# Disinfection of Nursery Irrigation Water with Chlorination, Bromination, and Ozonation

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## INTRODUCTION

Disinfection is the process by which pathogenic microorganisms are destroyed. There are many ways in which disinfection of irrigation water may be achieved. The degree of disinfection required depends on the source of the irrigation water, the type of disinfectant used, the dosage, and the contact time. Other factors nursery owners may consider when selecting a disinfectant are handling considerations, and equipment and chemical costs per gallon of water. Each of these variables will be addressed and compared for disinfection of irrigation water using chlorine, bromine, and ozone.

## WATER SOURCE QUALITY

Irrigation water is typically acquired from ground water, surface water, a pipeline of reclaimed wastewater (where available), or is recycled on-site. Each of these types of sources of water have different characteristics which can be generalized. The characteristics that need to be considered when selecting the most appropriate method of disinfection are turbidity, organic load, inorganic load, pH, and temperature. Groundwater tends to be uniform in quality, low in turbidity and color, but generally contains high concentrations of dissolved inorganics. Surface waters, alternately, tend to vary in quality, with high fluctuations in turbidity and color. Surface waters will also typically have lower mineral contents, but higher organic loads. Treated wastewater effluent will be similar to ground water with respect to uniform quality, low in turbidity and color, but may also be disinfected to some degree. Nursery runoff that is recycled on-site may contain high concentrations of pesticides or insecticides.

**Turbidity.** Turbidity, or the "cloudiness" of the water source, is perhaps one of the most important characteristics to observe when selecting a water source. Turbidity often interferes with the disinfection process. The suspended solids tend to surround and protect microorganisms from the disinfectant added to the water, thereby preventing the efficacy of the disinfectant. None of the three disinfectants is more effective than the other against turbidity. If the water source being used seems to be excessively cloudy, or turbid, a physical method of pretreatment, such as filtration, may need to be considered prior to the addition of a chemical disinfectant.

**Organic Load.** Organic materials can also reduce the effectiveness of a disinfectant by adhering to the microbial organisms completely shielding them from disinfection, reacting with the disinfectant to reduce the strength of the disinfectant, or completely neutralizing the disinfectant. The magnitude of the organic load will determine the "demand" of the disinfectant, or the amount of disinfectant required to react with the organics present. Both chlorine and bromine are susceptible to combining with organic matter. The biocidal properties of chlorine are rendered inert or minimally effective when combined with organics. The efficacy of bromine is not hindered when combined with organics (De Hayr et al., 1994). Ozone is an excellent oxidizer against refractory organic compounds, and destroys all organic matter present in the water (Metcalf and Eddy, 1991).

**Inorganic Load.** Similar reactions occur between disinfectants and inorganics as with disinfectants and organics. Several compounds such as iron, manganese, hydrogen sulfide, cyanides, and nitrogen-based compounds are rapidly oxidized, or consumed, by the disinfectant, greatly hindering the potency of the residual disinfectant. The combination of chlorine with ammonia results in chloroamines. The effectiveness of chloroamines has been reported to be as much as 80 times less than that of free chlorine (De Hayr et al., 1994). On the other hand, the formation of bromamines does not appear to reduce the disinfection properties of bromine. Therefore, far less bromine would be required, compared to chlorine, to achieve the same disinfection results. Again, ozone is also very effective in oxidizing inorganics, such as iron and manganese.

**pH and Temperature.** The pH of the water to be treated plays a significant role in the effectiveness of chlorine as a disinfectant. Hypochlorous acid is active primarily between a pH of 5 and 9. Over this pH range, the acid dissociates into the weaker hypochlorite ion. The hypochlorous acid is much more effective at disinfecting water, but it only works for a short time. The hypochlorite ion is subject to binding with organic/inorganic matter available in the water, which leads to bacterial inactivation. Hypobromous acid dissociates in much the same way, but, as discussed in previous sections, the effectiveness of the hypobromite ion is not hindered by radical organic/inorganic matter. Bromination, therefore, remains effective over a much broader pH range than does chlorination, (De Hayr et al., 1994). Ozonation, unlike chlorination or bromination, will be effective regardless of the pH of the water supply. However, the pH does influence the reaction pathways which occur. In general, conditions of low pH favor more direct oxidation reactions which provide for better disinfection (Metcalf and Eddy, 1991). Lower pH also allows for ozone residuals to remain in the water longer. The degree of success of disinfection is also indirectly related to temperature. Temperature can affect the rate of reaction of certain steps in the process, such as diffusion through the cell wall. While there is no optimum temperature range for disinfection to occur, the general rule of physical chemistry is that reaction rate will increase with increasing temperatures.

