rigate 85% more plants. The reduction in output is a saving in applied water costs, and also a reduction in the amount of run-off which needs to be dealt with. The new pump and controller allow more flexibility in planning irrigation. A pressure sensor and auto switch allow irrigation water to be used for hand hoses and tractor filling points, rather than more expensive "town water." Temperature sensors allow for automatic cooling in heat waves, and frost protection in winter.

We have learnt that making savings in water use requires an approach beyond just designing a new irrigation system. The lower output heads of the new system are more prone to wind drift, and on particularly windy days, the distribution pattern still lacks excellent coverage. As yet, hand watering of dry spots is still required, though on calm days is much reduced.

Overall, saving water is a complex process of planning and requires an integrated approach to design and the requirements of the crops being produced.

Water Disinfecting Techniques for Plant Pathogen Control©

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Water for irrigation is becoming harder to get and more expensive. In addition, the environmental performance of industries, including nursery production, is under public scrutiny. Water recycling addresses these issues but introduces challenges to embrace technologies and procedures to ensure plant-safe water reuse. The provision of disease-free water is part of this challenge.

INTRODUCTION

Many water sources for plant production need some form of treatment before the water can be reliably used for irrigation. Water treatment includes avoiding algal blooms, preventing precipitation of solid particles, controlling iron, and water disinfestation.

Water disinfestation is a treatment to reduce the risk of introducing disease via irrigation water and to control bacterial growth in the system. Many disease-causing organisms are easily transported in irrigation water from diseased plants to healthy ones. For example, *Fusarium* and the root rot causing fungi, such as *Phytophthora*, are readily spread.

PRETREATMENT

There are a number of disinfestation techniques available and their effectiveness is affected by different aspects of water quality. Disinfestation will be a lot easier, effective, and generally cheaper if the water is "clean" before treatment. It is a good idea to pretreat the water so that it is free of heavy sediments, floating material, fine colloidal clays, and organic matter. Beardsell and Bankier (1996) provide further detail on monitoring and treatment of recycled water for nursery production.

Heavy Sediments (Sands and Gravel). These can be removed in a sediment trap at the end of open drains. Water passes through a pool and the velocity that is carrying the sand and gravel along is reduced. This makes the sediments fall to the bottom of the pool. The trap needs regular cleaning to remain effective.

Floating Material. This can be removed at the collection point of run-off from any media storage areas, at the car park, and at the end of the drains from production areas. A simple baffle system removes media, oils, polystyrene, plastic, and plant material. It needs to be cleaned regularly.

Removing Clay Particles. This can be achieved with a flocculating agent like alum (aluminium sulphate) to clarify the water, preferably in a tank rather than a dam. Better still, avoid the problem in the first place and keep clay colloids out — seal catchments that collect recycling water and keep dam catchments well grassed.

Organic Matter. Organic matter can be removed by filtration. The best filters to use are media filters with 1-mm crushed basalt. This material is very angular and hooks organic matter effectively. Disc filters can also be used but must be fitted with at least 60-micron openings.

DISINFESTATION TREATMENTS

Water sources can be disinfested using nonchemical methods such as heat, ultraviolet radiation, and filtration or chemical treatments such as chlorine, chlorobromine, chlorine dioxide, and ozone.

NONCHEMICAL DISINFESTATION

Heat Disinfestation. This is effective in killing waterborne pathogens. Water is collected in a tank after being filtered and is then pumped into the first of two heat exchangers. The water is preheated here using the heat lost as the disinfested water that has already been through the system cools. Next the water is pumped to a second heat exchanger. The disinfested water is then stored in a separate tank until needed.

One gigajoule of gas in the second heat exchanger provides enough energy to treat about 10,000 litres of water. Gas prices vary widely within Australia. You will need to check prices locally before contemplating heat as a disinfestation system.

Micro-filtration. Filtration of water through very fine filters almost completely eliminates *Phytophthora* and most other waterborne pathogens, but, because the filter pores get clogged, this system needs regular maintenance. Recent technology improvements have increased the filter life to the point where they are now more cost competitive than just a few years ago.

Ultraviolet Radiation. Ultraviolet radiation (UV) is widely used in disinfecting drinking water. Mebalds et al. (1996) found that UV radiation is also an effective and environmentally friendly treatment for controlling *P. cinnamomi, F. oxysporum,* and *Alternaria zinniae*.

However, the water requires greater than 60% UV transmission after filtration. Have your water tested for turbidity before considering this method, as the water has to be free from suspended particles and tannins (iron and manganese ions absorb UV light, as do coloured chelates). A survey found that very few growers had water sources with UV transmission rates over 60%. Filtering generally does not greatly improve UV transmission of water, but it is a key element in UV treatment as it is needed to remove solids that may protect fungal spores from radiation.

