MICROIRRIGATION

Robert G. Evans
Supervisory Agricultural Engineer
USDA-ARS-NPARL
Sidney, MT 59270

Drip irrigation, also called trickle irrigation, bubblers and localized small microsprinklers, microspinners and microsprayers are collectively referred to as microirrigation. Microirrigation includes any localized irrigation method that slowly and frequently provides water directly to the plant root zone. The slow rate of water application at discrete locations with associated low pressure and the irrigation of only a portion of the soil volume in the field can result in relatively low cost water delivery systems, as well as reductions in water diversions compared to other irrigation methods. Drippers and bubblers are designed to apply water at atmospheric pressure, whereas microsprinklers apply water from about 50 to more than 250 kPa.

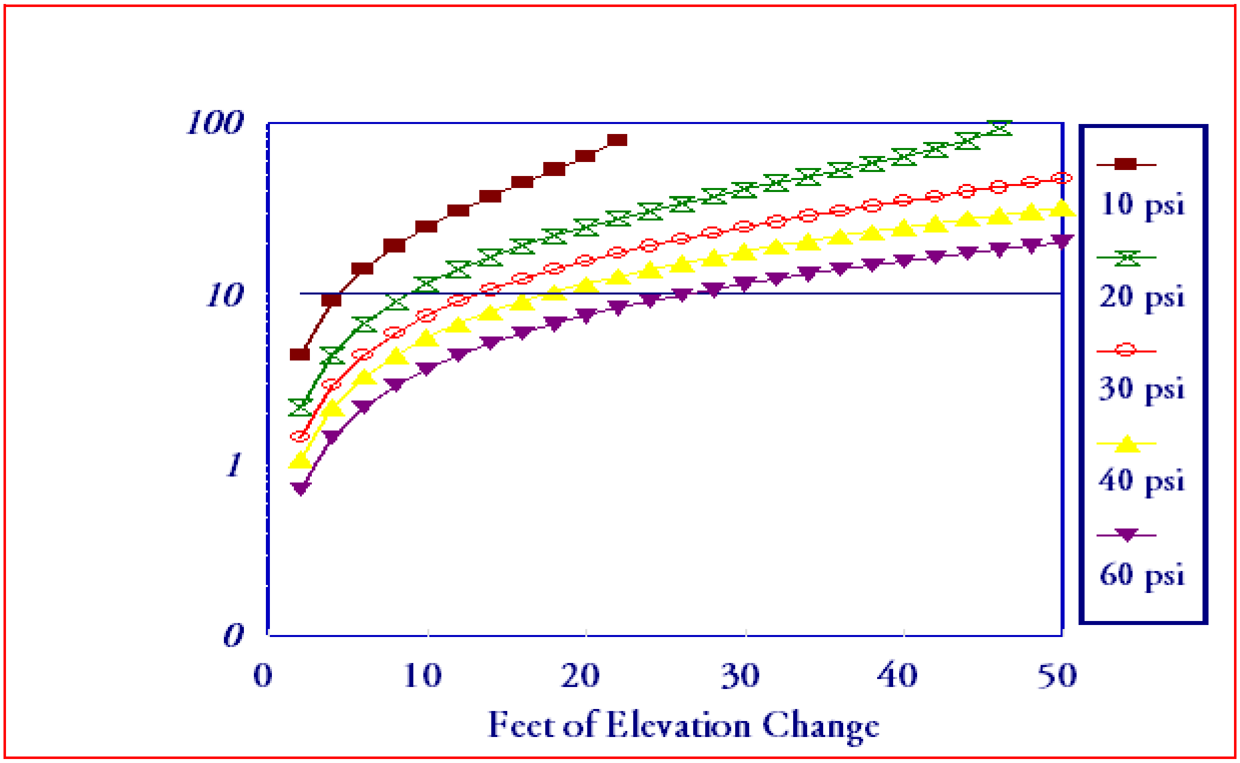
Microirrigation has the potential for precise, high level management and is an extremely flexible irrigation method to design. It can be adapted to almost any cropping situation and climatic zone. Microirrigation can be used over a wide range of terrain conditions, and it has allowed expansion of irrigated crop production into areas with problems soils (either very low or very high infiltration rates) and poor water quality that could not be used with other irrigation methods. It can be installed as either a surface or subsurface water application system.

