Chemigation
in the Pacific Northwest

A Pacific Northwest Extension Publication

Contents

Chemigation in the Pacific Northwest

W.L. Trimmer, T.W. Ley, G. Clough, and D. Larsen

Injecting agricultural chemicals such as fertilizers, herbicides, and insecticides into an irrigation system is commonly called *chemigation*. The use of chemigation has increased rapidly during the past few years; an estimated 12.8 million acres (5.2 million hectares) in the United States were chemigated during 1985.

Other names such as *fertigation, herbigation, insectigation, fungigation,* and *nemagation* (see "Glossary," page 21), are used to describe injection of specific chemicals. Chemigation can be an effective application method if the chemical is suited for this method of application and if the irrigation system is properly designed and operated.

This publication describes the specialized equipment, specific application conditions, accurate calibration, proper management, and safety precautions required for chemigation. Some legal aspects of chemigation such as pesticide registration are covered as well.

This publication covers only chemigation systems not connected to public drinking water supplies. All recommendations in this publication are advisory—be sure to follow *your* State's regulations. Some states require certification of chemigation operators.

Reasons for chemigation include:

- relatively uniform chemical distribution,
- flexible timing of chemical applications,
- possible economic advantage compared to other application methods,
- potential to use fewer chemicals, and
- less crop damage than with ground-applied chemicals.

The primary concern about using chemigation has been the possibility of contaminating groundwater and surface water if:

- injected chemicals flow back into the water source because of mechanical failure or power loss in the irrigation system;
- water backflows through the chemical injection system and overflows the chemical supply tank;
- there's back flow in the irrigation system after the pumping plant shuts down, creating a vacuum in the pipeline that might cause siphoning of the chemical from the chemical supply tank; and
- the chemical injection system continues to operate after a shutdown of the irrigation pumping plant, pumping the remaining chemical solution into the irrigation pipeline, where it can flow back into the water supply.

Additional pollution potential exists when the water-chemical mixture drifts and/or runs off onto nontargeted areas or when the water-chemical mixture is applied to open surface water areas within the field. Some states require that you report to the authorities any accidental chemical spillage.

The relative cost of chemigation compared with the cost of aerial or ground application depends on your answers to these questions:

1. Is the irrigation system is already in place?
2. Do you need to apply water anyway?
3. How many times will you chemigate each year?

Past analyses indicate that for just one application a year, chemigation is likely to be cost-effective only for chemicals that require incorporation. With two or more applications a year, however, chemigation is cost-effective.

Costs range from only a third to a half as much as aircraft or tractor applications and decrease significantly as the number of annual applications increases.

With the increased flexibility and lower costs, irrigators can change management practices and apply lighter applications of fertilizers more often.

Because of this, applying nitrogen fertilizer with the irrigation water, while using proper water management practices, is sometimes considered the best management practice to reduce the potential for nitrate leaching into ground water.

Without correct timing and amounts of irrigation, nitrogen application with the irrigation water may result in considerable leaching of nitrates into the groundwater.

Chemicals

Many different chemicals can be injected into irrigation systems, and each must be handled according to its intended use, physical properties, and the legal requirements associated with it. The three broad classes of chemicals we'll discuss are fertilizers, pesticides, and chemicals to disinfect irrigation systems.

Walter L. Trimmer, Extension irrigation specialist, Oregon State University; *Thomas W. Ley,* Extension irrigation engineer, Washington State University; *George Clough,* horticulturist, Hermiston Agricultural Research and Extension Center, Oregon State University; and *Dorrell Larsen,* Extension professor emeritus, University of Idaho.

Chemicals have physical characteristics that dictate the chemigation methods required. Chemicals can be soluble, wettable powders, oil-soluble, or gaseous. (The solubility of a few common chemicals is shown in appendix 1.)

Soluble chemicals

Soluble chemicals, those that can dissolve in water, are the easiest to handle and use. (See appendix 1.)

Whether a chemical is soluble depends on its physical properties, water temperature, and the irrigation water quality. For example, 9.8 lb of ammonium nitrate will dissolve in a gallon of water at 0C, but 72.6 lb will dissolve in a gallon at 100C.

