Cultural Perspectives

Limiting Factors--Humidity

Plants need six different limiting factors for good growth, four of which are found in the ambient environment (Figure A). In the last two issues, we looked at light and temperature and so humidity is next on the list. I can hear many of you bareroot nursery folks saying, "Oh great, humidity, there's no way that I can manage that in my nursery." Well, hold on. Although container nurseries have many more opportunities, humidity can be managed in one phase of bareroot culture-refrigerated storage.

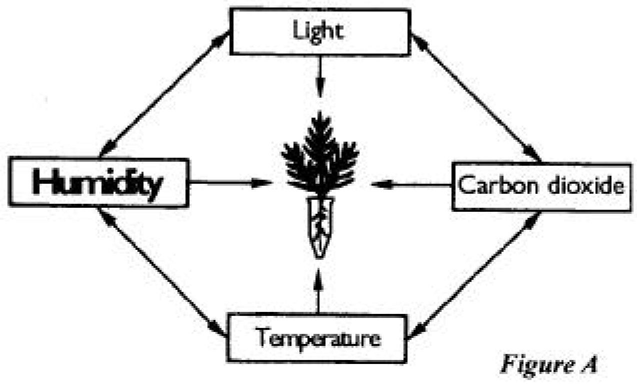


Figure A

What is humidity--pretty simple, right? Humidity is moist air: it feels hot and sticky in the summer, and cold and chilly in the winter. As you may have guessed, it's actually more complicated than that--isn't everything?

Biophysics of water vapor

Moist air can be defined as a two-component mixture of dry air and water vapor. The air and the water vapor simultaneously occupy the same space, but the water vapor acts independently of the other gases. The partial pressure of water vapor is a function of temperature and is unrelated to the total pressure of the air-water vapor mixture. So, the key to managing humidity is to realize that it is so closely tied to temperature.

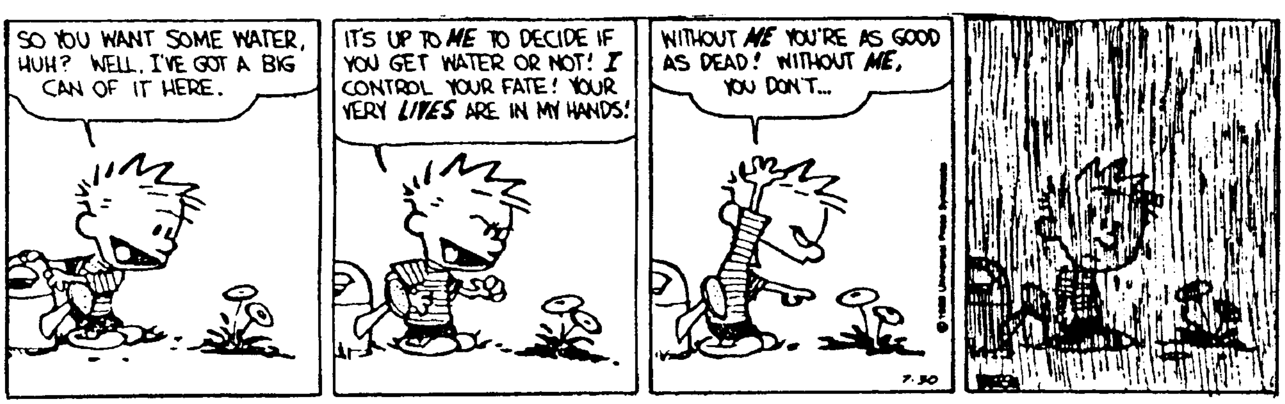
Water vapor pressure--The water vapor in a given volume of air exerts a partial pressure (e) that depends on the amount of the water vapor and its temperature. The water vapor pressure in the surrounding air is called the ambient water vapor pressure (e_a), and the vapor pressure of completely saturated air is the saturation water vapor pressure (e_s). The amount of water that the air can hold increases dramatically with temperature--the e_s approximately doubles for each 11 ° C (20° F) increase in temperature.

Water vapor pressure deficit (VPD)--The difference between the saturation water vapor pressure and the ambient water vapor pressure at the same temperature:

$$VPD = e_s - e_a$$

Dew point--The temperature at which $e_a = e_s$, and condensation occurs.

The VPD is important in horticulture because it represents the evapotranspirational demand of the surrounding atmosphere, as well as the proximity to the dew point. Therefore, growers can use the VPD to determine whether to irrigate because



seedling transpiration will be high, or whether to ventilate to avoid condensation. The dew point temperature is also handy to know because it helps growers minimize condensation which quickly leads to disease problems.

