Chlorination

<u>Chlorination</u> Chlorine treatment of nursery irrigation system is probably one of the most popular methods utilized for the control of pathogens. This article will discuss the different types of chlorination systems and the proper procedures required for effective control of pathogens.

Introduction. Chlorination is a chemical method of treating water to kill both plant and human pathogens.
<u>Effectiveness of treatment</u> depends on four factors:
(1) Chlorine concentration – the greater the concentration, the more quickly it disinfects. However, too much chlorine may also kill plants. Most plants are safe if residual chlorine concentrations are <100 ppm (3 meq/L). However, some floriculture crops are very sensitive to chlorine.

> Caution – If you are uncertain about a particular crop, please check with your local Farm Advisor.

(2) Duration of pathogen exposure to chlorine – effective exposure times may range from 1 minute to 24 hours.
(3) Initial cleanliness of water – dirty water ties up chlorine, reducing disinfectant efficacy.
(4) Water pH – Chlorine is more stable, and therefore more effective, when irrigation waters have a neutral pH.
(5) Pathogen type – some pathogens, such as *Phytopthora,* which can encyst (protective barrier), may require longer exposure times.
(6) Water temperature – Relatively high (>20C) or low temps (<10C) may decrease the effectiveness of chlorine.

When chlorine is added to the water supply, aside from killing pathogens, it may also bind to organic matter or chemicals such ammoniacal nitrogen. If chlorine binds to organic or chemical components, the chlorine is considered unavailable for pathogen control. Therefore, the effective or 'residual' chlorine concentration is reduced. This is the reason that chlorination is more effective with water sources that are not heavily contaminated with organic matter. When most pathogens are exposed to high enough concentrations of chlorine for a sufficient period of time, they will be killed.
Caution: <u>Pathogen populations and residual chlorine concentrations should be routinely monitored to ensure that disinfection is sufficient and that residual chlorine concentrations are not dangerously high for plant production.</u>

*Chlorination Advantages.
+<u>operation costs</u> – since chlorine injection requires limited energy.

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+Capital costs – low. Most costs are for chlorine.
+Exposure time – Most pathogens are killed within seconds to a few minutes of chlorine exposure.
+Technical components – Few technical components if sodium or calcium hypochlorite is used.
+Maintenance - low maintenance requirements. If chlorine gas is used, the injection system will need to be inspected periodically.
+Adaptability – very adaptable to small and very large production systems.
+Chemical control – Properly performed chlorination should not affect the chemical nature of the water.
+Space – Aside from chlorine storage, no additional space is required.
+Labor – System is low-labor input. Manual additions of liquid chlorine can be done. Some labor is required to routinely check equipment if chlorine gas is used.

*Disadvantages
-Chemicals – Residual chlorine can kill plants. Some plants are more sensitive than others. However, except for hydroponic systems, organic matter in water and media usually ties up excess chlorine before significant damage can occur on crops.
-Herbicide and Pesticide removal - Chlorine does not breakdown or remove most pesticides or herbicides.
-Floating debris removal - larger suspended debris should be removed, so that free chlorine is not inactivated by organic matter.
-Dissolved organic matter – Coloration due to dissolved organic matter and acids is not eliminated.

Chlorination Methods. There are three methods of incorporating chlorine into irrigation water:
(1) Sodium hypochlorite – commercial bleach which has 100,000-140,000 mg chlorine/L. This is often used in the industry.
!Caution to plants! – Sodium may accumulate in closed, recirculating production systems. In these cases, sodium levels should be monitored to prevent sodium toxicity.
!Danger – Potential Explosive! Sodium hypochlorite is can be explosive. If stored in improperly sealed vessels, and sodium hypochlorite begins to breakdown, it result in an explosion.
(2) Calcium hypochlorite – which has 350,000 mg chlorine/L. This is occasionally used, especially if sodium buildup is a concern with the use of sodium hypochlorite.
(3) Chlorine Gas – This is the least expensive of the three products. However, chlorine gas is dangerous to work with and there are many regulations that dictate its storage and use. If chlorine gas is considered, check with local agencies for the necessary permits.