Microirrigation can be used on most agricultural crops, although it is most often used with high value speciality crops such as vegetables, ornamentals, vines, berries, olives, avocados, nuts, fruit crops and greenhouse plants. In many cases, it can also be economically used for field crops, golf greens, fairways, cotton and sugarcane. However, the requirements for appropriate designs and management in humid areas can be considerably different from those in arid areas, and the technology and techniques suitable in one area may not work in another. Microirrigation will not be the most appropriate irrigation method in all situations.

The use of microirrigation is rapidly increasing around the world, and it is expected to continue to be a viable irrigation method for agricultural production in the foreseeable future. With increasing demands on limited water resources and the need to minimize environmental consequences of irrigation, microirrigation technology will undoubtably play an even more important role in the future. Microirrigation provides many unique agronomic and water and energy conservation benefits that address many of the challenges facing irrigated agriculture, now and in the future. Farmers and other microirrigation users are continually seeking new applications, such as waste water reuse, that will continue to provide new challenges for designers and irrigation managers.

Any irrigation system must be compatible with cultural operations associated with a specific crop. Adoption of microirrigation may require new or innovative adaptions to various cultural practices and even the development of new harvest and tillage equipment. For example, surface lateral lines can hinder traditional harvest operations, requiring pre-harvest removal of the tubing or development of a new harvester and harvesting techniques. Lateral lines can also be buried but this generally requires moving to minimal-tillage or permanent bed systems for perennial crops.

An in-depth understanding of the unique benefits and limitations of microirrigation systems is needed to successfully design and manage these systems. As with all other irrigation methods, there are definite tradeoffs with both positive and negative impacts on irrigation scheduling, efficiency, uniformity, ecology, crop responses and economics.



Plugging of Microirrigation Systems

Partial or total plugging of emitters is a chronic problem and the most serious constraint to the long-term operation of any microirrigation system. Inadequate consideration of the physical, biological and chemical characteristics of the water supply will result in serious plugging problems. The most critical design factors affecting plugging are: 1) emitter design; 2) filtration; and, 3) the chemical water treatment system. System operation and maintenance including inadequate flushing of pipelines will also have major effects on microirrigation plugging problems. However, the importance of proper emitter selection to avoid particulate accumulations cannot be overemphasized.

Causes of Plugging

Plugging of microirrigation systems may occur from single or multiple factors. Physical factors such as suspended colloidal clays, silts and other materials passing through filters, broken pipes, root intrusion and aspiration of soil particles into the emitter orifices are common physical causes of plugging. Chemical factors such as precipitation of carbonates and iron oxides, and precipitates from chemical injections are significant causes of emitter plugging. Likewise, organic and biological factors such as oils, algae, aquatic weeds, insects, fish, frogs, insects, spiders, fungi and bacteria can be major contributors. Low system pressures and flow rates may also exacerbate plugging problems. Table 1 presents a listing of relative problems associated with various water quality parameters.

Sediment. Routine flushing of pipelines is required to prevent emitter plugging from the gradual accumulation of particles which are too small to be filtered, but which settle out or flocculate at the distal ends of pipelines. Flushing velocities must be high enough (at least 0.6 m/sec) to transport and discharge heavy particulate matter from the pipelines. Flushing should be more frequent when large amounts of debris are present, while less frequent flushing may be adequate if only small amounts of debris are flushed. Applying surfactants or dispersing agents such as sodium hexametaphosphate through the microirrigation system may reduce some plugging problems by preventing the flocculation of silts and colloidal clays, allowing them to easily pass through the emitters or flushed from pipelines.

Automated flush valves are sometimes used as at the ends of the laterals to help flush fine particulates at the start of every irrigation, however, periodic manual flushing is still required. Use of these valves is not recommended since they tend to leak and waste water, requiring extra maintenance.

Algae and Bacterial Slimes. Chlorine injection is the most common and least expensive method to prevent clogging by biological growth (algae, colonial protozoa, sulfur bacteria, and other mucous organisms). Iron and manganese precipitating bacteria can be controlled by chlorine treatments, aeration or polyphosphates.

