different pore sizes and filtering ability (B) (A modified from Taylor and Wiesner 1999).



Several types of filters are commonly used in forest and conservation nurseries (Figure 4A), and the best choice depends on irrigation water source and quality.

Cartridge filters are made of paper or a spun fiber (Figure 4A) and are most appropriate for container nurseries that have irrigation water with a light sediment load such as that from wells or domestic sources. They would not be practical for bareroot nurseries using irrigation water containing suspended solids or if algae is present because the filters will quickly clog and have to be replaced. Cartridge filters come in a wide variety of pore sizes from 0.025 to 8 microns (µm), which can remove several waterborne pathogens (Figure 4B). Zoospores of *Pythium* spp. and *Phytophthora* spp. were also found to pass through membranes with pores of 0.40 to 0.45 µm (Hong and others 2003),

Screen filters come in all sizes and shapes and can be made of slotted PVC, perforated or mesh stainless steel, and nylon mesh, and should have a filtering capacity of 75 to 100 µm (Schultheis 2013). Most have to be manually cleaned but some self-cleaning models use high pressure water or brushes (Bartok 2000).

Disc filters consist of a stack of grooved wafers over which the water passes, and the degree of filtration is determined by the size and spacing of the grooves. They are best for irrigation water with a low concentration of suspended solids. Disc filters are cleaned and are cleaned by backflushing — by reversing the water flow into a separate drain (Bartok 2000).

Granular media filters, like the common swimming pool sand filter, are best for removing organic matter such as algae and suspended silt and clay particles (Bartok 2000). Depending on their construction, media filters are capable of removing suspended particles from 50 to 150 µm in diameter (Bisconer 2011), and are cleaned by backflushing.

Centrifugal filters are needed to remove sand and other heavy organic matter so would only be need for irrigation water from surface sources. Water is filtered with a spinning motion inside a steel cone, and particles larger than 75 µm are spun to the outside and then collect along the bottom where they can be cleaned out (Bartok 2000).

Biofilters or slow-flow filters are the newest category and researchers in Europe and Australia have shown they can remove waterborne pathogens including *Phytophthora* spp. , *Pythium* spp., and *Fusarium* spp. Biofilters are similar to granular media filters but the substrate is inoculated with beneficial microorganisms such as *Pseudomonas* spp. or *Trichoderma* spp. This substrate captures the waterborne pathogens and holds them long enough for the beneficials to attack and neutralize them. As the name implies, flow rates are relatively slow and the treatment tanks must be large; rates 25 to 80 gallons per hour per square foot of substrate are effective (Svenson 1999).

Ultra-filtration, with a membrane pore size of 0.02 to 0.10 µm, was effective in removing fungal and bacterial pathogens from irrigation water under laboratory conditions but would not be practical for the irrigation water quality in operating forest nurseries (Machado and others 2013).

3.2 Disinfection of irrigation water through chemical oxidation

My memories of oxidation-reduction reactions from chemistry class are something about oxygen's ability to strip electrons from other chemicals. Now, after all these years, I can finally see how that tidbit of chemical knowledge can actually be put to good use. In water treatment, the term oxidation refers the addition of chemicals to kill waterbone pathogens and chemicals that are strong oxidizers, such as chlorine, bromine, and ozone, are excellent disinfectants. These oxidizing compounds "burn" the pathogens and other suspended organic matter in irrigation water but leaves only harmless chemicals as by-products. The oxidation reduction potential (ORP) of any treatment solution is dependent on the concentration of the oxidizer, and its activity can be can be measured in millivolts (mV) (Newman 2004).

3.2.1 Chlorine. Chlorination is by far the most common water treatment for nurseries wanting to prevent pests that are introduced through the irrigation system (Fisher and others 2008a). Chlorine comes in many formulations, which differ considerably in safety and ease of use.

Chlorine compounds can be gas (chlorine or chlorine dioxide), solid (calcium hypochlorite or chlorine dioxide), or liquid (sodium hypochlorite). All chlorine products supply hypochlorous acid (HOCl), which is the sanitizing form of chlorine when dissolved in water (Table 1).

Chlorine gas. This is the traditional method of chlorination but many nurseries may not consider chlorine gas due to safety concerns. Chlorine gas is toxic at low concentrations, as well as corrosive. However, one large ornamental nursery that used 1.3 million gallons of water per day installed REGAL gas chlorinators and found this system very effective. Not only were they easy to install

Table 1 - Sources of chlorine for irrigation water treatment (modified from Newman 2004; Fisher and others 2008a).

Chemical	Form	Formulation	Injection Method	Target Chlorine Concentration	Safety Considerations
Chlorine	Gas	Cl_2	Chlorine gas is bubbled through the water, where it combines with the water to form hypochlorous acid: ($HOCl$) and hydrochloric acid (HCL)	1 to 2 ppm	Chlorine gas is very toxic, so requires protective clothing, masks, and must be handled carefully.
Sodium hypochlorite	Liquid or soluble tablets	$NaOCl$ - Household bleach is 3% to 6% $NaOCl$; industrial bleaches are 10% to 12% $NaOCl$	Liquids require a special injector that is resistant to corrosion and has a high injection ratio. Tablets are gradually dissolved in flow-through feeders.	1 to 2 ppm	Splash hazard for liquids so protective clothing and masks should be used. Tablets are least hazardous option.
Calcium hypochlorite	Soluble tablets	$Ca(OCl)_2$	Tablets are gradually dissoved in a flow·through feeders	1 to 2 ppm	Tablets are least hazardous option.
Chlorine dioxide	Soluble tablets	ClO_2	Injectors using tablets are now available.	0.25 ppm	Tablets are least hazardous option.

and maintain, but they paid for the injectors the first year and it cut their fungicide use by 50% (Majka and others 2008).

Chlorine dioxide. Although it is 25 times more effective than chlorine gas as a biocide, chlorine dioxide can be 5 to 10 times more expensive. Originally, generating chlorine dioxide on-site was problematic, but several commercial products are now available. The Ultra-Shield™ Chlorine Dioxide Water Treatment System features tablets that dissolve in water in less than 20 minutes to release chlorine dioxide and can be used for treating irrigation water. The AquaPulse System is a fully automated chlorine dioxide generator that produces chlorine dioxide for injection into irrigation systems (Fisher and others 2009).

Sodium hypochlorite. One of the oldest disinfectants, sodium hypochlorite was first used to kill disease-causing microorganisms by Louis Pasteur. Ordinary household bleach contains 3% to 6% $NaOCl$, whereas industrial bleaches are more concentrated (10% to 12% $NaOCl$). Due to this relatively low concentration, high volume injectors are needed that are also resistant to corrosion (Newman 2004). Still, sodium hypochlorite has been to treat nursery irrigation water (Fisher and others (2008b).

Calcium hypochlorite. Commonly available as tablets (Figure 5), calcium hydroxide is much easier to use and store than liquid bleach (Newman 2004). From a handling and safety standpoint, tablets were considered superior to other formulations (Ferraro and Brenner 1998). Chlorine tablets are not as corrosive and can be applied with injectors similar to those commonly used for swimming pools. A typical applicator schematic can be found in Fisher and others (2008b).