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Copper Ionization

History. The use of copper and silver ionization is a popular method of treating drinking water for pathogens. Historically, this method of water treatment gained popularity after the outbreak of *Lequionella pneumophila,* the bacteria responsible for Legionaires' disease, which occurred at the 58th state convention of the American Legion in Philadelphia, Pennsylvania in 1976. Since then, many hospitals and other public facilities have incorporated various methods, such as copper and silver ionization to kill pathogens in drinking water. The concentration necessary for pathogen control is approximately 100 ppb for drinking water and 20 ppb to treat pool water. However, the use of copper ionization in the nursery industry is relatively new. In this article we will discuss the use of copper ionization in the nursery setting, presenting its attributes and limitations.

What is Copper Ionization?
Ionization works via inserting copper-coated ceramic electrodes into one point of the water system. An electric current passes through this electrode, releasing copper ions (Cu^{2+}). These positively-charged copper ions are attracted to negatively-charged particles, such as organic matter, silt and clay particles and to the membranes of bacteria, algae and mold. If copper binds to the organic matter, silt or clay, then the copper becomes chemically inactive. However, if the copper binds to the membranes of the organisms, the organisms die.

Copper in Agriculture.
Copper is a heavy metal that has been traditionally used in agriculture as a bacteriacide on crops through applications of copper sulfate, which has been used alone or with other pesticides. In addition, copper is an essential plant nutrient, which is required at relatively low concentrations (0.002-0.003%) (20-30 ppm plant dry weight). In most nutrient formulations, especially micronutrient blends, copper is mixed into media at a rate of approximately 0.01-0.40 g/pot. For hydroponically-grown crops, copper is supplied at concentrations of approximately 0.05 ppm. Because of such relatively low requirements, any additional copper that is added to a plant system, either as a pesticide or fertilizer, should be monitored so that copper toxicity is avoided.

Copper Ionization in Nursery Production
Copper ionization has been used successfully in agricultural processes such as: (1) coolant pad water treatment to keep filters free of algae and (2) postharvest washing of fruits and vegetables. Information regarding copper ionization usage in irrigation water recycling systems is limited. In most copper ionization systems, recommendations are to maintain active copper ion concentrations at 0.50 to 1.5 ppm. Copper electrodes are inserted into the water system – preferably after the water has been filtered of debris

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and suspended clay and organic matter. The number of copper electrodes required will depend on the amount of water that needs to be treated, the cleanliness of the water (presence of organic matter and suspended clay) and the size of the electrodes. Some of the models currently available will treat about 200 gallons of water per minute. Additional electrodes will be required for higher flow rates.

***Advantages**

+Operation costs -- Moderate. Electrode replacement (up to $10,000) and the cost of electricity.

+Installation costs -- low. Financial outputs are primarily for installation of copper coated electrodes and electrical source.

+Chemicals -- Some companies claim that no additional chemicals are required for pathogen control. However, others indicate that oxidizers such as chlorine will still be needed, but at lower concentrations.

+Technical components -- few technical components or control systems.

+Maintenance -- low (occasional replacement of copper electrodes.)

+Pathogen removal -- Pathogens such as bacteria and fungi will be killed.

+Chemical effects -- Copper ionization will not alter the pH of the effluent water.

+Space -- requires no additional land for the construction of large treatment facilities.

+Algae control -- The system will kill algae on water and on coolant pads.

***Disadvantages**

- Copper toxicity of water. -- Some ornamental crops are sensitive to the copper concentrations (0.5-1.5 ppm) that are recommended to effectively treat water. No data is available on copper accumulation with long-term usage of copper ionization in a closed recycling irrigation system.