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Copper sulfate, chlorine, and organosulfur compounds are used to control algae and bacterial slimes in ponds or canals. The degree of control will vary with light and water temperature conditions. Some chemicals such as quaternary ammonium are effective when algal growth is slow to moderate, but will fail under rapid growth conditions.

Soil bacteria can sometimes be aspirated back into an emitter and produce slimes that glue small particles together and plug the orifices. These have been fairly successfully, but expensively, removed by strong solutions of hydrofluoric acid (1000 ppm) combined with a surfactant (Wuertz, 1992).

Table 1. Relative problems posed by various water quality parameters for microirrigation (Nakayama and Bucks, 1986)

Problem	Hazard Level		
	Low	Medium	High
PHYSICAL			
Suspended Solids	< 50 ppm	50 - 100 ppm	> 100 ppm
CHEMICAL			
pH	5.5- 7.0	7.0-8.0	> 8.0
Salt	< 500 ppm	500-2000 ppm	> 2000 ppm
Bicarbonate		< 100 ppm	
Manganese	< 0.1 ppm	0.1 - 1.5 ppm	> 1.5 ppm
Total Iron	< 0.2 ppm	0.2 - 1.5 ppm	> 1.5 ppm
Hyd. Sulfide	< 0.2 ppm	0.2 - 2.0 ppm	> 2.0 ppm
BIOLOGICAL			
Bacterial Pop.	< 10K / L	10K - 50K / L	> 50K / L

Chemical Plugging. Chemical precipitates can cause plugging of irrigation systems (Nakayama and Bucks, 1986; Hills et al., 1989, Burt and Styles, 1994; Burt et al., 1995). Precipitates of iron oxides, iron sulfides, calcium carbonates, and manganese oxides in irrigation water can clog emitters. These problems are most commonly found when using ground water supply systems, but not always. Changes in water pH, temperature, pressure, dissolved oxygen, chlorination and other chemical injections can induce chemical precipitations. Calcium precipitates are white, iron oxides are reddish-brown whereas manganese oxides and iron sulfides are dark-blackish colored materials.

Concentrations of 0.15-0.22 mg/l of iron (≥ 2 ppm) in irrigation water may be problematic when water pH exceeds 5. Manganese oxides greater than 2 ppm will need treatment if water pH is 9 or greater. Chlorine injection will cause oxidation and precipitation of iron and manganese (plus kill any iron and sulfur precipitating bacteria that are present). The general recommendations are to inject 1 ppm of free chlorine/0.7 ppm soluble iron or 1.33 ppm free chlorine per ppm soluble manganese before the filtration system. Calcium and magnesium problems are best addressed by the injection of acids to maintain a water pH between 6.0 and 6.6. Temporary storage or aeration of water is a recommended pretreatment for elevated levels of iron and manganese to facilitate oxidation and precipitation before entering the irrigation system.

Plugging by other chemical precipitates can often be reduced by acid treatment to lower pH and prevent precipitates from forming, avoiding the injection of insoluble fertilizers or incompatible fertilizer/chemical mixes, and regular flushing of lines. Sometimes it is possible to avoid precipitation problems by carefully injecting various incompatible chemicals at different locations in a mainline so that they are sufficiently diluted and mixed before the next chemical is injected. For example, injection points of acid and chlorine should be a minimum of 3 ft apart.

Chemigation

Chemigation is required for sustainable operation of microirrigation and includes the injection of chlorine, nutrients, pesticides and pipeline and emitter cleaning agents. The use of chemicals through microirrigation systems requires an in-depth understanding of the water and soil chemistry of each field and a clear idea of the objectives. A more detailed discussion of general design and management considerations for chemigation is presented in other publications.

Microirrigation inherently offers tremendous benefits for chemical injection and applications. Consistent soil water contents and wetted soil volumes tend to increase plant uptake efficacy of many chemicals. Water soluble nutrients can be injected to closely match crop requirements, increase nutrient use efficiencies, and reduce costs. Systemic pesticides and some soil fumigants may be injected with high efficacy, if labeled.

The first rule of chemigation is safety. Special chemigation safety devices, check valves and air relief valves are required for all chemical injection systems under federal and state regulations. Well heads must be protected from reverse flows, system drainage or back siphoning. Electric and hydraulic interlocks with time delays must be installed between the injectors and irrigation pumps to prevent chemical injection when the irrigation system is not operating.