Mode of action. Hypochlorous acid oxidizes all forms of organic material, not just fungal pathogens or algae. For this reason, irrigation water must be prefiltered to remove other types of suspended organic material so that the hypochlorous acid is more effective for pathogen control. Chlorine is most effective in irrigation water with a slightly acid to neutral pH (6.0 to 7.5), and its activity drops off rapidly at either lower or higher pH values. For example, almost 3 times the amount of sodium or calcium hypochlorite would be needed at pH 8 to have the same effectiveness in water with a pH of 7 (Fisher and others 2008c). One advantage of

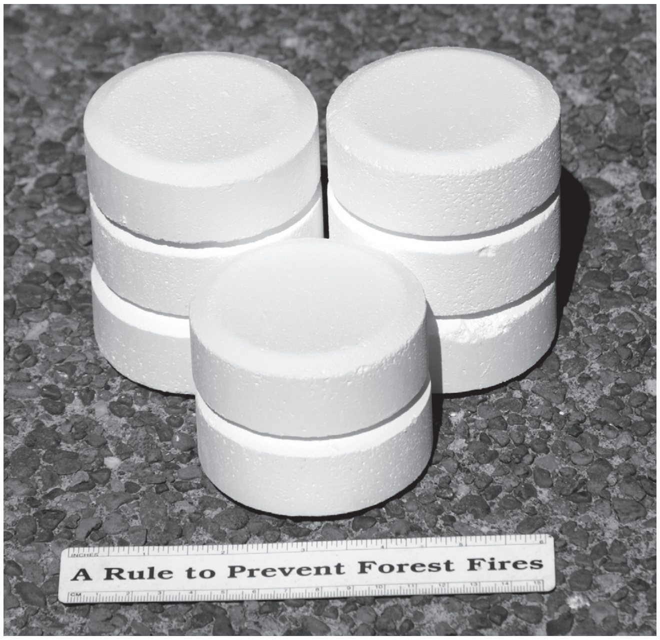


Figure 5 - Tablets are considered the safest way to supply chlorine or bromine for disinfecting irrigation water (Ferraro and Brenner 1998).

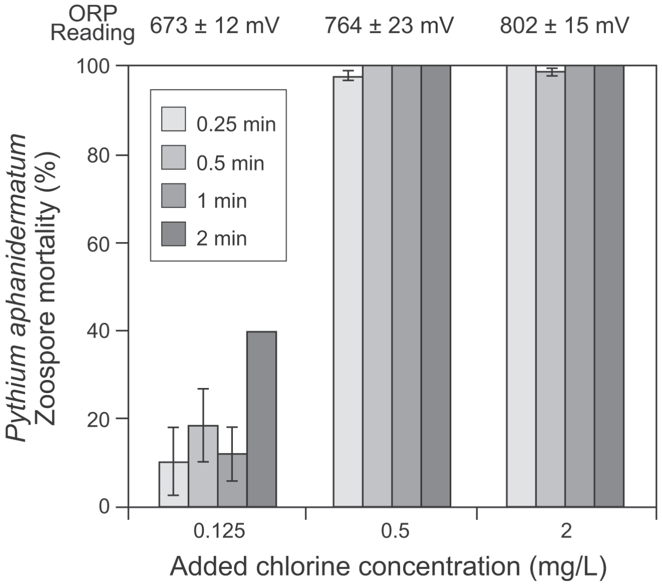


Figure 6 - All Pythium *spp. zoospores were killed after 0.5 min exposure to 0.5 ppm chlorine, which produced an oxidation reduction potential (ORP) meter reading of 764 mV (modified from Lang and others 2008)*

chlorine dioxide is that it is effective at a much wider pH range (Fisher and others 2009).

Target concentration. Chlorine activity is typically reported as free residual chlorine or total chlorine. Free residual chlorine is the more practical measurement because it reflects the chlorine available for disinfection after the background demand of suspended organic matter and biofilm has been satisfied (Fisher and others 2008c). In a controlled research trial, 100% of the *Pythium aphanidermatum* zoospores were killed after 0.5 min exposure to 0.5 ppm chlorine after the water pH was reduced to 6; this produced an oxidation reduction potential (ORP) meter reading of 764 mV (Lang and others 2008) (Figure 6). Operational research has shown that 1 to 2 ppm residual free chlorine is required at the farthest sprinkler head, which may require an initial injection of up to 6 ppm of chlorine. Although 2 ppm free chlorine effectively controls zoospores of *Pythium* and *Phytophthora* species in irrigation water, the more resistant fungal structures such as chlamydospores, oospores and hyphae in suspended organic matter may not be controlled at this concentration (Wick and others 2008). Control of mycelial fragments of *Phytophthora* required 8 ppm chlorine compared with 2 ppm for zoospores, whereas 12 to 14 ppm free chlorine were required to control *Fusarium oxysporum* conidia and *Rhizoctonia solani* mycelia (Hong and others 2003). For algae control, injecting enough chlorine to maintain at least 1 to 3 ppm of free chlorine at the end of the irrigation line was found to be effective (Nye 2013).

Phytotoxicity. Maintaining free residual chlorine levels at no more than 2 ppm should avoid phytotoxicity, but testing on your specific crop is always recommended. A research trial with a variety of ornamental shrubs, showed that a 5 minute exposure to 2.4 ppm free chlorine killed waterborne pathogens without reducing the plant value (Cayanan and others 2009).

Monitoring. A chlorine meter can be purchased for $150 to $300; be sure that the meter measures free chlorine, rather than total chlorine. An ORP meter, which costs $100 to $400, is better way to monitor the disinfecting power in your irrigation water – the higher the millivolts reading, the greater the sanitizing power. In tests at the University of Florida, commercially available Extech and Hanna Instruments ORP meters produced results similar to a higher-cost laboratory sensor (Fisher and others 2008b). Lang and others (2008) consider ORP meters to be essential for nursery managers using chlorination. When the irrigation water of a greenhouse using chlorine injection was measured at the sprinkler head, it had an ORP reading of 825 mV with 1.4 ppm free chlorine and 2.25 ppm total chlorine (Newman 2004).

3.2.2 Bromine. Although bromine (Table 2) has an oxidation potential 21% lower than chlorine (Newman 2004); it is reported to have a higher activity against algae, bacteria, fungi, and viruses (Austin 1990);. Bromine reacts more quickly than chlorine and this may provide some benefits in reducing the required contact periods (De Hayr and others 1995). Agribrom™ is available in tablet form (Figure 5), and can be applied through a inexpensive pool chlorinator in which water gradually dissolves the tablets and disperses bromine into the irrigation water. One nursery that propagated cuttings with a mist system installed a pool chlorinator

Table 2 - Bromine compounds used to disinfect irrigation water (modified from Fisher and others 2008a).