-Effectiveness reduced with dirty water -- Since copper ions are positively charged, they will be attracted to and bind to negatively charged particles of organic matter and clay, making the copper ions inactive. Therefore, greater injection (release rates) of copper ions from electrodes will be needed to keep the copper ions at concentrations effective to kill pathogens.

-Herbicide and Pesticide removal -- Does not remove other chemicals from the water.

-Floating debris removal -- Does not break down or remove floating debris.

-Dissolved organic matter -- Coloration due to dissolved organic matter and acids is not removed from the water.

-Clay and silt removal -- Clays and other soil particles are not effectively removed with copper ionization.

-Copper accumulation in closed recycling systems -- Copper will bind to organic matter and clay that settles out in reservoirs. Therefore, if this sludge is recycled back into the media, copper concentrations in the sludge could be toxic to some

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crops. Tests should be performed to check copper concentrations of the sludge and media before use on crops.

Conclusions. When used properly, copper ionization can be used in some nursery systems to control pathogens. However, the primary concern is that copper concentrations in closed recirculating systems should not increase to toxic levels. In a recent study, copper toxicity was documented for chrysanthemum (*Dendranthema*), miniature rose (*Rosa*), and geranium (*Pelargonium*) at 0.32 ppm, 0.15 and 0.50 ppm, respectively.

Copper Toxicity Symptoms:
Leaves: Reddish brown lesions, which coalesce in severe cases.
Roots: Stunting and death of root tips and an increased production of lateral roots. Under severe toxicity the entire root system will senesce.

When treating recycled waters, always check for effective control of pathogens, regardless of the treatment process being used. In the case of copper ionization, additional tests should be conducted to determine the copper levels in media and waters. Copper sensitivity tests should also be conducted on new plants that are suspected of being sensitive to the copper concentrations that are used in the growing system.

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Ultraviolet Light

History. The use of ultraviolet light (UV) is becoming more common to sanitize 'cleaner' water sources, since it does not require the addition of any chemicals. Some hospitals, hotels and nursing homes are using UV light to sanitize potable water sources to ensure that water is free of human pathogens. When properly used in some nursery facilities, UV light may help kill any remaining organisms that may remain in the water after all clarification and filtering processes have been performed. The use of UV treatment in nurseries is in the developmental stages. Since water sources and the degrees of water cleanliness vary among nurseries, small pilot systems should be installed and tested to ensure that UV treatment processes will work for specified nurseries.

What is UV light and how does it work in water treatment?

Ultraviolet light fits into the light spectrum of wavelengths from 100-400 nanometers (nm). This is the same light wavelength that is notoriously known to cause skin cancer in humans. Visible wavelengths range from 390-810 nm. The UV light, like chlorine treatments, kills the pathogens (bacteria, fungi, and viruses) suspended in water. However, since it is a light source, the water must be clean of suspended clays and organic acids for the light to pass through the water column to kill pathogens. Because of this limitation, UV light treatment is more suitable for hydroponic systems rather than production facilities that use organic media (peat, pine bark) or run water over soils that contain clays since the dissolved organic acids and clays will reduce water clarity and thus reduce the effectiveness of UV treatments.

Ultra-violet light sources.

There are three types of UV sources: (1) low pressure mercury vapor lamps; (2) Xenon flashlamps; and (3) excimer lasers. Low-pressure mercury lamps emit a wavelength of 254 nm. The use of 'high' pressure mercury lamps may also be used, but they also emit wavelengths of 190 nm, which results in the formation of ozone in the water. This ozone can also sanitize the water to a certain degree. Xenon flashlamps emit pulses of light that is a higher power source of emission. However, Xenon lamps also emit wavelengths over a larger spectrum, some of which are not UV, making Xenon lamps less energy efficient. The third source of UV light is the excimer laser, which emits pulses of light (248 nm).

