Role of Water in Nurseries

"Water is the driver of nature" - Leonardo da Vinci

Organisms have evolved either around or in or around water, and life as we know it would be impossible without it. The importance of water has been known since ancient times. The Greek philosopher Aristotle recognized water as one of the four basic elements along with earth, air, and fire. Almost every plant process is affected either directly or indirectly by water, and so nursery managers and growers must have a good understanding of the physical, chemical, and biological properties of water.

Fascinating Facts about Water. The chemical structure of water (two hydrogens and one oxygen atom) is structurally simple yet biologically profound. The lack of symmetry in the water molecule produces polarity - a positive charge at one end of the molecule and negative at the other (Figure 1). The bipolar electrical charge creates an intense attraction between the hydrogen and oxygen atoms in adjacent water molecules, and these hydrogen bonds are responsible for most of water's amazing properties. Someone once calculated the force of hydrogen bonds as 21 billion times that of gravity, which explains why water is one of nature's most stable compounds. A substance with the low molecular weight of water should exist as a gas at the normal temperatures but, due to strong hydrogen bonding, it is a liquid. Water has the most anomalous properties of any common substance. The strong polarity of the water molecule causes them to surround dissolved ions and molecules and weakens the forces between them. This strong **dielectric constant** makes water an excellent solvent **(Table 1)**. In fact, water is so effective at dissolving other compounds that it is almost impossible to find chemically pure water in nature. The high dielectric constant is biologically important because water carries mineral nutrients, and organic products of photosynthesis as well as dissolved oxygen and carbon dioxide. Water also has remarkable softening properties, reducing the hardness and strength of soils so that it can be tilled. On the negative side, the high dielectric constant of water causes it to absorb ions and leach them from soils, growing media, and even from seedling foliage. Novice growers might think that irrigating with pure distilled water would be beneficial but the opposite is true. Excessive leaching of nitrates, phosphates, and pesticides can cause environmental pollution if they leave the nursery as surface runoff or leach to groundwater.

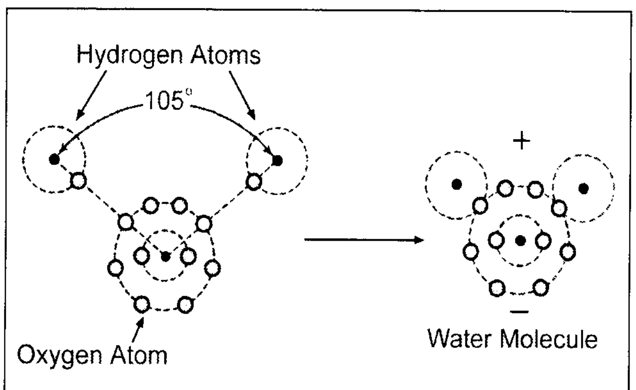

Figure 1. The bipolar charge of the water molecule causes hydrogen bonding which is resposible for most of water's remarkable properties (Hartman and others, 1981)

Another amazing property of water is its **anomalous expansion**. Water is unique in having its maximum density at 4 °C (39 °F) and so ice floats, which has important implications for life as we know it **(Table 1)**. This property also has some negative consequence for nurseries. Because liquid water expands when it freezes, succulent seedling tissues can be instantaneously killed by a relatively minor radiation frost. Irrigation pipes and pumps also can be ruined if they are not properly drained or filled with antifreeze before winter. Finally, volume expansion on freezing contributes to frost heaving which can kill young seedlings in bareroot seedbeds or after outplanting. Water also has a very **high latent heat of vaporization** which means that 540 calories of heat are required to evaporate 1 gram of water. This property is responsible for energy distribution and the hydrologic cycle on a global basis, as well as evaporative cooling at the seedling level **(Table 1)**. The latent heat of fusion—80 calories of heat are released when 1 gram of water freezes—is also unusually high and explains why seedlings can be protected from frost with irrigation. Water's **high specific heat and thermal conductivity** cause its temperature to rise or lower more slowly than other materials which gives water its great temperature buffering properties. On a practical basis, these properties dampen rapid temperature change in bodies of water as well as plant tissues. Water also has a **high surface tension** for liquids, which is again caused by the strong hydrogen bonding between water molecules **(Table 1)**. This slows evaporation and also creates strong capillary retention in soil pores and plant cells. Thus, high surface tension is responsible for the large reservoir of available water in soils and growing media.

Effects of Water on Seedling Growth. Water has four major influences on the growth of seedlings in forest and conservation nurseries:

1. Constituent - Water composes 80 to 90 % of the fresh weight of plants and is an important part of the protoplasm that fills every living cell. Dehydration first slows metabolic processes and eventually leads to a state of dormancy and, at extreme levels, to death.