The irrigation water's ability to dissolve a chemical can be limited by the acidity or alkalinity (pH) and dissolved solids such as sodium, calcium, magnesium, nitrates, and carbonates.

Injecting a chemical can change the pH of the water. Raising the pH (making it more alkaline) with such chemicals as anhydrous and aqueous ammonia and phosphorus can precipitate calcium and magnesium salts, plugging irrigation systems.

Changes in pH can be countered by injecting acid or caustics. If 300 lb of ammonium nitrate are dissolved in water, 185 lb of calcium carbonate must be added to neutralize the acidity. Water with a pH lower than 6.5 can cause corrosion. Injecting more than one chemical can produce chemical reactions that form nonsoluble products.

Wettable powders

These are insoluble, but they can stay in suspension with agitation in the chemical supply tank and maintain a relatively uniform concentration when you inject them.

Oil-soluble chemicals

Oil-soluble chemicals require special handling because of their flammability. In addition, you must carefully inject oil-chemical mixtures to ensure the mixture is well dispersed. Even when properly injected, oil-chemical mixtures tend to separate in the irrigation system.

Past research has found that this separation means the chemical isn't evenly divided as it travels past the first outlets in the system.

Applying nitrogen

Applying nitrogen through irrigation systems, especially drip systems, promotes the growth of micro-organisms, including algae and bacterial slimes. This growth can foul pipelines and clog sprinklers and emitters. Disinfectants, such as chlorine, can be used to keep systems clean.

Gases

Gases such as chlorine or anhydrous ammonia can be effectively injected, but the main problem is volatilization of the gas into the atmosphere, once it's discharged from the irrigation system. We don't cover chemigating with gases in this publication.

A major difference

A major difference between chemicals is whether a given chemical:

* must be incorporated in the soil to be effective;
* must be applied only on the foliage; or
* (in the case of disinfectants) remains resident in the irrigation system.

How a chemical is applied affects the timing of application and the volume of water that must be applied with the chemical.

The pesticide label

While some irrigators have applied nitrogen fertilizer with irrigation water since the late 1950's, the injection of pesticides into irrigation systems in the early 1980's triggered concern about potentially polluting water sources.

Because of this concern, the U.S. Environmental Protection Agency (EPA) began regulating pesticides under the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA). More recently, the EPA Label Improvement Program (LIP) changes were made so that the statement "the label is the law" can be applied to EPA regulations concerning pesticide injection.

In 1987, the EPA issued Pesticide Registration (PR) Notice 87-1 on a label improvement program for pesticides applied through irrigation systems.

This notice required registrants of pesticide products to state on each product label whether it was intended to be applied by chemigation. If it may be applied through irrigation systems, the label must include directions for use when applied by chemigation as well as statements concerning backflow prevention and other safety requirements.

PR Notice 87-1 states that no pesticide products labeled for agricultural, nursery, turf farm, golf course, or greenhouse use may be released for shipment after April 30, 1988 unless the product bears an amended label that complies with the Label Improvement Program.

If a specific pesticide product isn't intended for chemigation, EPA PR Notice 87-1 requires that fact to be stated on the pesticide label with the statement: "Do not apply this product through any type of irrigation system."

If a pesticide is intended to be applied by chemigation, all of the following general statements will be included on the product label:

1. "Apply this product only through [a specific type (or types) of irrigation system]. Do not apply this product through any other type of irrigation system."
2. "Crop injury, lack of effectiveness, or illegal pesticide residues in the crop can result from nonuniform distribution of treated water."
3. "If you have questions about calibration, you should contact State Extension Service specialists, equipment manufacturers, or other experts."

4. "Do not connect an irrigation system (including greenhouse systems) used for pesticide application to a public water system unless the pesticide label-prescribed safety devices for public water systems are in place."
5. "A person knowledgeable of the chemigation system and responsible for its operation, or under the supervision of the responsible person, shall shut the system down and make necessary adjustments should the need arise."