Ultraviolet light Usage in Nursery and Floriculture Production

Ultraviolet light treatments are used in the water recycling system at the point after all other water clarification processes such as sand/charcoal filtration or flocculation have occurred. This ensures that the water is clear enough for the most effective UV light penetration into the water column.

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***Advantages**

+Operation costs – The cost of operation will be low if the water source is already clarified. Cost of treatment will increase with the degree of water cloudiness.

+Installation costs – Relatively lower for cleaner water supplies such as those of hydroponic systems.

+Chemicals – No chemicals, regardless of the light source utilized.

+Technical components -- Few technical components or control systems.

+Maintenance -- low

+Pathogen extermination -- Pathogens such as bacteria and fungi and viruses will be killed.

+Chemical effects – No effect on water pH.

+Space – Relatively small space required for installation of light source and power supply.

+Algae control -- The system will kill algae suspended in the water source.

+Nontoxic to plants – UV treated water has no toxic effect on plants.

***Disadvantages**

-New technology – The use of UV light in nursery systems is still being studied. Therefore, much of the troubleshooting needs to be conducted.

-Chemical effects – light sources will chemically denature chelates that may be used to keep micronutrients such as iron in a soluble form.

-Effectiveness reduced with dirty water – Since the UV light must pass through the water, any dissolved or suspended substances such as organic acids or clay will reduce efficacy of the UV light treatment.

-Herbicide and Pesticide removal -- Does not remove other chemicals from the water. The effects of UV light may break down light-sensitive herbicides and pesticides. Consult manufacturer for specific chemical questions.

-Floating debris removal -- Does not break down or remove floating debris.

-Dissolved organic matter -- Coloration due to dissolved organic matter and acids is not removed from the water.

-Clay and silt removal -- Clays and other soil particles are not removed.

-Exposure time –UV light may require an exposure time of 30 seconds or longer, depending on the clarity of the water. Slower flow rates will be required, but lower flow rates will also reduce water turbulence and efficiency of treatment.

Conclusions. When used properly, UV light treatment may be used on some nursery systems to kill pathogens. However, the most successful use of this technology will be with cleaner water systems such as those used in hydroponic systems. However, if using chelated micronutrients such as iron chelates, the use of UV light may cause denaturing if the chelates.

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Ozonation

History. Ozone is a strong oxidizing agent, twice that of chlorine, and has been used since the beginning of the 20^{th} century to disinfect water. As environmental regulations become increasing restrictive for the use of chemical disinfectants, alternative methods must be developed which are effective, but do not produce harmful residues. In this article we will discuss the treatment of recycled irrigation water with ozone, presenting its attributes and limitations with regard to its specific use in the nursery industry.

Ozone, Free Radicals, and Oxidizing Agents – Oh My!

***Ozone** = a chemically unstable gas molecule that consists of 3 oxygen atoms linked together. This molecule would like to have 2 more electrons to become more stable. Since an ozone molecule 'takes' electrons from another molecule, it is considered an oxidant.

***Oxidant** = any chemical that is capable of taking electrons away from another chemical. These types of chemical reactions were originally termed 'oxidation' because it was believed that oxygen was the only chemical able to take electrons from another molecule. In the process, the oxygen bonded with the molecule it took electrons from. However, chemicals other than oxygen are now known to be oxidants, but the term 'oxidation' is still used in the literature. The ability of a specific chemical environment to cause oxidation is measured as '<u>redox potential' (REDOX)</u> or 'oxidation reduction potential' (ORP). ORP values of 700 mv should provide complete disinfection.
OPR values less than 300 mv are usually considered safe for most aquatic life.

***Free radical** = any atom or molecule (group of atoms) that has at least one unpaired electron, but has an overall 0 charge (it is a particle that is neither positively or negatively charged). Even though this free radical has a charge of 0, it still needs to have the unpaired electron teamed up with another electron. All free radicals are oxidants since they have the ability to take electrons from other molecules. Ozone is <u>not</u> a free radical because all of its electrons are paired together. However, when ozone breaks down during oxidation reactions, oxygen free radicals (O·) and hydroxyl free radicals (HO·) can be produced.