2. Solvent - This "Universal Solvent" distributes gases, ions, and other solutes throughout the plant. Water carries mineral nutrient ions into the roots and then through the xylem to the foliage where they are used in photosynthesis. Then, photosynthate and other organic compounds are then carried back throughout the plant by way of the phloem to fuel the cell metabolism and provide the organic building blocks of all plant tissue.

Table 1 - Exceptional properties of water that affect nurseries

Property	Biological Significance	Practical Use in Nurseries
Specific Heat and Thermal Conductivity	One of the highest values of temperature regulation in water and organisms.	The high water content in plants buffers extreme changes in temperature.
Latent Heat of Vaporization	Highest of common liquids. A relatively large amount of heat is needed to convert liquid water to water vapor. This property is responsible for evaporational cooling.	Allows photosynthesis to occur in strong light without high temperatures which would damage leaf tissues. Another practical application is that light irrigation or misting lowers potentially damaging temperatures.
Latent Heat of Fusion	Highest of common liquids. A surprisingly large amount of heat is released when water freezes.	This property is practically used in nurseries during freeze protection with irrigation.
Dielectric Constant	The ability of water to neutralize attraction between charged particles is very high, and so it is known as the "universal solvent".	Water can dissolve mineral nutrients and transport them into roots and through plants, as well as carry dissolved oxygen and carbon dioxide. Water also "softens" soils.
Surface Tension	Very high for common liquids. Reduces evaporative losses, and causes capillary tension.	Explains why water can be carried upwards in xylem tissues, and is responsible for retaining water reserves in soils and growing media.
Volume Expansion on Freezing	Nearly all liquids contract as they freeze, but water has a maximum density at 4 °C (39 °F) and so ice floats.	Irrigation water is available during winter because surface layers of ice keep ponds from freezing solid. On the negative side, this is why irrigation pipes burst if not properly drained.

3. Reactant - Water is a biochemical reactant for many plant processes, but most importantly, photosynthesis, which has been rightly called the most important chemical reaction in the world:

$$CO_2 + H_20 + \text{Sunlight} = C_6H_{12}0_6$$

Water also serves as a substrate or ligand for many other important chemical reactions. More specifically in nurseries, water is necessary to bring seeds out of dormancy and stimulate the hydrolysis of the stored starches to sugars to feed the developing embryo. The young germinant requires a steady supply of water to fuel the photosynthetic process which produces the energy needed for rapid growth.

4. Maintenance of turgidity - Plants are "leaky", however. To capture the very low amount of CO_2 in the atmosphere, 500 kg. (I ,102 lbs) of water is lost to produce 1 kg. (2.21 lbs) of dry matter. Therefore, the vast majority of water that we apply during irrigation is used just to keep the stomata open so that CO z can easily enter the leaf. If seedlings are allowed to lose turgidity the stomata begin to close photosynthesis slows, and eventually stops all together.

Like all things, however, you can have too much of a good thing and an excess of water affects seedling growth in negative ways. Very fine-textured soils or growing media will hold too much water and not allow adequate exchange of oxygen and carbon dioxide, eventually suffocating the roots. Many pathogens thrive

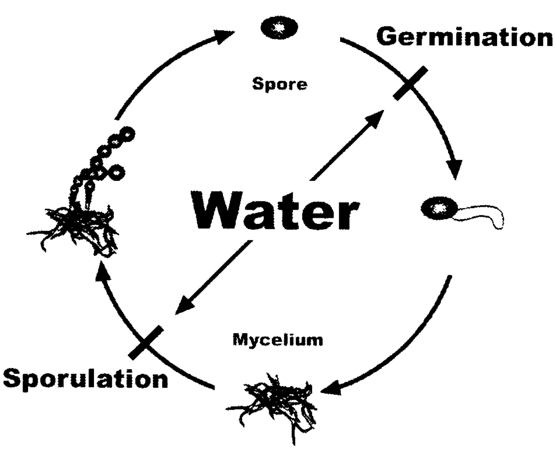

Figure 2. High humidity stimulates sporulation of dormant fungi like Botytis cinerea, and free surface water promotes spore germination and penetration of plant tissues.

in overly wet conditions including damping-off fungi (see section in Integrated Pest Management in this issue). One of the best examples of how excess water can harm a seedling crop is with fungi like *Botrytis cineria.* The body of the fungus is the mycelium which remains dormant under low humidity conditions and can remain in this dormant state almost indefinitely. If the humidity is allowed to remain at high levels, however, the Botrytis fungus quickly produces fruiting bodies which release airborne spores into the air. If the spores happen to land on plant tissue with free water, they can germinate and penetrate the epidermis and initiate an infection **(Figure 2)**

So, you can see that water is a truly remarkable substance that is the most important limiting factor affecting seedling growth and nursery management. Growers must learn to provide enough water at the right time to minimize water stress and stimulate seedling growth and development. Over-irrigation leaches fertilizers or pesticides which can cause environmental pollution, and also promotes excessively high humidity which favors pathogens.