Relative humidity (RH)--Although the actual amount of water vapor in a given volume of air is called the absolute humidity, the most practical measurement of humidity is the relative humidity, RH can be defined as the ratio of the amount of moisture in a volume of air to the total amount of moisture that can be held at saturation at a given temperature and atmospheric pressure. To compute RH, the ambient water vapor pressure is divided by the saturation water vapor pressure and is expressed as a percentage: e

$$RH (\%) = \frac{e_a}{e_s} \times 100$$

Because both RH and VPD are related to temperature, these humidity indexes can be obtained from handy reference charts when two of the three values are known (Table 1).

Measuring humidity

It is relatively difficult to measure humidity compared to the other atmospheric variables. Relative humidity is the only measure of humidity that is routinely monitored in forest and conservation nurseries, although new environmental computer systems can now calculate vapor pressure deficit.

Any instrument that measures humidity is called a hygrometer. A psychrometer is a common type of hygrometer that consists of two adjacent temperature sensors: a dry bulb sensor that measures ambient temperature and a wet bulb sensor that is covered with an absorbent cloth. This cloth is wetted with distilled water and both sensors are ventilated with air moving at a rate of at least 3.5 m/s (12 feet per second) until the wet bulb temperature reaches a steady state. The difference in temperature between wet bulb and dry bulb sensors is known as the wet-bulb depression. Charts and tables are available for converting the wet and dry bulb temperature to relative humidity or dew point.

Three types of psychrometers are commonly used in container nurseries. The sling psychrometer (Figure B) is whirled manually in a circular motion until the wet bulb temperature stabilizes. With the aspirated psychrometer, the thermometer; remain stationary

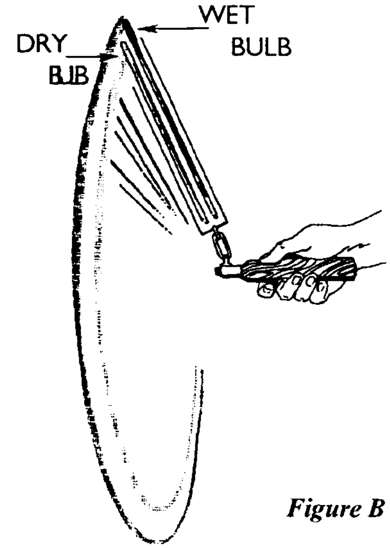


Figure B

is drawn across the bulbs with a small fan. A hygrothermograph measures relative humidity as well as air temperature, and records them on a chart to document diurnal and daily trends.

Effects of humidity on seedling growth

Managing the proper humidity level in forest and conservation nurseries is biologically important for two reasons. First, a moderate 1-rufl-nidity level keeps the stomata open so that seedlings can photosynthesize without losing excessive amounts of water through transpiration (Figure C). This is even more important when plants are being propagated vegetatively by cuttings or grafting. Most of the transpirational water loss occurs through the stomata on the leaves, which must also remain open long enough to absorb sufficient

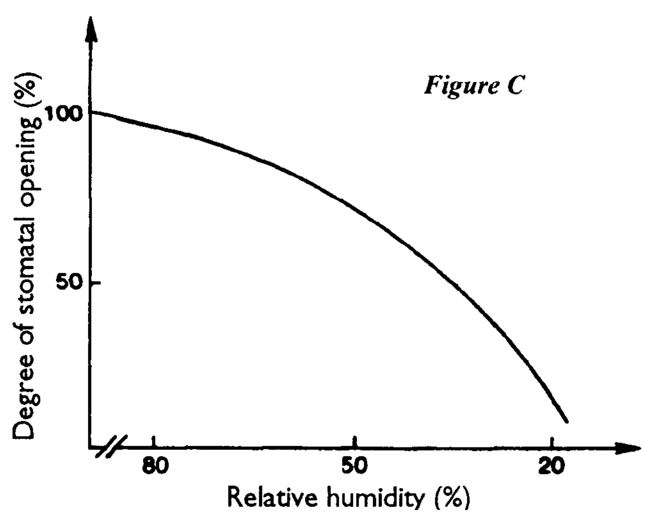


Figure C

carbon dioxide (C02) for photosynthesis. A moderate transpiration rate is also beneficial because it cools the leaf and keeps it near the optimum temperature for photosynthesis and other metabolic processes. Other seedling growth processes, such as cell enlargement, also depend on positive turgor pressure.

The second effect of humidity on seedling growth is indirect. Excessive humidity encourages nursery pests, especially fungal pathogens, but also algae, mosses, and liverworts. Even some insect pests, such as fungus gnats, thrive under the high humidity conditions that are often found in nurseries.