Form	Active Ingredient	Solubility	Injection Method	Target Concentration
Tablets or granules	1-Bromo-3-chloro-5,5-dimethyl-2,4-imadazolidinedione	Slowly	Tablets or granules are slowly dissolved and the supernatant injected into the irrigation system	5 to 35 ppm bromine

for around $100 and used Agribrom tablets to maintain 5 to 25 ppm of bromine (Klupenger 1999). Typically, 5 to 10 ppm of bromine is needed to inactivate most microorganisms, and research has shown very little phytotoxicity even on sensitive plants at bromine rates as high as 100 ppm. One comparison with the use of chlorine concluded that bromination was the least expensive, most effective method of disinfecting irrigation water (Ferraro and Brenner 1998).

3.3 Other options for disinfecting irrigation water

3.3.1 Activated peroxygen. This stabilized mixture of hydrogen peroxide (H_2O_2) and peracetic/peroxyacetic acid is injected directly into irrigation lines, but requires an injector with a high injection ratio and that is resistant to corrosion (Parke and Fisher 2013). Several commercial products are available such as ZeroTol®, which has been used by container nurseries for many years and GreenClean®,which is particularly effective against algae (BioSafe Systems 2013). Although Zero Tol® can be used by organic growers, its high cost may be prohibitive for continual water treatment (Newman 2004).

3.3.2 Copper ionization. Copper solutions have been used to control plant disease since Bordeaux mixture was developed in the late 1800s. For treating irrigation water, copper ions are generated by applying a direct electrical current across copper electrodes as water passes through a series of pipe chambers (Emmons 2002). Copper ionization has strong residual activity, which means the copper ions travel with the water and attack pathogens throught out the irrigation system and even in the soil or growing medium. Research has shown that 0.5 to 1.0 ppm of free copper significantly reduced *Pythium* spp. *Phytophthora* spp. and other waterborne pathogens, while 1.0 to 2.0 ppm effectively reduced algae. A variety of copper ionization systems are commercially available from around $5,000, but it is important to select one designed for nurseries instead of swimming pools. Copper ionization systems can be designed for water flow rates from a few gallons to thousands of gallons per minute. The electrical conductivity (EC) of the water would obviously affect the ionization process so, where EC can fluctuate frequently as in water recycling systems, precise monitoring is required (Fisher and others 2008d). The Aqua-Hort® system features controls that control ionization based on water quality and flow rate, and uses magnetic coils to increase the copper ion activity (Aqua-Hort 2013). One nursery generated 20 to 25 ppm copper into a stock tank, and then injected this treated solution at a ratio to maintain the desired 0.5 ppm level in the irrigation lines (Emmons 2002). The issue of copper pollution of leached irrigation water is a concern but has not proven to be a problem when copper ionization systems are properly designed and operated.

3.3.3 Heat. Pasteurization is one of the oldest methods of disinfesting water, and maintaining a temperature of around 200 °F (93 °C) for 30 seconds is sufficient to kill most plant pathogens. However, due to the high energy demand, heat treatment is much too expensive for the large volumes of water required for most irrigation systems (Parke and Fisher 2013).

3.3.4 Ozone. The first discovery of ozone was in 1839, and the name comes from the Greek word "ozein," which means "to smell." Ozone is the strongest oxidizer and has an oxidation potential that is 52% higher than chlorine (Newman 2004). The first application of ozone generation for water treatment was in France in 1906 and today most European and some US cities use ozone for drinking water treatment instead of chlorine. Several ozone generators are available commercially (Zeitoun 1996). A corona ozone generator that uses electrical energy to produce ozone, which is then dissolved into the irrigation system with a venturi system, has been recommended; typical swimming pool generators that use ultraviolet light to generate ozone are not (Hayes and others 2009). Ozone is effective against all waterborne pathogens including nematodes and viruses but needs at least 4 minute contact time. Ozone has a half life of 4 to 20 minutes and so the generator should be installed in the irrigation line (Ferraro and Brenner 1998). Water filtration before treatment is absolutely necessary. Dissolved ozone residual levels in the range of 0.01 to 0.05 ppm control algae, but should be below 1 ppm to avoid phytotoxicity. Dissolved ozone can be measured with test kits or commercial monitors. Because it is a strong oxidizer, ozone activity can be most effectively and economically monitored with an oxidation-reduction potential meter (Hayes and others 2009). Unlike the chemical water treatments, ozone does not leave behind any by-products; instead, ozone molecules break down to oxygen. As a bonus, ozonated irrigation water was found to have a suppressive effect on existing liverworts in container stock (Graham and Dixon 2012). In a comparison between ozone and chlorination, one nursery found that operating costs were less with ozonation and that the investment in a generator was amortized in 2 to 3 years (Roberts 1993). For worker safety, ambient ozone gas monitors can be programmed to automatically shut down the generator if a leak occurs and if ozone is used indoors, safety criteria set by the Occupational Safety and Health Administration must be met (Hayes and others 2009).

3.3.5 Ultraviolet radiation. Electromagnetic radiation in the 100 to 400 nanometers (nm) wavelengths is considered ultraviolet (UV), so named because it is closest to violet light but beyond the light sensitivity of the human eye. Not all UV light is the same, however, and only radiation known as UV-C (240 to 280 nm) is useful for disinfecting irrigation water. Because UV light must hit each microorganism, water turbidity must be very low — a maximum of 2 nephelometric turbidity units (Fynn and others 2009). Water is treated in a disinfection chamber where it passes by special lamps that generated the UV light (Figure 7); because suspended minerals or other matter can be deposited on the lamp housing, many UV water treatment systems feature some sort of automatic wiping system. Effectiveness of disinfection depends on UV light intensity and duration of exposure; 250 mJ/cm^2 (250,000 µwatt-sec/cm^2) will eliminate most waterborne pathogens (Newman 2004). Because UV radiation has no residual effects, it is often combined with chlorination or ozone treatment, which produces a synergistic effect. When UV light combines with ozone, the sanitizing effect is increased. If you are considering UV light water treatment be sure to consult with experts to make certain that it is properly designed for your conditions (Fynn and others 2009).

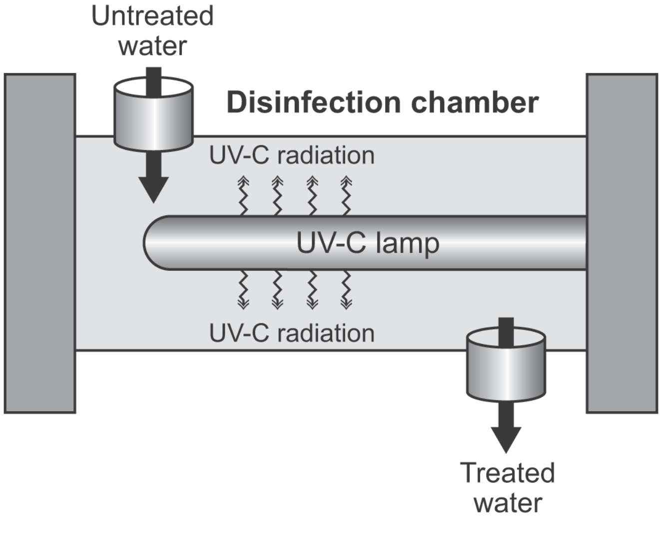


Figure 7 - Ultraviolet (UV) lamps create high energy radiation that kills waterborne organisms as they pass through a disinfection chamber (modified from Newman 2004).