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Micronutrients - Manganese

Of all the micronutrients, manganese is second only to iron in the amount required by seedlings **(Table 2)** but it wasn't until the early 1900's that manganese was proven to be essential for plant growth. Manganese has some metabolic functions that are similar to other micronutrient metals, so manganese deficiency is often confused with iron or zinc deficiency.

Role in Plant Nutrition.

Physiologically, one of the most important functions of manganese is its involvement in the "Hill Reaction" during photosynthesis, which the process responsible for the splitting of water and evolution of oxygen. Manganese also acts to protect the photosynthetic system against photo-oxidation, thereby maintaining the integrity of the lamellar system of chloroplasts. When manganese becomes deficient, the lamellar system becomes disorganized, resulting in lowered chlorophyll production, reduced photosynthesis, and resulting in the characteristic deficiency symptom of chlorosis **(Figure 3).** Manganese is also a catalyst in a variety of other enzyme systems where it plays a role in carbohydrate synthesis, and lipid metabolism. As a structural component of ribosomes, manganese is involved in nucleic acid synthesis.

Manganese is important for root development since it influences the supply of soluble carbohydrates: Low manganese levels impact carbohydrate reserves in roots more than in shoots, reducing root elongation and particularly lateral development. For this reason, manganese deficiency weakens the root system in a similar fashion to when seedlings are grown under low light levels. Since soluble carbohydrates are needed for synthesis of organic nitrogen compounds such as amino acids, manganese indirectly exerts an influence of nitrogen metabolism (especially ammonium). Thus, it is conceivable that a manganese deficiency can lead to increased susceptibility to ammonium toxicity because the carbon skeletons needed to detoxify ammonium would be in short supply. It has also been noted that manganese-deficient plants are more susceptible to cold injury. This may in part be due to this same shortage of soluble carbohydrates which act like anti-freeze in plant cells.

Manganese also has a role in protecting seedlings against pathogens as it is involved in phenol and other plant defense systems. Adequate manganese levels help the plant resist fungal invasion by inhibiting the pectolytic and proteolytic enzymes produced by pathogens to attack roots. When roots are well supplied with carbohydrates, they can easily outgrow pathogens and have lower levels of free amino acids which provide food for soil pathogens.

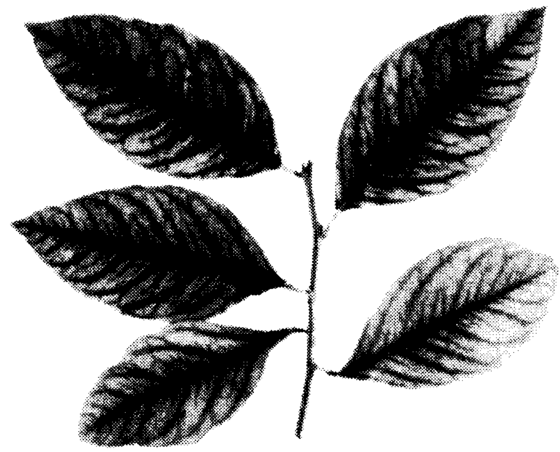

Figure 3. Interveinal chlorosis is the first visible indication of manganese deficiency although this sympton can also be caused by other micronutrient deficiencies (Labanaukas, 1965).

Availability and Uptake.

Manganese is widely distributed in nature, similar to iron, but is found in smaller quantities in agricultural soils. It has been found to be completely absent in sandy soils in high rainfall areas. The balance of iron to manganese is particularly important and a 2:1 ratio, on a parts per million (ppm) basis, is recommended. The available form of manganese is the divalent cation (Mn^{2+}) which is taken up by roots roughly in proportion to its availability in the soil solution. In soils, pH strongly affects manganese availability **(Figure 4)** and this is why over-liming is a common cause of deficiencies. High organic matter

Table 2 - The seven essential micronutrients and their typical concentrations in seedling tissue