Slow Sand Filtration. Slow sand filtration passes water slowly through a medium (sand or manufactured volcanic rock fibres) and microorganisms, living in the filter, kill pathogenic bacteria and fungi. Soon after the filter process begins, a skin forms on the surface of the filter bed. It is made up of organic and inorganic material and a wide range of biologically active microorganisms that breakdown organic matter.

Gail Barth (1998) found that irrigation water with a high algal or silt content needed pre-filtering prior to slow sand filtration. In terms of effectiveness, Barth (1998) recommends a layer of 100 mm of water be maintained over the filter surface and that this layer of water be constantly circulated with the use of a small pump from the overflow tank or from the filtered reservoir.

CHEMICAL DISINFESTATION

Chlorination. Chlorination is the most widely used disinfectant in the ornamental industry. One of chlorine's biggest advantages is its ability to provide a stable residual that helps clean slimes out of the irrigation system as well as benches and paths. If chlorine is to be effective in controlling the spread of pathogens, it is essential to accurately control both the free chlorine content and the pH. Chlorination is unsuitable if the pH of water is above 7.5. Unfortunately a survey of recycled water in Australian nurseries has shown that its pH is often above 7.5, so acidification prior to chlorination is necessary.

Chlorine comes in a gas, liquid, or powder form. Current safety requirements preclude gas. Liquid (sodium hypochlorite) is more convenient for accurate dosing than powder. Check the free chlorine percentage of your sodium hypochlorite, as it varies in different states of Australia. A metering pump is used to accurately supply the desired concentration of residual free chlorine. These pumps can be used to adjust the chlorine rate to meet the range of water quality variation throughout the season.

When using chemical solutions in an irrigation system on town water, a suitable backflow device is required to stop reversed flow to the water service.

Chlorobromination. Bromine has a similar action as chlorine in disinfesting water. Just as chlorine needs to form hypochlorous acid, so too, bromine needs to be formed into hypobromous acid to be active. This is best done by adding sodium bromide to sodium hypochlorite. Thus chlorobromination provides two oxidising agents, hypobromous acid and hypochlorous acid.

Hypobromous acid is a very effective disinfestant over a wide pH range. At pH 8.5, 60% of bromine is still present as hypobromous acid whereas with chlorine very little hypochlorous acid remains at pH 8.5. Recycled water commonly used in horticulture contains various and fluctuating levels of ammonium and other nitrogen-based compounds. Both bromine and chlorine react with these compounds to form bromamines and chloramines. Chloramines are poor biocides, while bromamines show disinfestation properties comparable to free bromine which means less chemical should be required when using bromine.

Chlorine Dioxide. Chlorine dioxide is a greenish-yellow gas that is relatively unstable and cannot be stored or transported. For this reason it is formed on-site by combining hydrochloric acid with sodium chlorite. Chlorine dioxide concentrations are also affected by impurities in the water, and sensors need to be installed to adjust the generator output to maintain the required concentration.

Despite its complexity and high capital cost, chlorine dioxide has advantages. The material is a potent oxidant with rapid contact time kill rates at a low concentration and will work in water with pH as high as 10.

Ozone. Ozone is an unstable gas that occurs naturally in the earth's upper atmosphere. Passing dry air or oxygen through a high-energy electric field produces ozone. The oxidation potential of ozone is about twice that of chlorine and it reacts more rapidly and is less affected by pH and temperature. Ozone can control algae, oxidise manganese and ferrous ions, and many agricultural chemicals including some herbicides. It coagulates natural water constituents, which improves filtration.

Ozone does not produce environmentally unfriendly by-products as chlorine and bromine do. However it has a number of disadvantages. For example, it is expensive and it is difficult to measure the "residual" since it breaks down quickly.

Special consideration must be given to the materials in contact with ozone as it quickly corrodes brass, rubber, and many plastics. Stainless steel is suitable, as are silicon "O" rings. The major disadvantage is its cost. It is a highly unstable gas and must be generated on site, an expensive process. Mebald et al. (1996) has more information on the use of ozone and chlorine dioxide for disinfestation.

TIPS FOR SUCCESSFUL DISINFESTATION

- Know the quality of the water you are treating. This can change constantly.
- Before choosing a water disinfestation strategy you should do a complete analysis of water quality over an extended period (say 12 months), as seasonal variation can be substantial.
- Whatever disinfestation system you select, pre-treatment has a big bearing on its success.
- Chemical systems need monitoring to ensure the right dose is available.
- It may be necessary to install automatic pH adjustment equipment in the system, as most recycled water has a high pH, which is unsuitable for many disinfestation systems.
- If you are adding nutrients to your water, wait 30 min after treatment before injection.
- Where frequent backflushing of the filter is required, automation may be desirable (adapted from Rolfe et al., 2000).

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