4. Additional information and training

Obviously, treating irrigation water to prevent waterborne pathogens from entering your nursery is a complicated subjects and there are many options. An excellent source for learning more about water treatment methods is the educational center of the Water Education Alliance for Horticulture website (www.watereducationalliance.org). Applied research and efficacy tests for different water treatment technologies can be explored by selecting "grower tools" and "waterborne solutions." Many articles and videos about water treatment technologies are available, and growers can register for upcoming webinars and workshops on this website.

For specific information about the waterborne pathogen *Phytophthora* spp. and especially the new threat of *Phytophthora ramorum*, nursery managers can take a Phytophthora Online Course: Training for Nursery Growers at URL: http://oregonstate.edu/instruct/dce/phytophthora/module2.html.

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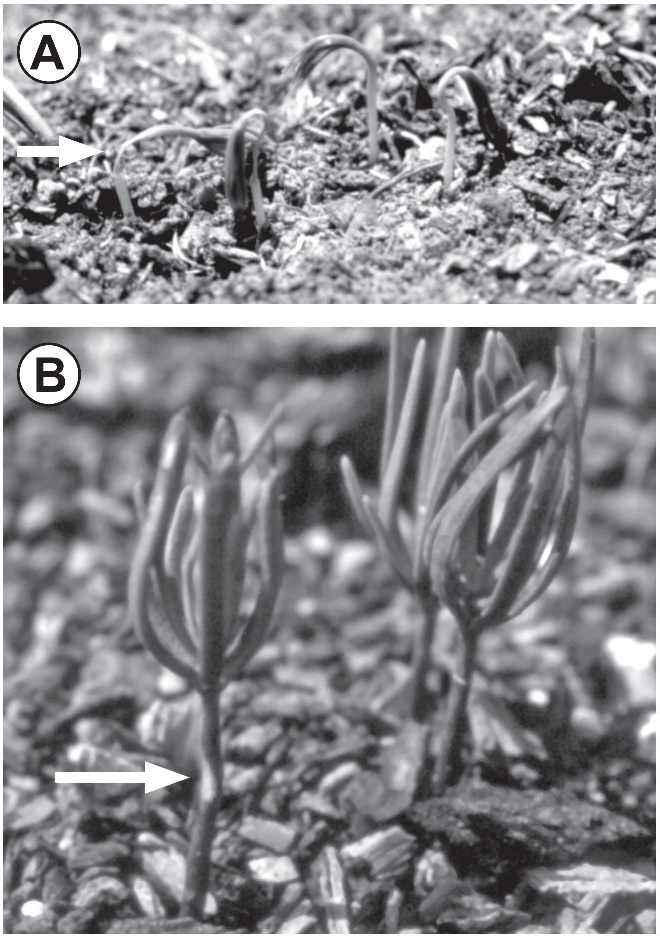
Pesticide Precautionary Statement

Using Water to Cool Nursery Crops

by Thomas D. Landis

Heat injury to nursery seedlings has been a problem since the early 1900s, and considerable research was done over the following 25 years to develop cultural practices to prevent it. Although growth losses due to excessive heat undoubtedly occur, the most obvious damage has been stem girdling of newly emerged seedlings by direct sunlight (Hartley 1918). Young, newly emerged, succulent seedlings are killed by a constriction at the ground line (Figure 1A), whereas older nursery stock often develops a white spot on the sunny side of the stem (Figure 1B). Vigorous plants may be able to outgrow this injury but others form a stem canker that causes structural weakness. The stem of damaged seedling may eventually bend or even break at the injury site (Barnard 1990).

Although this damage is more common in seedbeds, both bareroot and container stock have been affected. Cooling with irrigation or "water shade" has been proven effective in numerous studies. For example, midday sprinkler irrigation reduced surface soil temperatures almost 30°F (16.6°C) and the cooling effect lasted for more than 4 hours (Stoeckeler and Slabaugh 1965; Figure 1C).



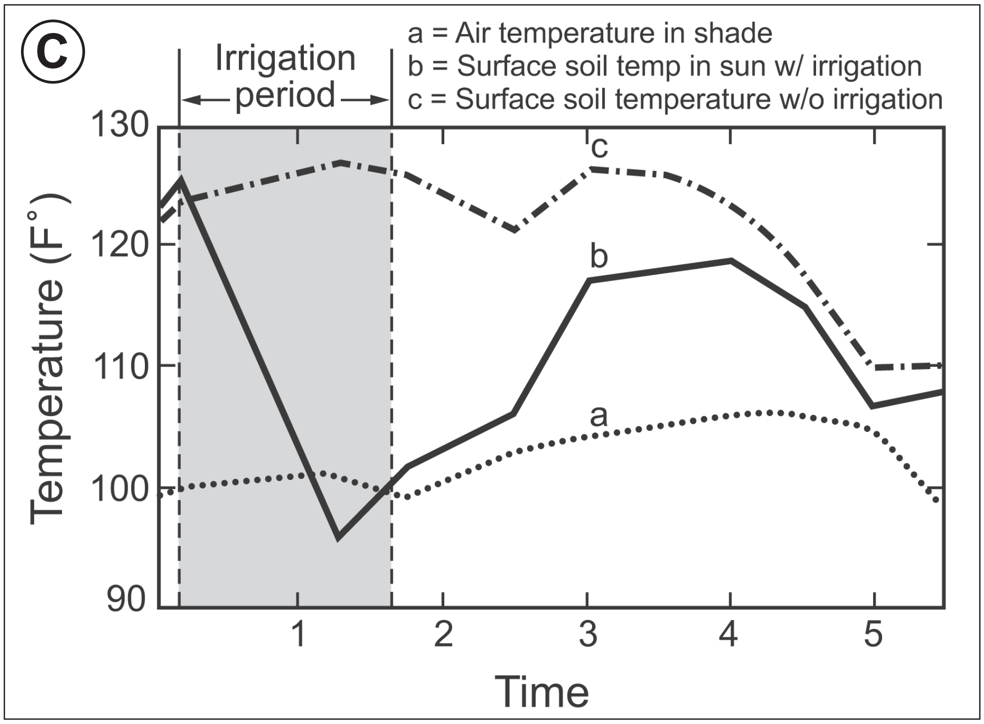


Figure 1 - The most serious type of heat injury to nursery crops is damage to stem tissues in succulent young seedlings, causing stem girdling (A) or cankers (B). The cooling effect of irrigation has been proven in a research trial at a North Dakota bareroot nursery where midday sprinkler irrigation significantly reduced surface soil temperatures for more than 4 hours (C) (C - modified from Stoeckeler and Slabaugh 1965).

1. The basic physics

Before we go any further, let us review some basic concepts of heat transfer. Heat is usually known as sensible heat, which is the familiar type that we can measure with a thermometer. Latent heat, on the other hand, is related to phase changes from a gas to a liquid or from a liquid to a solid. When water freezes into ice, heat is given off in an exothermic reaction; however, when liquid water evaporates, heat is absorbed — an endothermic reaction. Water has the highest latent heat of vaporization of all common liquids (540 calories per gram), which means that when growers apply sprinkler irrigation on hot sunny day, the subsequent evaporation removes heat from their crops and their immediate environment. For each gallon of water that is evaporated, around 9400 Btu of heat are absorbed (Bartok 2003).