Chemical injection areas should always be securely fenced with appropriate containment facilities in the event of a spill. Special protective equipment, safety showers and any required chemical neutralizing agents should be readily accessible and clearly marked. Personnel must be specifically trained and, in many areas, licensed for chemical applications. Injection of any pesticide into an irrigation system must be specifically permitted by the pesticide label and may also be subjected to additional state regulations. Detailed records of all chemical applications need to be maintained for safety, evaluation, legal and regulatory requirements.

All chemicals and chemical-water mixtures must be checked to avoid phytotoxic effects before any injection occurs. In addition, it is critical that all the chemicals being injected at one time are compatible with each other and the water chemistry and concentration limits are not exceeded so that precipitates do not form and plug emitters. Some chemical combinations such as calcium nitrate and phosphoric acid will immediately form a precipitate creating a severe plugging situation. Emulsifiable pesticide concentrates and wetable powders may require special design and management considerations (e.g., mechanical supply tank agitation) to help ensure uniform applications and reduce plugging. Water acidification to lower pH may sometimes be required prior to injection of a chemcial. Precipitation tests should be conducted at the same dilutions, pH and other conditions that the chemicals will be applied.

All chemical injections should be filtered. Injection should occur after the pump and before the media or final screen filters to trap any undissolved material. Injection installations should always provide for complete mixing and uniform concentrations before the chemicals reach the field. Materials should be injected into the center of the water flow to ensure quick dilution to reduce deterioration of the filter tanks, piping, valving or other components. Generally, injection rates should not exceed 0.1% of the system water flow rate although concentration limits (chlorine) and label requirements for pesticides are usually less.

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All system components must be able to withstand the effects of corrosion from injected basic and acidic chemicals at the expected concentrations at each location. Consult material compatibility tables and match materials with the chemicals. For example, concentrated sulfuric acid is not compatible with PVC tubing and will quickly create a hazardous situation, but PVC is acceptable when the acid is greatly diluted. As a general rule, uncoated metallic components (except specific stainless steels) should be used as little as possible.

The use of positive displacement pumps is recommended for liquid chemcial injections. The pumps should be adjustable and able to inject any water soluble chemical at low concentration levels (e.g., 1 - 100 ppm). The use of an in-line mixing chamber after injection is recommended. A flow meter or other flow detection device can be connected to a controller that is programed to inject a specified amount of chemcial from a nurse tank into the irrigation system at specific times. Injection rates with orifice or venturi type injectors are very sensitive to system hydraulic pressure changes and should be carefully monitored and system pressures rigidly controlled.

Fertilizers and other agrichemicals (except chlorine) should never be left in the pipeline when the system is not operating. Pesticide and fertilizer injections should be made in small, frequent doses that fit within scheduled irrigation intervals that match plant water use to avoid unnecessary leaching. Likewise, excess water applications for leaching soil salts should never be done when chemicals (except chlorine) are being injected.

The general “one-fourth” rule-of-thumb is that chemigation should start after one-fourth of the irrigation set time, injection should occur during the middle two-fourths, and the lines flushed with clean water during the last one-fourth of an irrigation event.

There are numerous products being promoted as universal line or emitter cleaners, biocides and fertilizers. These products should be used only if these claims can be proven with unbiased, high quality research. Many of these materials are costly, only treat symptoms without addressing the underlying problems and eventually fail.

Chlorination

The most common chemical injected into microirrigation systems is chlorine because it is a very effective and cost efficient biocide. Injection of chlorine, ozone or the other strong general biocide are required to eliminate algae and microbial problems. It should always be part of the water treatment program on all microirrigation systems regardless of the water source since lines can be easily contaminated during installation, through emitter orifices or line breaks.

Most chlorination programs inject during every irrigation event, generally at the end of the irrigation cycle. Periodic “shock treatments using high dose rates on a weekly basis are also effective. It is important to inject chlorine upstream from the filters to remove any undisolved or precipitated material and to prevent algae and other organisms from plugging the filtration surfaces or pores.