The challenge to the nursery manager is to maintain humidities that are high enough for good seedling growth but not so high as to encourage pests.

Seedling water relations--Humidity has a significant effect on evapotranspiration rates, but remember, relative humidity is controlled by temperature. Under still conditions, the rate of evaporation from a wet surface is a function of the relative humidity and temperature and is proportional to the vapor pressure deficit. At a constant temperature, the higher the relative humidity, the lower the vapor pressure deficit (Table 1). And so, under operational conditions, increasing temperature is more of a controlling factor than absolute humidity in determining evapotranspirational demand. For example, when the RH of the air decreases 30% (from 80 to 50%) and the temperature stays at 30° C (86° F), the VPD increases 2.5 times; however, if the absolute humidity remains constant and the leaf temperature increases just 101 C, from 10 to 200 C (50 to 68° F), then the VPD increases over five times.

Another less-appreciated factor affecting evapotranspiration is wind. Under calm conditions, water vapor collects near an evaporating surface, forming a boundary layer. If the humidity in the boundary layer approaches saturation, the evaporation rate will almost cease, even though the surrounding air is much drier. Wind removes the boundary layer and replaces it with drier air, thus increasing the evaporation rate. For example, if the air in the boundary layer was 20° C (68° F) with 90% RH, and it was replaced by air at the same temperature and 60% RH, the VPD would increase over fourfold--from 0.23 to 0.93 kPa (Table 1).

Vegetative propagation--Maintenance of the proper humidity is of particular concern in

***Table 1**—The evapotranspirational demand, as measured by the water vapor pressure deficit, is a function of relative humidity (RH) and temperature*

Air Temp.		Vapor Pressure Deficit (kPa)										
°C	°F	0%RH	10%RH	20%RH	30%RH	40%RH	50%RH	60%RH	70%RH	80%RH	90%RH	100%RH
40	104	7.37	6.63	5.90	5.16	4.42	3.69	2.95	2.21	1.47	0.74	0.00
35	95	5.63	5.07	4.50	3.94	3.38	2.82	2.25	1.69	1.13	0.56	0.00
30	86	4.24	3.82	3.39	2.97	2.54	2.12	1.70	1.27	0.85	0.42	0.00
25	77	3.17	2.85	2.54	2.22	1.90	1.59	1.27	0.95	0.63	0.32	0.00
20	68	2.33	2.10	1.86	1.63	1.40	1.17	0.93	0.70	0.47	0.23	0.00
15	59	1.71	1.54	1.37	1.20	1.03	0.86	0.68	0.51	0.34	0.17	0.00
10	50	1.23	1.11	0.98	0.86	0.74	0.62	0.49	0.37	0.25	0.12	0.00
5	41	0.87	0.78	0.70	0.61	0.52	0.44	0.35	0.26	0.17	0.09	0.00
0	32	0.61	0.55	0.49	0.43	0.37	0.31	0.24	0.18	0.12	0.06	0.00

vegetative propagation. The transpiration rate of cuttings must be kept low for several weeks or even months so that they can maintain enough turgor to produce new roots. Special rooting environments are constructed to maintain these higher humidifies. Grafted seedlings are often kept in greenhouse conditions because the high humidifies reduce the moisture stress on the scions.

Nursery pests--Although most pathogenic fungi thrive under high humidity, certain plant pathogens particularly favor this environment. The fungus that causes grey mold is a notable example. The spores of *Botrytis cinerea* require free moisture to germinate and penetrate seedling foliage, and high humidifies are conducive to the subsequent spread of the fungus. Grey mold becomes serious in the fall when cooler temperatures cause moisture to condense on seedling foliage, especially in overly dense seedling canopies. Grey mold is also one of the most common storage molds in forest and conservation nurseries. Latent infections are often not noticed during seedling grading, and so the fungus is introduced into the storage container. Botrytis thrives in the humid, dark environment of seedling storage.

The growth of cryptogams (moss, algae, and liverworts) is stimulated by high humidifies. In extreme cases, mosses can form mats that completely prevents the infiltration of water and liquid fertilizers. Even some insect pests can be related to high humidity environments. Dark-winged fungus gnats can build up damaging populations in greenhouses that have excessive amounts of moss and algae.

Modifying Humidity in Nurseries

Bareroot nurseries have few options for modifying humidity, but can manage the microenvironment in their seedbeds by careful control of seedling spacing and irrigation rate and timing. Container nurseries with enclosed growing structures can use heating and ventilation equipment to manage humidity. The type of greenhouse covering has even been shown to affect humidity levels.