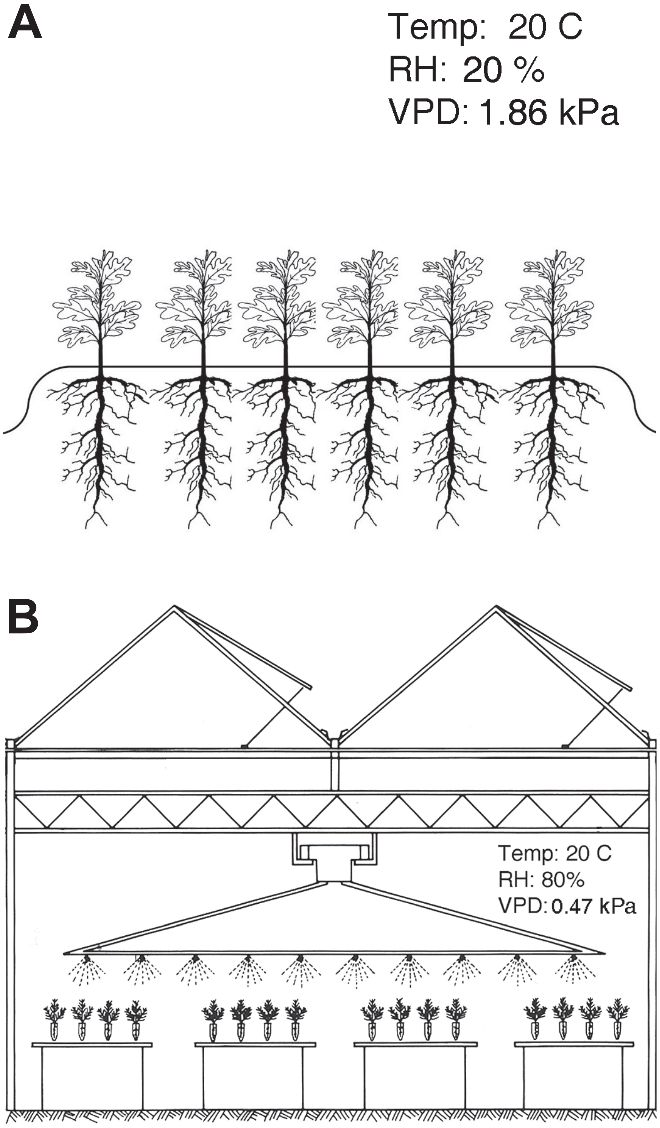


Figure 2 - The vapor pressure deficit (VPD) is a reflection of the evapotranspirational demand of the atmosphere surrounding the crop. VPD will always be higher in bareroot beds (A) and open compounds than in enclosed structures such as greenhouses (B).

The potential for cooling with irrigation also depends on the atmospheric demand for water vapor - the vapor pressure deficit (VPD). The VPD is important in nursery work because it reflects the evapotranspirational demand of the surrounding atmosphere, which is important to know before you consider cooling with irrigation. VPD is primarily a function of temperature and relative humidity, although wind must also be considered (Landis and others 1992). For example, in an open bareroot field (Figure 2A), the VPD would be much greater than that in a closed greenhouse (Figure 2B). Even in the humid southeastern states, the potential exists for 10 to 20 °F (5.5 to 11.0 °C) of cooling below the ambient temperature during the warmest part of the day (Bartok 2003).

Figure 3 - Irrigation water quality is critical to the success of cooling with irrigation. Water with high levels of dissolved salts can plug irrigation nozzles and leave unsightly spots on plant foliage.

2. Importance of water quality

Although any water source can be used to cool plants on a hot day, water with a low level of dissolved salts will cause less problems (Evans and van der Guzik 2011). When water evaporates, it leaves behind any dissolved minerals (that is, salts) on your sprinkler heads or crops (Figure 3). The standard index of irrigation water quality is measured as electrical conductivity (EC). EC is a measure of the salinity (total salt level) of an aqueous solution. EC meters measure electrical charges carried by the salts that are dissolved in a solution — the more concentrated the salts, the higher the reading. All irrigation water contains some salt ions, the result of rain water trickling through soil and rocks; for instance, water percolating through calcareous rocks or soils picks up calcium, magnesium and bicarbonate ions. Because salts are left behind when surface water evaporates, irrigation water from dry climates will have higher EC readings than water from a humid climate (Landis and Dumroese 2006). These mineral deposits are particularly troublesome when using sprinkler irrigation to cool crops because the water application rates are too low to wash away excess salt deposits (Evans and van der Guzik 2011).

Table 1 - Irrigation water quality test criteria for cooling with irrigation (modified from Evans and van der Guzik 2011; Hopkins and others 2007).

Quality Indices (Do not exceed)	
pH	7.5
Electrical conductivity (EC)	2 dS/m (2 mmhos/cm)
Lime deposition potential (lesser of sum of Ca + Mg, or $C0_3$ + HCO_3	4 meq/l
Specific Ions Measured in parts per million (ppm or mg/l), or milliequivalents per liter (meq/l)	**Conversion Factors** To convert from ppm to meq/l, divide by this number; to convert from meq/l to ppm, multiply by the same factor
Calcium (Ca)	20
Magnesium (Mg)	12.2
Sodium (Na)	23
Chloride (Cl)	35.5
Carbonate ($C0_3$)	30
Bicarbonate (HCO_3)	61

So, before you consider cooling with irrigation, the first step is to take water a sample and have it chemically analyzed. Irrigation water quality is typically reported in units of parts per million (ppm), milligrams per liter (mg/l), or milliequivalents per liter (meq/l); conversion factors are provided in Table 1.

Several water quality indices can be used to determine whether your irrigation water is suitable for cooling your crops. The quickest test is EC: if the amount of total salts in the water is too high (EC > 2 dS/m), the water should not be used for crop cooling (Table 1). Irrigation water pH can also provide clues. When the pH of irrigation water exceeds 7.5, the potential for calcium carbonate precipitation is high (Evans and van der Guzik 2011). One of the most widely-used water quality indexes is the lime deposition potential (Hopkins and others 2007). Lime deposition occurs when calcium or magnesium carbonates precipitate out of irrigation water, leaving white residues or deposits. Water with a high lime deposition potential rating can cause crusts (scale) that can plug irrigation nozzles and white residues on plant foliage (Figure 3). These residues are not damaging in themselves but may reduce the saleability of your plants. The lime deposition potential of irrigation water is calculated from water test results as the lesser of the sum of the calcium and magnesium ions, or the sum of carbonate and bicarbonate ions. The higher the number, the higher the risk of lime deposition and irrigation waters with LDP values greater than 4 should not be used for irrigation cooling (Table 1).