***Antioxidant** = any chemical that protects an organism from being oxidized or any chemical that inhibits the ability of oxidants to oxidize. Blueberries are good for you because they have a lot of antioxidants!

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Note: *In the world of oxidation reactions and free radicals, two general assumptions in chemistry must be understood: (1) most compounds are stable at an electrical charge of 0, and (2) electrons are only stable as pairs. –*

Let's put this in more simple terms, but we need a few analogies.

Electrons = shoes.

Reductant (electron givers) = Stu and Sue Electronzinski.

Oxidants = Stu and Sue's eight teenage girls.

Stu and Sue(reductants – electron givers) had eight teenage girls (oxidants – electron takers) who always wanted to buy pairs of shoes (pairs of electrons). The girls always hung out with mom and dad because knowing their parents, (the electron givers that they were), they would buy them more shoes. Because of this situation, the family was always together. One day, one of the girls was going to her prom, but she was missing a shoe (an electron) from her favorite pair (You could say that she became a 'free radical'). However, Stu and Sue came to the rescue and bought her a new pair of her favorite shoes. The family lived happily ever after – The end.

How does ozone work in disinfecting irrigation water?
Ozone disinfects water by oxidizing (adding oxygen/removing electrons) the membranes and key physiological reactions in living organisms and different types of chemicals suspended or dissolved in the water. In addition, as ozone breaks down, it produces free radicals (Equation 1). These free radicals also disrupt cell membranes and physiological processes by upsetting the electron balance of the cell wall structures and chemical pathways.

Equation 1 $O_3 + H_2O \rightarrow O_2 + 2OH\cdot$
Ozone + water → oxygen + 2 free radical hydroxyls

Procedures for ozonation of irrigation water
(1) Provide a relatively pure oxygen source. The use of regular air will not work since it is only 21% oxygen.
(2) Electrically charge the oxygen (O_2), which forms ozone (O_3). This is often performed through corona discharge or plasma discharge units. Over 80% of the energy is wasted in the form of heat, which must be removed from the ozone generator, since heat will decompose ozone.
(3). Bubble the ozone through the water source. An injection rate of 1 oz per 1,000 gallons of water with a one hour exposure time is target rate, but may vary according to different water sources. Treated water should be maintained in a closed pressurized system to prevent off-gassing of the ozone.

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(4) Ultraviolet light can be used to increase the rate of breakdown of ozone, which causes the rapid increase in free radical hydroxyl (·OH) groups. This acts as a better disinfectant. This technique is called 'Advanced Photo Oxidation'.
(5) Deactivate excess ozone by venting through an activated charcoal filter.

*Advantages
+Powerful disinfectant with no chemical residues – Ozone breaks down to oxygen. So there are no chemical residues directly from ozone.
+No additional chemicals – proper ozonation will require no other chemical control.
+No chemical storage – since ozone is made on-site
+Easy monitoring – efficacy of system easily monitored by measuring the ORP (redox potential).
+Maintenance –low maintenance unless oxygen source is not clean, then electrodes must be cleaned.
+Pathogen control – Most pathogens will be killed.
+Algae control -- The system will kill algae.
+Pesticide breakdown – many pesticides will be oxidized.