It is extremely difficult to set ideal humidity levels for nurseries because relative humidity varies so much with temperature. Optimum humidity levels change during the growing season, and are also different for seedlings and cuttings.

Seedlings-- Little formal research has been done on ideal humidity levels for nurseries. Most of our current knowledge has been obtained through experience and observation in operational container nurseries. Container growers try to keep their RH levels from 60 to 80% during the growing season, and from 45 to 50% during the hardening phase. Managing humidity is most critical during the germination period. Seeds must never be allowed to dry out and so mulches or seed coverings are commonly used. Many nurseries use light, frequent irrigation to keep the soil or growing medium "moist but not wet" to discourage damping-off. When temperatures in the growing area become excessive, many nurseries apply a fine mist to cool the seedlings. Some of the mist evaporates before reaching the ground, thus lowering the air temperature. Irrigation should be scheduled early in the day to allow time for the moisture on the seedling foliage to evaporate.

At the beginning of the Hardening Phase, many bareroot and container nursery managers curtail irrigation and induce a moderate moisture stress. Because this is difficult in container nurseries with enclosed growing structures, many nurseries move their seedlings from the greenhouse at the beginning of the hardening phase, and others remove the covering.

Vegetative propagation-- Significantly higher humidifies are required for all types of vegetative propagation compared to seedling culture. In all types of cuttings, the normal water supply has been completely severed and so water stress can quickly become severe. This problem is particularly critical with softwood cuttings, which have leaves that are still transpiring, and hardwood cuttings, which root slowly. Maintaining relative humidity values as close to 100% as possible is desirable; once cuttings have rooted, they are gradually hardened to ambient conditions by allowing humidities to decrease. Newly grafted plants also benefit from highly humid environments until the grafts have taken and normal internal water relations have resumed.

During vegetative propagation, humidity can be increased by spraying fine droplets of water into the air. Both mist and fog systems have been used--the difference is the size of the droplet. Mist droplets are large enough to settle out in a few seconds and will wet the surfaces on which they land. Fog droplets are almost invisibly small and will remain suspended for several minutes, during which most will evaporate. When properly applied, fog will not wet seedling foliage. So, although they are considerably more expensive, fog systems are less likely to stimulate nursery pests.

Overwinter storage-- Control of humidity is very critical during the storage period, but it is a balancing act: seedlings must be kept humid enough so that they don't dry out, but not so wet that they are damaged by storage molds.

Seedlings can be stored under refrigeration (1 to 2° C) for a few months provided they are disease--free, clean, and properly packaged. Most nurseries used some sort of storage container with a moisture-retentive plastic liner, whereas others try to humidify the storage environment. The latter is much easier in theory than in practice. A recent trial showed that unbagged Sitka spruce (*Picea sitchensis)* seedlings in humidified cold storage had significantly poorer root growth potential, outplanting survival, and first-season shoot growth compared to seedlings stored in plastic bags. The cause of this difference in outplanting performance was poor humidity control--the unbagged seedlings had significantly lower root moisture content (Table 2). Also significant was the fact that the moisture loss was greatest during the first month of storage. The take-home lesson is that proper packaging maintains high in-bag humidity levels, which are much more important than the ambient humidity in the storage facility.

Storage molds get worse with time and so, for long-term storage (> 3 months), most nurseries are using freezers (-1 to -2° C). It is operationally difficult to maintain 100% humidity in freezer storage, and the physics of humidity at subfreezing temperatures is something that we really don't want to get into here. Proper packaging is even more critical for freezer storage. You all can relate to what happens to food that is kept in your frost-free refrigerator too long--it gets "freezer-burned." Bags or boxes with moisture-retentive liners have proven effective in maintaining high in-bag humidity in freezer storage.

So, there's a brief introduction to humidity and how it affects seedling growth. We've discussed light, temperature, and humidity so far, and next issue we finish-up the atmospheric limiting factors and take a look at carbon dioxide.

Table 2–Root moisture content (RMC) and root growth potential (RGP) for Sitka spruce seedlings under three cold storage treatments at four dates during the storage period

STORAGE TREATMENT	ASSESSMENT DATE							
	JANUARY 17		FEBRUARY 15		MARCH 15		APRIL 24	
	RMC	RGP	RMC	RGP	RMC	RGP	RMC	RGP
Humidified--Unbagged	296	4.0	127	5.3	117	2.2	62	2.6
Humidified--Bagged	342	4.5	226	4.7	225	4.7	219	5.2
Unhumidified--Bagged	352	4.5	265	5.9	234	4.2	224	4.8

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