Safety equipment

A properly engineered chemigation system has several components: an irrigation pumping plant, a chemical injection device, a storage tank for the chemical, calibration devices, a backflow-prevention system, and related safety equipment.

Table 1 lists the chemigation safety equipment required by the EPA Label Improvement Program. We'll explain these in more detail as well as some EPA-approved alternative equipment.

The backflow prevention system and other safety equipment are the antipollution devices installed to minimize the potential of groundwater and surface water pollution when:

1. water backflows through the chemical injection system and overflows the chemical supply tank, and
2. the irrigation pumping plant shuts down because of mechanical or electrical failure and allows a portion of the water and chemical mixture to flow directly into the irrigation water supply.

The latter situation is especially serious if the chemical injection equipment continues to operate after the irrigation pumping plant shuts off. This could pump the remaining chemical solution into the irrigation pipeline—and possibly allow it to flow directly into the water source.

Alternative equipment

The EPA has approved some alternative safety equipment to substitute for the devices required by the Label Improvement Program. Under certain conditions, these include alternative backflow prevention devices; substitutes for normally closed, solenoid-operated valves on the injection pump suction line; and the positive displacement injection pump.

These devices are listed in table 1. In some cases, these alternative devices may be less expensive, more reliable, or more readily available than some of those devices originally required. We've highlighted each alternative (boxes, A, B, and C) as we discuss the safety device it substitutes for.

Table 1.—Minimum required chemigation safety equipment for protecting water sources[a]

Devices required by EPA Label Improvement Program	EPA-approved alternative devices
Backflow prevention assembly Irrigation main line check valve, air/vacuum relief valve, low pressure drain and inspection port	Gooseneck pipe loop
Interlock between irrigation pumping plant chemical injection device	Interlock between low pressure switch and chemical injection device.
Chemical injection line check valve	Chemical injection line check valve with minimum of 10 psi cracking pressure
Normally-closed solenoid operated valve on chemical suction line	Chemical injection line check valve valve on with minimum of 10 psi cracking pressure
	Normally closed, hydraulically actuated valve
	Air/vacuum relief valve on chemical injection line between injection pump and injection line check valve (only on chemigation systems using a positive- displacement injection pump)
Irrigation main line pressure switch connected to irrigation pump power source to shut irrigation system down under low pressure conditions	None

[a]Your State chemigation laws may further limit specific devices acceptable within the State.

Backflow-prevention devices

Combination backflow prevention assembly. The backflow-prevention assembly specified in the EPA Label Improvement Program combines an irrigation pipeline check valve, an air/vacuum relief valve, an inspection port, and a low-pressure drain.

(Box A shows the gooseneck pipe loop, the alternative that EPA allows under certain conditions.)

The combination assembly's purposes are:

- to prevent water from flowing back into the water source;
- to drain minor leakage past the check valve, away from the water source;
- to break siphoning action; and
- to allow easy inspection for proper operation of the check valve.

Irrigation pipeline check valve. Check and vacuum relief valves (antisiphon devices) are needed in the irrigation pipeline to keep water and/or a mixture of water and chemical from draining or siphoning back into the irrigation well or water supply and polluting the water.

Both of these valves are located between the irrigation pump discharge and the point where you inject chemicals into the irrigation pipeline (figures 1 and 2). Note that the check valve:

- must have positive closing action (spring-loaded);
- must have a watertight seal;
- must be easy to repair and maintain (see figure 3);
- shouldn't have metal-to-metal seals; and
- should be installed with fittings that allow for easy removal for maintenance and repair.

If you're using a centrifugal pump in the irrigation system and you must keep the pump primed for automatic operation, you must use a second check valve upstream of the backflow prevention assembly. Don't inject chemicals into the suction side of a centrifugal pump.

Existing backflow valves in irrigation systems may not be suitable for chemigation. If the irrigation system pumps water at high pressure, the backflow valve may be a slow-closing type, designed to protect the pumps and pipelines from pressure surges during startup and showdown.

This is especially true for large irrigation-pumping installations. In large irrigation systems, smaller chemigation valves located near the fields where chemicals will be applied will be more suitable than a single backflow valve.