Certain dissolved salt ions, such as chloride, can directly "burn" plant foliage. Crops vary considerably in their tolerance to chloride, but irrigation waters with less than 70 ppm chloride is considered safe for most plants (Hopkins and others 2007).

Unfortunately, irrigation water cannot be treated in any economical way to remove potentially damaging salts because of their associated energy costs. For example, reverse osmosis is very effective but the process is energy intensive and only about 10 percent of the original volume of water is usable after treatment (Hopkins and others 2007).

3. Methods of applying irrigation for cooling crops

In traditional agriculture, sprinkler irrigation has been used to reduce crop temperatures in 3 different ways (Evans and van der Guzik 2011):

Water evaporation in the air. When growers apply a fine mist of water to their crops, heat is absorbed from the surrounding air (Figure 4). This is the least efficient method, however, because the cooled air must reduce plant temperatures by convective heat transfer.

Hydrocooling. Water is applied directly to leaves and the sensible heat is carried away by liquid runoff. This would be impractical in forest, conservation, and native plant nurseries because it requires large quantities of water and leads to saturation of the soil or growing medium.

Sprinkler irrigation. When just enough water is applied to throughly wet plant foliage, the temperature of the leaves drops when the surface water evaporates back into the atmosphere (Figure 4). This relatively large amount of latent heat loss by means of conduction is the most effective way to cool crops.

3.1 Bareroot nurseries and open growing compounds

Although the evapotranspirational demand is always higher in bareroot seedbeds and open compounds than in enclosed structures, the only practical option for applying water to crops is through traditional sprinkler nozzles. "Water cooling" consists of brief applications of sprinkler irrigation, especially during seedling emergence when surface soil temperatures can exceed 112 °F (45 °C) on a warm. sunny day (Thompson 1984). The temperature at which irrigation for cooling is started gradually increases as seedlings become larger (Table 2). Soil color is critical as dark soils absorb the most solar insolation and sandy soils absorb more heat than finer-textures clays. The critical soil temperatures for cooling vary with seedling age and species. Therefore, species adapted to cooler and moister climates, such as Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), are less tolerant to heat damage than most pines (McDonald 1984). Some nurseries use air

Table 2 - Generalized calendar guidelines for determining when to irrigate to cool surface soils during seedling emergence (Duryea and Landis 1984).

Calendar Date	Not to Exceed Soil Temperatures
Prior to July 1	90 °F (32 °C)
July 1 to August 1	95 °F (35 °C)
After August 1	100 °F (38 °C)

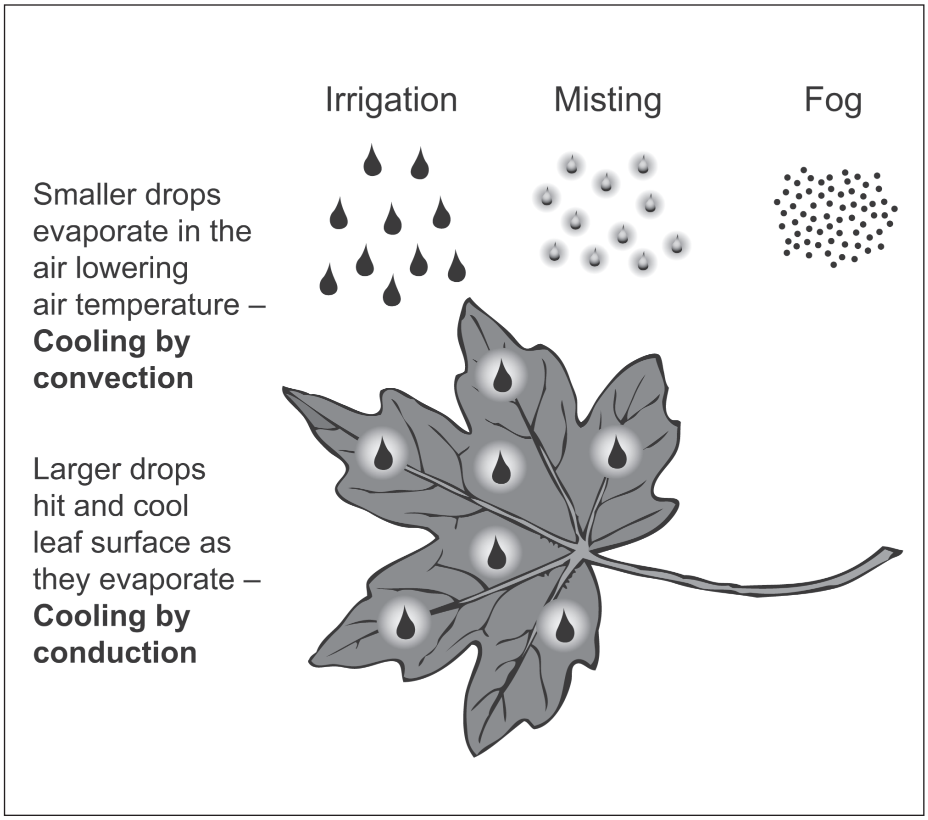


Figure 4 - Irrigation can be applied in 3 different droplet sizes to cool crops. The larger drops of from conventional irrigation nozzles (A) coat the plant foliage that is cooled when the latent heat of vaporization is removed by conduction. Mist nozzles create finer droplets (B) that cool the surrounding air through evaporation while some reach the leaf surfaces. Fog nozzles are the newest are create very fine droplets (C), which stay suspended until they evaporate. True fog does not create wet surfaces.

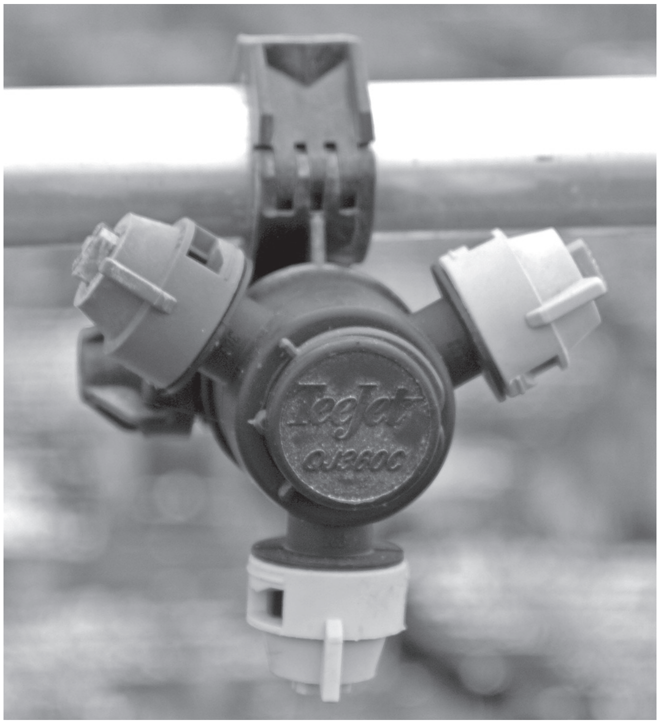


Figure 5 - Irrigation booms can be fitted with special nozzles that allow growers to change from standard irrigation to misting.

temperature to monitor when to water cool young seedlings but there is no substitute for actually measuring surface soil temperatures. Wind increases evaporation and reduces sprinkler efficiency so the US Forest Service JH Stone nursery in Medford irrigated for 30 min when wind speed was 6 mph and below but increased to 45 to 60 min when wind speed was higher (Morby 1982). In Southern nurseries, watering during the heat of the day can reduce surface soil temperatures by as much as 20 °F (11.1 °C) and the ambient air temperature may drop 10 to 15 °F (5.6 to 8.3 °C) or more, depending on humidity levels (May 1984). Sprinkler irrigation of pine seedlings in North Dakota reduced surface soil temperatures from 120 °F to 100 °F (48.8 to 37.8 °C) after 30 min of watering and this temperature reduction lasted for 4 hours or more (Figure 1C).