Element	Symbol	Average Concentration in Plant Tissue (%)	Adequate Range in Seedling Tissue (ppm)	
			Bareroot	Container
Iron	Fe	0.01	50 to 100	40 to 200
Manganese	**Mn**	**0.005**	**100 to 5,000**	**100 to 250**
Zinc	Zn	0.002	10 to 125	30 to 150
Copper	Cu	0.0006	4 to 12	4 to 20
Molybdenum	Mo	0.00001	0.05 to 0.25	0.25 to 5.00
Boron	B	0.002	10 to 100	20 to 100
Chloride	Cl	0.01	10 to 3,000	--------

increases canon exchange capacity and thereby insures good manganese availability. The Mn^{+4} ion is the oxidized, unavailable form of manganese. Plants under stress have manganese oxidizers present and so a biologically-induced deficiency is theoretically possible.

The range between manganese deficiency and toxicity is relatively narrow and is strongly influenced by competing canons, especially calcium, magnesium, and iron. In soils, manganese toxicity is possible if the proper conditions exist but this is relatively rare. Toxicity should not be a problem in artificial growing media because *Sphagnum* peat moss and vermiculite contain so little manganese. Container growers have complete control over manganese levels through fertilization. Nursery managers should consult a specialist if manganese toxicity is suspected because of the sensitive balance of micronutrient interactions.

Diagnosis of Deficiencies and Toxicities.

Deficiency Symptoms—Manganese deficiency symptoms are very similar to those of iron with interveinal chlorosis of young leaves **(Figure 3).** The major difference is that, with manganese deficiency, the chlorosis usually progresses to necrosis whereas foliage with severe iron deficiency will eventually change in color from yellow to almost white. Foliar symptoms do vary between species, however. For example, manganese deficient white spruce *(Picea glauca)* seedlings exhibited chlorosis and browning of apical needles whereas Douglas-fir *(Pseudotsuga menziesii)* seedlings showed no foliar symptoms, only reduced growth. Proper diagnosis is important because adding iron fertilizer to a plant deficient in manganese can make the problem worse because iron competes with manganese for uptake. Therefore, it is advisable to perform seedling nutrient analysis on symptomatic tissue before deciding to apply fertilizer.

Toxicity Symptoms—Manganese toxicity is relatively common in agriculture although the critical concentrations vary widely between crop species. Manganese toxicity has not been documented on commercial conifer seedlings such as Douglas-fir and white spruce and, in fact, both species exhibited luxury consumption without apparent adverse effects. The principal foliar symptom is brown spots surrounded by bands of chlorotic tissue. Manganese toxicity also induce deficiencies of other mineral nutrients, especially calcium and magnesium. Under waterlogged conditions, high concentrations of manganese can develop and lead to toxicity and high temperatures can accelerate the condition.

Monitoring. The manganese status of nursery soils or growing media can be monitored by soil tests, irrigation water tests, or seedling nutrient analysis.

Chemical analyses of soils or growing media only determine total manganese and therefore are relatively useless for determining its real availability to seedlings. Because of the major effect of pH on manganese availability **(Figure 4),** growers should monitor soil and water pH on a weekly basis and watch for any trends. The general target pH of 5.5 is appropriate for most conifer crops but other broadleaved seedlings and noncommercial natives may have different requirements.

Manganese becomes unavailable if irrigation water is alkaline. Most good nursery sites typically have irrigation water that is neutral or slightly acidic, but it may exceed pH 7.0 when other dissolved salts are present, especially bicarbonate ions. It is relatively easy to lower water pH with the injection of phosphoric acid because the excess hydrogen ions bond with the hydroxyl ions to form water. Other acids can also be used but are more dangerous and caustic. The need for acid injection and the amount of acid to use per volume of water must be determined with a laboratory titration.

Seedling nutrient analysis can be used to diagnose manganese deficiency and interpretation is much more straight-forward than with iron. However, because of the variability that can exist, paired samples of normal and healthy plants should always be taken.

Manganese Management. There are basically two options for managing manganese in nurseries: maintain a