Air/vacuum relief valve. The air/vacuum relief valve allows air into the pipeline when the water flow stops. This prevents the creation of a vacuum that could lead to siphoning. The air/vacuum relief valve allows the back side of the check valve to drain so minor leakage from a malfunctioning check valve can be intercepted and drained away.

Inspection port. An inspection port should be located between the pump discharge and the mainline check valve. This port must be at least 4 inches (200 mm) in diameter to allow visual inspection to determine if the check valve leaks. Inspect these ports at least once a year. In many cases, the vacuum relief valve connection can serve as the inspection port (see figure 4).

Low-pressure drain. Place an automatic low-pressure drain on the bottom side of the irrigation pipeline directly under the inspection port. If the mainline check valve should leak slowly, the water and chemical solution will drain away from—rather than flow into—the well. The drain valve must incorporate some type of cup or dam to intercept minor leakage from the check valve.

The drain should discharge at least 20 feet (6.5 m) from the well or water source, and the flow should be directed away from the well or water source. You may need a hose or pipe to conduct the discharge from the drain to the minimum distance of 20 feet (6.5 m).

Some manufacturers produce backflow-prevention assemblies with all these features in one well-designed package. An example is shown in figure 4.

Interlock

The irrigation pumping plant and the chemical injection device must be interlocked or connected so that if the irrigation pumping plant stops, the chemical injection device will also stop. This will prevent injection of the chemical mixture from the supply tank into the irrigation pipeline after the irrigation pumping plant stops.

Examples of this feature are shown in figure 1 for internal combustion engines and in figure 2 for electric motors.

When a separate, small electric motor provides the power on electric motor-driven irrigation pumping systems, you must interlock the electric controls for the two electric motors, so both motors will stop when either the electric motor on the irrigation pump stops or the irrigation system stops (figure 2).

All wiring must conform to the National Electric Code. Some agricultural chemicals are flammable and require the use of explosion-proof motors and wiring. If you're injecting a pesticide, consult the label for specific information before you use it.

For internal combustion engines, the chemical injection device can be powered by belting to the drive shaft or an accessory pulley of the engine (figure 1). Other alternatives include operating the injection equipment off of the engine electrical system (12 VDC), or using the power source (oil or electric) of the sprinkler system drive.