3.2 Container nurseries

Greenhouses and other enclosed structures offer a couple of more options for cooling crops with water: misting and fog. Misting requires a different type of nozzle than standard irrigation and fog requires a special high-pressure system. Boom irrigation offers a unique opportunity to manually switch from standard irrigation to misting using special rotating heads (Figure 5). In addition, the speed of irrigation booms can be increased to just wet plant foliage without saturating the growing medium.

Misting. Mist nozzles is the older technology that runs on standard irrigation water pressure of 20 to 100 psi (2 to 7 bars) but uses smaller nozzle orifices to generate smaller droplets (Figure 4). Misting is primarily used to cool the air and crops in propagation structures but also helps keep humidity high, which reduces transpirational water loss (Stanley 2011). Misting is ideally suited for keeping seeds “moist, but not wet” during germination and cooling surface temperatures during emergence. It can also be used, however, to cool the greenhouse environment on hot, sunny days. Be aware that many so-called fog systems from hardware stores or irrigation suppliers produce droplets larger than 50 microns so these are technically mist sytems (Bartok 2003).

Fog. Fog can be defined as water droplets around 10 micron (um) in diameter which, as a frame of reference is about 1/10th the diameter of a human hair (Figure 4). Fog systems use very pressure water (1,000 psi = 70 bars) to generate these fine droplets and specialized piping and nozzles are required. Because they use relatively little water (5 gph = 18.9 lph), water requirements are minimal. Greenhouses have been cooled as much as 27 °F (15 °C) by well-designed fogging systems (Stanley 2011). Although it can reduce plant water use, fogging is not intended to provide significant water for irrigation purposes and, because it doesn’t wet plant foliage, the disease potential is less. Fog systems are typically used in greenhouses with natural ventilation systems and especially for propagating cuttings. When compared to wet wall and fan systems, properly designed fog systems produces more uniform cooling throughout the growing area (Both 2007). Fog systems are best managed through computerized environmental control systems that can continually monitor temperature and relative humidity and calculate vapor pressure deficits (Bartok 2003). Fogging requires water of the highest quality to keep the very small nozzle orifices from plugging with salt deposits.

4. Summary

Excessive heat can be a problem in both bareroot and container nurseries, although fully controlled greenhouses have more cooling options. Although stem injuries to succulent young seedlings is the most visible type of injury, prolonged hot spells induce severe moisture deficits that can be reflected in reduced growth rates. Growers should capitalize on the high latent heat of evaporation of water and cool their crops through irrigation, misting, or fog. Research has shown that the beneficial effects of irrigation can last many hours after the water has been turned off. The need for water cooling should be determined by routinely monitoring temperatures in the seedbed or at crop level in the greenhouse, especially during the critical periods of seed germination and seedling emergence.

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Climatic change and assisted migration: Strategic options for forest and conservation nurseries

by Mary I. Williams and R. Kasten Dumroese

In light of current studies (for example, Gray and Hamann 2012; Zhu and others 2012) that show climate will change faster than plants can adapt or migrate naturally, it begs the question, "What does this mean for forestry, specifically forest and conservation nurseries?" Growing trees that just survive may become more important than promoting fast growth rates for superior genetics (Hebda 2008). In a recent survey of state and commercial nurseries in the US, most state nurseries have not explored how changes in climate will impact their abilities to select, produce, and provide trees that are suitable to projected climatic conditions (Tepe and Meretsky 2011).

> *Although we focus more on trees and reforestation in this article, the discussion and concepts we present are applicable to all native plants — trees, because of their long-lived status, pose special circumstances for assisted migration.*

Land managers are being advised to acknowledge climate change predictions in their reforestation plans, but uncertainty about predictions, current client demands, and existence of current plant transfer guidelines constraint active measures (Tepe and Meretsky 2011). The practice of restricting native plant movement to environments similar to their source has a long history in forest management (Langlet 1971), however, transfers must now factor in climate change because plant materials guided by current guidelines and zones will likely face unfavorable growing conditions by the end of this century. Seed transfer guidelines and zones are used to determine the safest distance that a population can be moved to avoid maladaptation (Johnson and others 2004). To facilitate adaptation and migration, we will need to modify transfer guidelines in the direction of climatic change – to suit target tree species and populations. This is going to require more information than we currently have, but now is the time to address the issue.

So where do we go from here?

Adaptive strategies such as assisted migration are an option for some tree populations. From a forestry perspective, we have been properly moving trees for a long time, by using seed transfer guidelines. Assisted migration takes this one step further; it is the movement of species and populations to facilitate natural range expansion in a direct management response to climate change (Vitt and others 2010). This does not necessarily mean moving plants far distances, but rather helping genotypes, seed sources, and tree populations move with suitable climatic conditions to avoid maladaptation (Williams and Dumroese 2013). We can avoid the inclination to use foreign plant materials just because they grow well (Hebda 2008), we are not at that point yet. Evaluating species that might naturally migrate is an option. For example, in Canada, Alberta anticipates that future climatic conditions might be suitable for growing ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) that currently grow near the province but are now absent in the province (Pedlar and others 2011).

Movement of populations to sites that are climatically suitable for growth and productivity at some point in the future is a challenging component of assisted migration (Pedlar and others 2011; Potter and Hargrove 2012). For a species or population, this may entail moving seed across seed-zone boundaries or beyond transfer guidelines (Ledig and Kitzmiller 1992). Methods using transfer functions and provenance data have been developed to guide seed movement under climate change (for example, Beaulieu and Rainville 2005). Online tools are available to assist forest managers and researchers in making decisions about matching seedlots with outplanting sites and seed transfer. The Seedlot Selection Tool (Howe and others 2009) is a mapping tool that matches seedlots with outplanting sites based on current or future climates for tree species such as Douglas-fir and ponderosa pine and Seedwhere (McKenney and others 1999) can map out potential seed collection or outplanting sites based on climatic similarity of chosen sites to a region of interest. Preliminary work in Canada on most commercial tree species demonstrates that target migration distances would be short, occurring within current ranges (O'Neill and others 2008; Gray and others 2011). For some tree species, target migration distances are < 125 miles north or < 328 ft up in elevation during the next 20 to 50 y (Beaulieu and Rainville 2005; O'Neill and others 2008; Gray and Hamann 2012; Pedlar and others 2012).