Chlorine activity increases exponentially with decreasing pH with optimal values are between 5.5 and 6.0, often requiring simultaneous injection of acids. However, a pH of about 6.5 is generally preferred for fertilizers and other chemicals. In these cases, chlorine is injected downstream from acids after the water pH has been lowered. Chemical compatibility and production of harmful gases can be a concern if chlorine is injected simultaneously with some pesticides and fertilizers, even at low rates. Chlorine may also inhibit the activity of some agrichemicals. Separate injection points and pumps should be used if it is necessary to simultaneously inject chlorine with other chemicals including acids.

Chlorine is available in several forms. Gas chlorinators provide a lower cost per unit of chlorine than liquid or solid forms, and are commonly used with larger (e.g., >5 ha) microirrigation systems. However, chlorine gas is extremely dangerous and experienced commercial firms should be used to fill chlorine supply tanks, adjust injectors, and fix leaks. Only the highest quality gas regulators should be used. Local regulations may require fencing, automatic leak detectors with alarms, high quality regulators, and safety equipment including gas masks. Never locate gas chlorinators in enclosed buildings or near houses and livestock containment areas. These installations should always be located in open areas where any gas leaks can readily dissipate into the atmosphere.

Liquid forms of chlorine are also common. Usually a ten to fourteen percent solution of sodium hypochlorite ($NaOCl$) is used, which is a more concentrated form of common household laundry bleach. The material is quite corrosive and is injected into an irrigation system in the same manner as a liquid fertilizer. Self-dissolving sodium hypochlorate pellets are sometimes used in small microirrigation systems. Calcium hypochlorite is commonly available in granular form for treating swimming pools, however, its use can lead to calcium precipitate plugging problems and is rarely used in microirrigation systems.

Free residual chlorine, also referred to as unassociated chlorine, at concentrations of about 1 ppm for at least 30 minutes is usually sufficient to kill most bacteria and algae. Chlorine tends to associate with sulfides, iron bacteria, slime bacteria and other water constituents, so enough must be injected into the system to meet the required reactions and still leave a residual of at least 1 ppm free chlorine at the distal ends of the lateral lines. Use free residual chlorine (D.P.D.) test kits, which are carried by many irrigation equipment and swimming pool suppliers, or special specific ion probes to monitor microirrigation systems.

Chlorine Injection Rate Calculation

Gas: lbs/day = 0.012 x ppm x gpm

Liquid: lbs/day = 0.006 x ppm x gpm / $\%Cl_2$

ppm is targeted value of chlorine in the system in parts per million, gpm is total system flow rate in gallons per minute, and $\%Cl_2$ is the % concentration of chlorine in the solution (usually around 12%).

Continuous chlorination at low rates providing 1 to 2 ppm of free residual chlorine through the whole irrigation event is recommended where plugging potentials are high. Intermittent treatments (e.g., every 4-10 days) consisting of an 8 to 20 ppm pulse of free residual chlorine should be injected over a period of 30 to 60 minutes at the end of an irrigation event so that all lines contain chlorine when shutoff. Superchlorination shock treatments as high as 50 to 500 ppm may sometimes be required to control some algae, bacterial or root intrusion problems, and should always be followed by a thorough flushing of the mains, submains and laterals. Automation should be considered when farm personnel lack the specific skills needed to safely monitor and reliably chlorinate.

pH Control

When irrigation water has a pH of 7.5 or higher, the potential for calcium carbonate precipitation is high. Acidifying compounds are commonly used to maintain a water pH around 6.6 to keep carbonates in solution, reduce bicarbonate levels and to improve chlorine activity. Acidification may also be required to lower water pH to prevent mineral precipitation from some fertilizers. In addition, various acids are often injected to clean deposits from pipelines and emitters.

Acidifying agents must be well mixed and diluted before contacting valves and other system components. Acids should be injected before injection of chlorine, fertilizers and other chemicals using separate injection ports and pumps.

Bicarbonate levels of 100 ppm or higher in the irrigation water may cause plugging, especially when injecting fertilizers such as calcium nitrate. If combined levels of calcium and magnesium are higher than 50 ppm, calcium phosphates could precipitate. Magnesium can combine with ammonium fertilizers to create a magnesium-ammonium phosphate precipitate. Acidifying the water to at least 6.6 is usually sufficient to prevent such phenomena. However, if the volume of injected acid exceeds about 0.2% of the system capacity for reducing bicarbonates, it may be more practical to aerate the water in a small holding reservoir until precipitates have formed and settled to the bottom.