*Disadvantages
-Lengthy treatment period – Depending on the amount of organic matter in water, ozone exposure may require up to 20 minutes to 1 hour to achieve 100% mortality of pathogens.
-Space allocation – Since the efficacy of ozone is related to its concentration and exposure time, collection tanks for treated ozone water will be needed so that ozonated water can be stored long enough for effective disinfection.
-High operation cost – for electrical source.
- Increased water pH – Ozone will increase water pH, so water acidification may be necessary.
-Effectiveness reduced with dirty water – organic matter will react with ozone, decreasing the amount of ozone available to kill pathogens.
-Floating debris removal - Does not break down or remove floating debris.
-Pathogen resistance – the chlamydospores and microsclerotia of some pathogens are more difficult to kill with ozone.
-Clay and silt removal -- Clays and other soil particles are not removed or broken down.
- Chelates destroyed – if chelates for iron or other nutrients are used, ozonation may react with the chelates, precipitating the nutrient out of solution.
-Element precipitation – ozone may oxidize and precipitate out of solution some essential nutrients such as iron, even if chelates are not being used.
-Plant toxicity – ozone is toxic to plants, so ozone levels should below toxicity levels before applying to water.

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Heat Disinfection

History. Heat to sanitize materials has been more commonly used to sterilize substrates in the nursery industry. However, heat has also been used to sterilize water, especially for nurseries in European countries. Since no chemicals are added in this process, there is no concern regarding chemical storage or chemical residues. This article will briefly describe disinfection of irrigation water through heating for the specific use in nursery production facilities.

How does heat treatment work?

All living organisms have a certain heat tolerance, the ability to withstand a certain maximum temperature for a specified period of time. Once this time or temperature is exceeded, the organism dies. Viruses are killed at temperatures as low as 130F (55C) if that temperature is maintained for a period of 1.5 hours. At higher temperatures, the required heat duration for organism death decreases.

Procedures for heat treatment of irrigation water

Metal heat exchangers are situated at one point along the water treatment system. The number and size of exchangers will depend on the volume of water that needs to be treated during a given time period. Prior to passing over the heat exchanges, the water pH may be acidified to 4.5 to prevent calcium accumulation on the exchangers. If the water is particularly dirty, filtration may be recommended prior to heat treatment. After heating, the water must be cooled before using on plants.

***Advantages**

+N<u>o chemical residues</u> – since no chemicals used.
+<u>No additional chemicals</u> - proper heating procedures will require no chemical treatment.
+<u>Maintenance</u> – no maintenance, unless calcium builds up on exchangers.
+<u>Pathogen control</u> - all pathogens will be killed.
+<u>Algae control</u> - the system will kill algae.
+<u>Plant safe</u> - if cooled sufficiently after heat treatment, there are no potential toxicities from heating.

***Disadvantages**

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-Difficult monitoring - water must be check through laboratory procedures to ensure that that all pathogens are killed.
-Water cooling - water must be cooled prior to usage.
-Lengthy treatment period - depending on the maximum temperature utilized, heating duration may take up to 1.5 hours to achieve 100% mortality of pathogens.
-Space allocation - since the efficacy of heat treatment is related to exposure time at a certain temperature, tanks will be needed to hold treatment water and cooling water.
-High operation cost - for electrical source, natural gas, or oil.
-Water pH - water will require acidification to approximately 4.0-4.5 prior to heating (to prevent calcium buildup on heat exchangers), and then will have to be neutralized (to crop requirements) after heat treatment.
-Floating debris removal - does not break down or remove floating debris.
-Clay and silt removal - clays and other soil particles are not removed or broken down.
-Chelates destroyed - if chelates for iron or other nutrients are used, temperatures up to 150F should not be a problem. However, accidental temperatures near boiling (212F) will denature chelates.
-Pesticide breakdown - please check pesticide labels for temperature stabilities in solutions.

Conclusions. When used properly, heat treatment can be an effective method to disinfect irrigation water in some nursery systems. Some of the primary limitations to heat treatment systems are space for holding tanks for heating and cooling water and the high cost of heating water.

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Reverse Osmosis, Nanofiltration, Ultrafiltration and Microfiltration Processes

Membrane-Mediated Filtration Processes

There are basically four types of membrane-mediated filtration processes: (1) Reverse Osmosis, (2) Nanofiltration, (3) Ultrafiltration, and (4) Microfiltration. All of these techniques involve passing dirty water through membranes, which filter out unwanted substances. Pressure (energy) is also required to pump the water through the membranes, with the smaller-pored membranes requiring more pressure to force water through the pores compared to the larger pored membranes. The major differences between these systems are the sizes of the membrane pores. The advantages and disadvantages of these systems are described in Table 1 and the relative sizes and weights of chemicals and organisms found in irrigation water are described in Table 2.