## DOSAGE

The dosage is the amount of chemical added to the irrigation water which includes the demand, or the initial amount needed to achieve a certain percent kill, plus a residual amount which is needed if the water is going to be stored prior to use. A residual can be accomplished by using chlorine and bromine. Ozone, generally, does not leave a residual. The demand is primarily dependent upon the quantity of organic or inorganic matter present in the water supply, and is determined experimentally. When applying chlorine, the dosage might be a continuous low concentration, which will keep the water supply chlorinated for a longer period of time, or a higher concentration for a shorter duration. Typically, it will be necessary to apply a dose of 5 to 10 ppm of chlorine to achieve a residual of 1 to 3 ppm of free chlorine. For water sources high in organics/inorganics, it may be necessary to apply a dose of as much as 25 to 30 ppm in order to achieve the same amount of residual free chlorine (De Hayr et al., 1994). Free chlorine in excess of 7 ppm can cause plant damage, reinforcing the need to frequently monitor water for demand and residual.

The dose for bromine is generally lower as breakpoint bromination is not relevant, and the initial dose is, essentially, "free" bromine. Typically, 5 to 10 ppm of bromine is needed to inactivate most microorganisms (Zeitoun, 1996). This dose will not increase much when the source water contains higher organics and inorganics since bromine is hardly effected by the presence of these contaminants. The dose of ozone will equal its demand since there is no residual associated with this disinfectant. Generally, ozone dosage is 1 to 5 ppm (Montgomery, 1985). Ozone dosage is not effected by organics, ammonia content, or pH, so the quality of the water content is irrelevant. Furthermore, if a higher dose of ozone is applied, it can provide a source of oxygen to the plant root system (Zeitoun, 1996).

## CONTACT TIME

The contact time, or residence time, is the length of time in which the chemical disinfectant must remain in contact with microorganisms to achieve a desired degree of purity. This amount of time is dependent on many factors, and can really only be determined experimentally. Generally speaking, the longer the contact time, the greater the kill. With chlorine and bromine, the residual can be a small concentration (i.e., 1 ppm) that is maintained continuously in the water stream, or a larger concentration is applied (up to 10 ppm) for 15 to 30 min per day. Bromine reacts much more quickly than chlorine, and requires less contact time. The recommended contact time for ozone is a minimum of 4 min, since it has a half life *of 4 to 20 min. Ozone disinfection should be generated just prior to using the water* for irrigation.

## SAFETY

The safest form of disinfectant discussed here would be solid forms of chlorine or bromine. Due to the unstable nature of chlorine gas and ozone, these chemicals can be extremely dangerous if handled improperly. The safest chemicals to use for disinfection from a handling perspective are chlorine or bromine tablets. The equipment used for tablets or powders is far less sophisticated, and requires less training compared to ozone generators or handling of chlorine gas cylinders (Austin, 1989). Phytotoxicity can occur with excessive free chlorine concentrations, which requires frequent monitoring. Phytotoxicity was found to be insignificant to sensitive bedding and foliage plants when bromine concentrations were present in concentrations as high as 100 ppm (Austin, 1989). Excessive ozone is in fact helpful, not harmful, to plants by increasing the oxygen content.

## COST

Cost is dependent on the dose which, ultimately depends on the quality of the water supply. This is probably one of the most important factors when deciding which method to use for disinfection. Approximate chemical costs, per pound of chemical, are shown below. These costs were obtained from various chemical supply companies, and averaged together (costs do not reflect the use of equipment for generation and dispersion):

**Chlorine gas ($Cl_2$):** \$0.77 $kg^{-1}$ (\$0.35 $lb^{-1}$)

**Bromine ($Br_2$):** \$2.20 $kg^{-1}$ (\$1.00 $lb^{-1}$)[granular]

**Liquid chlorine (NaOCl):** \$2.51 $kg^{-1}$ (\$1.14 $lb^{-1}$)

**Ozone ($O_3$):** \$1.06 $kg^{-1}$ (\$0.48 $lb^{-1}$)

**Solid chlorine ($Ca(OCl)_2$):** \$2.84 $kg^{-1}$ (\$1.29 $lb^{-1}$) [tablets]; \$2.51 $kg^{-1}$ (\$1.14 $lb^{-1}$) [granular]

## SUMMARY

Overall, the least expensive, most effective method of disinfection seems to be bromination. This chemical remains effective over varying degrees of water quality, residuals can be maintained, it is safe to handle, and does not appear to be harmful to plants regardless of the dose. Another benefit to bromine over chlorine is that phytotoxicity does not occur as frequently as with higher doses of applied chlorine. The downfall of chlorine and bromine is that they both produce by-products, which may or may not be harmful to plant life, where the ozonation process does not produce by-products. Ozonation is highly effective as a disinfectant, and, if the cost of the ozone generator is discounted, can be a cost-effective alternative to disinfection.

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