Water acidification may lower the pH of soils with low buffering capacities, especially when acidifying fertilizers are also used. Some crops are sensitive to low pH and the soils may require remedial measures when using this practice. The pH of the water should not be below 4.5 for extended periods because of possible damage to system components, although it is sometimes necessary to use water with a pH of about 3 for 6 to 8 hours to remove carbonates from partially plugged emitters.

Sulfuric acid is a commonly used acidifier that must be used with proper equipment and precautions. Spent sulfuric acid from copper and other metal refining activities is an inexpensive acidification source, but it often contain traces of heavy metals and its use is not recommended.

A mixture that is sometimes used as an acidifying agent is a combination of urea and sulfuric acid (e.g., 52-54% acid) that is safer to use than pure acids. It also serves as a fertilizer source but its sole use for pH control often exceeds annual crop nitrogen requirements. New and possibly less expensive compounds are on the horizon to control carbonate solubility such as polyphosphates, organo-phosphates, and organic polymalaic acids. These polymers may be mixed with detergents but do not persist in the environment. They are safer to handle than sulfuric or hydrochloric acids, but should be throughly tested for rates, effectiveness and their affect on infiltration and soil sodicity under specific water quality conditions before use.

Fertigation

Fertigation through microirrigation systems is very effective in both arid and humid areas where nutrients and other salts are leached to the perimeter of the wetted zone. Thus, crops almost always respond well to fertigation with microirrigation systems, especially on sandy soils with low cation exchange capacities. Fertilizer applied by conventional methods may be unavailable to microirrigated crops in arid areas unless it is placed within the irrigated zone. Irrigation scheduling programs should always accompany a microirrigation fertigation approaches to balance water and crop needs.

A complete discussion of fertigation managment and design is beyond the scope of this paper, however, some excellent references exist, such as Burt et al. (1995) and Doerge et al. (1991). Fertigators should carefully study these materials and information provided by the fertilizer providors, have their water chemistry analyzed, and consult with knowledgeable persons prior to injecting any fertilizers into a microirrigation system.

Since only a small percentage of the root zone is wetted, combining low volume irrigation and fertigation affects soil water and nutrient distributions and consequently root development. Acidification of some soils may be a problem with acid based fertilizers, and alternatives such as calcium nitrate should be considered. A balanced fertilization program may require supplemental foliar applications of micro nutrients.

Soil sampling for nutrient monitoring will be complicated by long term fertigation programs which will cause large spatial variability in chemical concentrations. Soils data should be complemented with periodic nutrient analyses of leaves or other plant parts. It is important to follow consistent sampling procedures and maintain long term records.

As a rule, never inject any chemical (e.g., anhydrous ammonia or aqua ammonia) into a microirrigation systems that could raise the pH of the water without pre-acidification to counteract the effect. These chemicals can cause mineral precipitates if the water pH is greater than 7.5 and calcium and/or magnesium bicarbonates are present. In addition, these fertilizers are subject to volitization which decreases efficacy.

Phosphorous attaches to soil particles and moves only slowly, but its most likely to move under high soil water regimes common to microirrigation. Phosphate fertilizers often cause precipitates and present a major emitter plugging risk, especially with high pH water with elevated calcium and magnesium levels. Phosphorous fertilizers should be injected only when the water pH is less than 6.6.

Phosphoric acid can be intermittently injected into microirrigation systems to lower pH. It also serves as a fertilizer source for phosphorous. Continuous injection of phosphoric acid at 15 ppm-P can also help minimize root intrusion on subsurface systems, but should be done in combination with a good chlorine/biocide program. Phosphoric acid is not a biocide. However, the amount of phosphoric acid required to lower the irrigation water pH to acceptable levels over a growing season often exceeds the crop's annual requirement for P.

Some micro-nutrients such as boron should be injected with great care using multiple small applications through a microirrigation system because a minor mistake or malfunction could result in acute toxicity to the plants. Over-application of some micronutrients may change solubility limits and cause problems with availability of other micronutrients (e.g., excess iron can induce manganese deficiency).