Reverse Osmosis (RO) – also called hyperfiltration, utilizes membranes with the smallest pores of the four filter systems. Because of the relatively small pores, dissolved salts, charge particles, and compounds of molecular weight greater than about 200 daltons (1 dalton = 1 atomic mass unit [amu]), as well as most pathogens are removed from the water. Nurseries that are forced to use low quality (salty) water, usually must utilize RO to remove dissolved salts. Since this process removes dissolved salts, including fertilizer, one should not utilize this method after fertilizer has been added to the irrigation system; otherwise you are removing your fertilizer from the irrigation water.

Nanofiltration – utilizes membranes of a larger pore size than those used in RO; however, pores are still small enough to filter out larger sized molecules (≈ 200-1000 daltons). These pores are usually large enough to allow chelated nutrients to pass through, since most chelates such as iron-EDTA have a molecular weight under 500 daltons. Also, some charged particles may not pass through these filters.

Ultrafiltration – utilizes membranes with pore sizes of approximately 1.0 to 20 nm, which are larger than pores of nanofiltration systems. No dissolved salts (fertilizer) will be removed with this system. However, ultrafiltration will still remove suspended clay and pathogens such as bacteria, nematodes and most fungal spores and some viruses. However, some smaller viruses will not be removed. Therefore, it may be necessary to do addition sanitation treatments to the water.

Microfiltration – utilizes membranes with pore sizes of approximately 100 to 10,000 nm (0.0002 to 0.0100 mm). While this filtration system requires the least amount of energy

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to pass water through the membranes, it also does not screen out most pathogens; therefore, additional sanitation treatments will be required. This process is sometimes used before the RO process.

Table 1. Physical characteristics, cost of operation, and advantages and disadvantages of four types of membrane-mediated filtration systems. One Dalton = 1 atomic mass unit (amu)

Membrane type	Approximate filtration pore size	Relative Cost	Advantages	Disadvantages
Reverse Osmosis	0.1 nm	High	*removes charged ions *removes compounds ≥ 250 amu *almost essentially all pathogens	*removes dissolved fertilizer
Nanofiltration	1.0 nm	Moderate	*removes some charged ions. *removes compounds ≥200-1000 amu *removes essentially all pathogens	*may remove some chelates
Ultrafiltration	1- 20 nm	Low	*removes bacteria *fungal spores *removes nematodes	*virus may not be removed
Microfiltration	100 to 10,000 nm	Lowest	*requires least amount of energy	*many pathogens will not be removed

Table 2. Relative sizes of water and fertilizer molecules and some common pathogens sometimes found in irrigation water. Sizes of pathogens are ranges, since there are many types of viruses, bacterial and fungi. Please note that there is no correlation between weight and size, since some organism may be denser (heavier) than other organisms or chemicals of the same size.

Organism/particle	Weight (Daltons)[z]	Size (nm)
Water molecule	18	0.20 nm
Iron-EDTA chelate	526	NA
virus	7,000,000	20 to 200nm
E. coli	Over 3,000,000,000	2000 nm
Fungal spores	NA	2000 to 5,000 nm
nematodes	NA	300,000 nm and larger

[z]A dalton is equal to 1 atomic mass unit (amu).

Maintenance.
*Flushing -All membrane systems will require periodic flushing of membranes, the frequency of which is dependent on the cleanliness and the volume of water being treated during a given time period.
*Concentrate Disposal – The residues collected will need to be disposed of, the method of which will depend on regulations in your region.
*Membrane replacement – Membranes will need to be replaced after a given period of usage

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