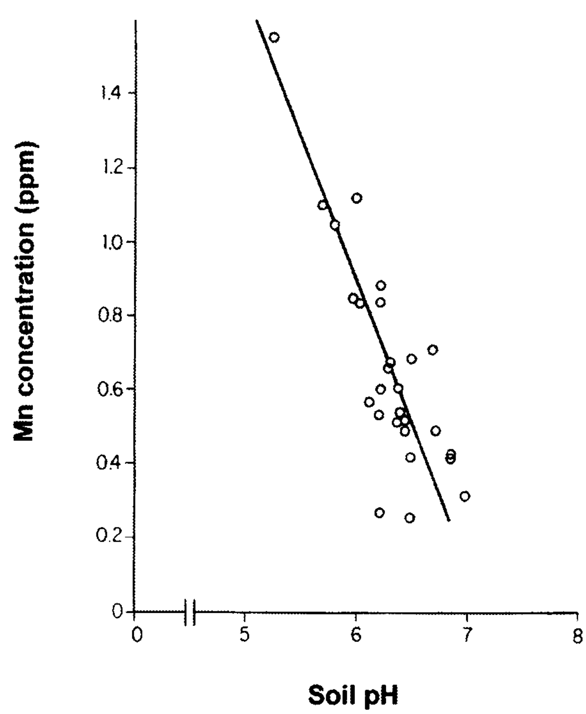

Figure 4. Manganese availability in soils is strongly affected by pH and so overliming can lead to deficiencies (Tisdale and Nelson 1975)

slightly acid pH and, if warranted, insure a steady supply of fertilizer:

pH Maintenance—The pH of the rhizosphere that affects nutrient uptake is determined by both the soil or growing medium and the irrigation water. In bareroot nurseries, high pH can be a problem if the site has either alkaline or calcareous soils or irrigation water, and lime-induced manganese deficiencies have been documented. Water is much easier to treat and acid injection is commonly recommended for container nurseries, but treating the water has not solved the problem in bareroot nurseries. In particular, calcareous soils are highly buffered and the excess calcium ions can still cause problems after the pH has been lowered. The pH of alkaline or over-limed soils can be lowered with sulfur applications although this can take many years with calcareous soils.

The situation is completely different with artificial growing media as they only contain very small amounts of manganese or other micronutrients, and most of these are organically bound so they are released slowly. The pH of the growing medium has a very minor effect on manganese availability unless there are problems with alkaline irrigation water, as noted above. Therefore, container growers should maintain a target pH of 5.5 to 6.5 and provide a continuous supply of manganese through fertilization.

Fertilization—Manganese can be supplied from inorganic fertilizer salts or organic compounds known as chelates **(Table 3).** Manganese sulfate is very soluble and is effective as either a soil or foliar application. Frits are slow-release fertilizers that consist of micronutrients impregnated in a glass powder which have release rates for up to one year. Manganese chelate consists of Mn^{2+} ions surrounded by an organic shell that maintains availability under adverse soil conditions, such as high pH, and is more effective as a foliar spray than for soil incorporation. Chelation also helps protect against over-fertilization because the nutrient is slowly released from the organic complex. Unlike iron, which comes in several types of chelates, manganese is not as affected by pH so the EDTA form works well under all conditions.

Manganese sulfate and chelate is also available in a variety of micronutrient mixes **(Table 3).** Although the actual manganese concentration can vary by two-fold between the various products, all supply adequate levels. Some soluble mixes can be injected through the irrigation system whereas others can be incorporated into the growing medium. Fertigation is recommended whenever possible because it insures that a uniform amount of manganese will be available throughout the growing season. The most comprehensive list of manganese fertilizers and their US suppliers can be found in the Farm Chemicals Handbook. In Canada, Plant Products Co. Ltd. offers a wide variety of chelated fertilizers.

Table 3 - Some common fertilizers containing manganese

Fertilizer	Chemical Notation	Manganese (%)	Use in Nurseries
	Single Nutrient Fertilizers		
Manganese sulfate	$MnSO_4 \cdot 3H_2O$	26 to 28	Only for foliar applications
Manganous oxide	MnO	41 to 68	Foliar or soil applications*
Manganese oxide	MnO_2	63	Foliar or soil applications*
Manganese frits	MnO_2	10 to 25	Only for soil applications
Manganese chelate	MnEDTA	13	Foliar or soil applications*
	Multinutrient Fertilizers		
Soluble Trace Element Element Mix – STEM®	Manganese as $MnSO_4$	8.0%	Foliar or soil applications *
Micromax®	Manganese as $MnSO_4$	2.5 %	Incorporation in growing media
Plant-Prod® Chelated Micronutrient Mix	Manganese as EDTA	2.0 %	Foliar or soil applications*
Osmocote Plus®	Manganese as $MnSO_4$	0.07%	Incorporation in growing media

In conclusion, manganese availability is usually not a problem in bareroot nurseries with good quality soil and irrigation water. If a deficiency is diagnosed, then either manganese sulfate or chelate can be applied to correct the problem. In container nurseries, a steady supply of manganese should be supplied as soluble fertilizer. Chelates are recommended because there is less chance of over-fertilization.

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