Whilst having to fulfill client demands in current forestry plans and efforts, it will be difficult for nurseries to plan for future demands. With some collaboration, however, we can shift the focus to producing plant materials that grow and survive by modifying past and current projects and implementing studies and strategies. Many existing projects, such as provenance and common garden studies can be transformed with little modification to look at adaptation and response to climatic conditions (Matyas 1994). Information such as where the plant comes from, where it is planted on the site, and how it performs (growth, survival, reproduction, and so on) can guide nursery practices to increase the proportion of species that survive and grow well (McKay and others 2005; Millar and others 2007; Hebda 2008). Nurseries can work with geneticists to explore genotypes that may be resilient to temperature and moisture extremes. The target plant concept (Landis et al. 2010), culturing of stock types for specific outplanting goals and objectives, can be employed to identify and propagate plant materials from hot and dry extremes of a species range. Using disturbed areas as outplanting sites to test assisted migration is a perfect opportunity to also evaluate genotypes, seed mix diversity, and age classes (Spittlehouse and Stewart 2003; Millar and others 2007; Jones and Monaco 2009), although this may mean that nurseries carry tree species that may not be presently native to the outplanting site.

Assisted migration may not be appropriate for every species or population. Establishment of healthy stands is vital now to prepare forests before major changes occur. Further, there is little point in planting the standard species or stocks in regions highly sensitive to climate change (Hebda 2008). Reductions in fire frequency from 100 to 300 y to 30 y, for example, have the potential to quickly shift some forest systems to woodlands and grasslands (Westerling and others 2011), thereby negating the objective to plant trees and instead shifting the focus on other plant species to establish. By 2100, an estimated 55% of landscapes in western US may exhibit climates that are incompatible with vegetation ecosystems occurring there today (Rehfeldt and others 2006).

Because the frameworks and techniques for production and outplanting already exist, forest nurseries can work with researchers and practitioners to start the ball rolling and hopefully curtail significant social, economic, and ecological losses associated with impacts from a rapidly change climate. Changing policies will require collaboration and discussion of how predicted conditions will affect forests, how nurseries can plan for the future, and how clients can be encouraged to plant trees adapted to future conditions, such as warmer conditions and variable precipitation patterns (Tepe and Meretsky 2011). Fortunately, many state nurseries, especially in the eastern half of the US, already carry tree species and seed sources collected from sites further south (often beyond state borders) than the anticipated outplanting sites, suggesting that plant materials being planted now may be adapted to warmer conditions.

Whatever the chosen adaptive strategies, forest and conservation nurseries need to be included in the dialogue for climate change planning. The science and practice of growing trees and other native plants to sustain ecosystems will greatly benefit by increased collaboration between practitioners and researchers (McKay and others 2005). A challenge will be determining when demand for these climate-adapted/assisted migration candidates will occur (Hebda 2008), but nurseries and researchers can prepare for potential demand by broadening their capacity, increasing expertise, and experiment with different genotypes and seed sources.

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Editorial: The Difference Between a Job and a Profession

by Thomas D. Landis

Growing up, my mom and dad continually stressed the importance of education and I still remember my dad explaining to me the difference between a job and a profession. I've been thinking a lot about this since I retired almost 10 years ago. Some people are surprised that I still want to work, and have made comments like: "Oh, so you failed retirement". My response is that you can retire from a job, but you don't ***want*** to retire from a profession.

I went to the internet to clarify the distinction between a job and a profession, and here's what I found (Wikianswers 2013):

> *Job stands for "just over broke" thus requiring minimal education and one with little to no experience will suffice to get the job done. One can easily be replaced at a job.*
>
> *Profession is a commitment to a higher level of education where one must attend and acquire skilled training. A profession requires critical thinking skills. The ability to master technique and a desire expand one's knowledge. Usually a profession has a distinct body of knowledge specific to that profession. A profession should be rewarding to self and those served by the profession. A profession should provide the professional with adequate means of compensation. Finally, a profession should be one that the individual continues to desire to return to day after day without dread.*

Okay, so much for the clinical definitions. Here are my thoughts about what it means to be a professional:

Taking pride in your work. Here's where I disagree with the traditional distinction: I believe that it doesn't take a college degree to be a professional. Around nurseries, I have seen many professionals at work and many of them don't have a college education. These folks love what they are doing and are doing it for more than just the salary. Nursery work involves constant problem solving and I have been amazed at the skill, innovation, and dedication that our crews exhibit every day.

Providing a Service. In a profession, you want to provide a valuable service and give something back to your community. Nursery folks know that what they are doing is a public service, and that reforestation and restoration are good for the earth. They know that what they are doing is making a difference.

Exhibiting Creativity. Unfortunately, I don't have any artistic talent but my work give me the chance to practice creative thinking. It's very satisfying to solve problems in nurseries, and there's nothing more rewarding than walking through nursery beds or a greenhouse and experiencing the beauty of healthy, growing plants. You can't fake it in nurseries - either your stock is green or healthy, or it's not.

Well, as many of you know, I like to search for the humor in any situation so let's close with these cartoons.

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"It's good to know about trees. Just remember nobody ever made any big money knowing about trees."

New Nursery Literature

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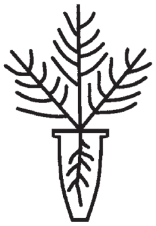

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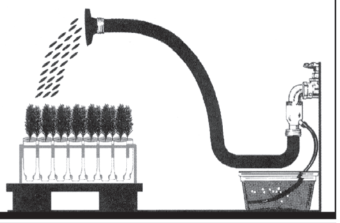

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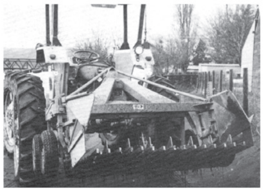

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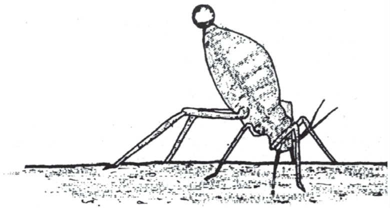

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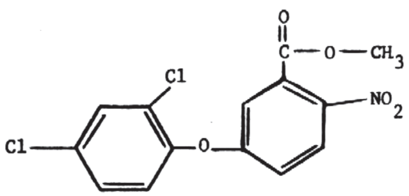

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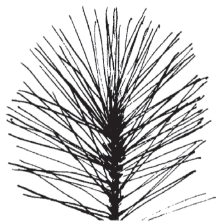

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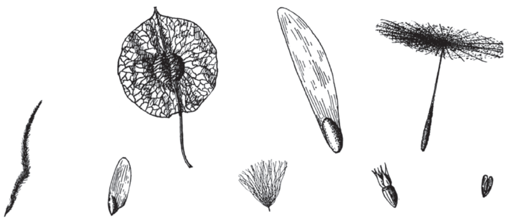

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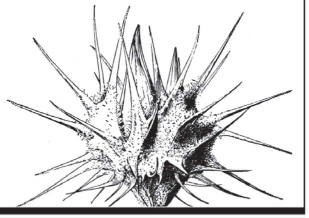

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