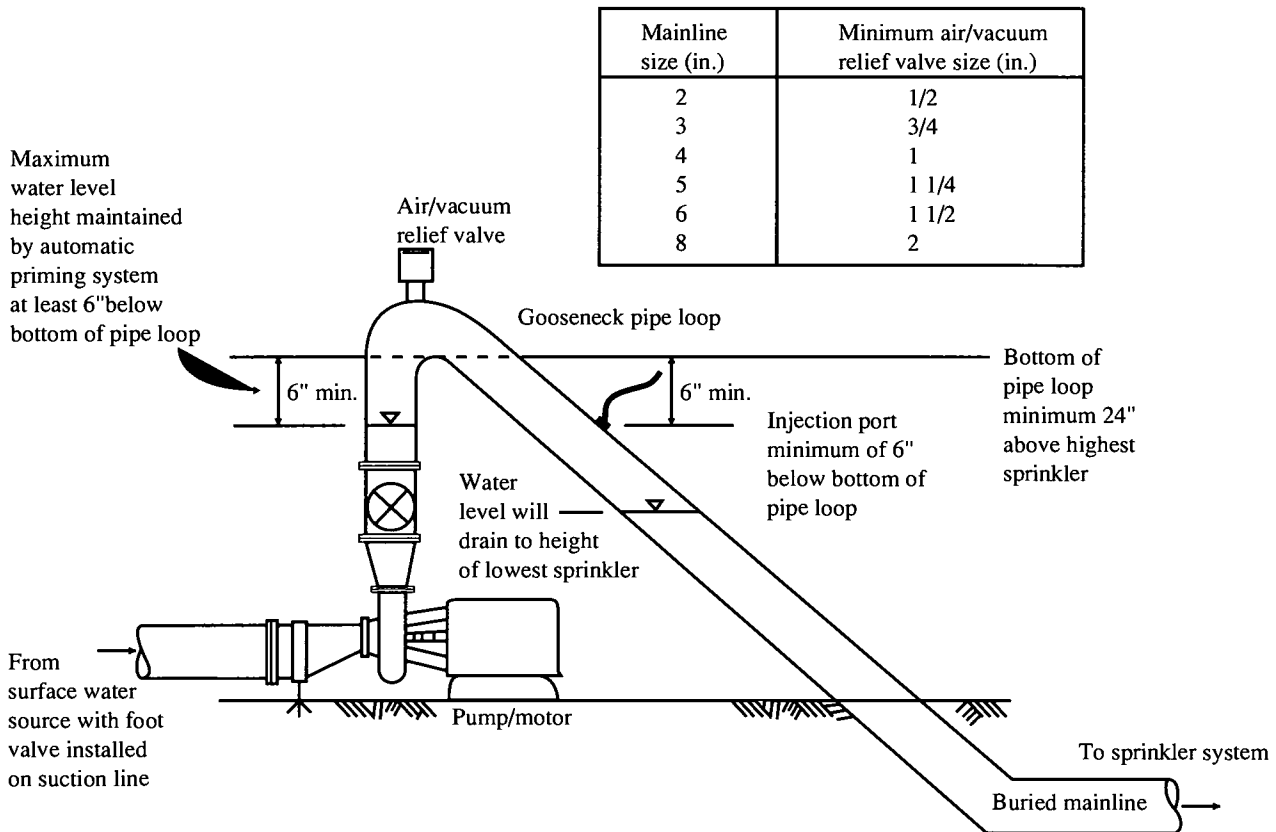*In all cases, it's essential that if the irrigation water supply stops, the chemical injection also stops.*

Chemical injection line check valve

A check valve in the chemical injection line is needed to stop water flowing from the irrigation system into the chemical supply tank, and to prevent gravity flow from the chemical supply tank into the irrigation pipeline after an unexpected shutdown.

Box A.—EPA alternative backflow prevention: Gooseneck pipe loop

Under certain conditions, you can replace the main line backflow prevention and antisiphon device with a gooseneck pipe loop located in the main water line, immediately downstream of the irrigation water pump, as shown here:

Mainline size (in.)	Minimum air/vacuum relief valve size (in.)
2	1/2
3	3/4
4	1
5	1 1/4
6	1 1/2
8	2

Maximum water level height maintained by automatic priming system at least 6"below bottom of pipe loop

Air/vacuum relief valve

Gooseneck pipe loop

6" min.

6" min.

Bottom of pipe loop minimum 24" above highest sprinkler

Injection port minimum of 6" below bottom of pipe loop

Water level will drain to height of lowest sprinkler

From surface water source with foot valve installed on suction line

Pump/motor

To sprinkler system

Buried mainline

The bottom side of the pipe at the loop apex must be at least 24 inches (0.6 m) above the highest sprinkler or other type of water-emitting device. The loop must have a combination air and vacuum relief valve at the apex of the pipe loop to break any siphoning action.

Locate the pesticide injection port downstream of the apex of the pipe loop and at least 6 inches (15 cm) below the bottom side of the pipe at the loop apex.

If you omit this check valve and the injection pump stops, irrigation water could possibly flow back through the chemical line into the chemical supply tank, overflowing the tank and causing a spill around the irrigation well. The chemical then may eventually move down through the soil to the ground water.

It's recommended—and possibly required by State law—that this check valve have a minimum opening (cracking) pressure of 10 pounds per square inch (psi; 70 kPa) to prevent gravity flow from the chemical tank, through the injection pump, and into the irrigation pipeline. It should be constructed of chemically resistant materials.

Chemical suction line valve

You can install a normally closed solenoid valve between the chemical supply tank outlet and the intake side of the injection device. This provides positive shutoff on the chemical injection line. This valve should be electrically interlocked with the engine or motor driving the injection device. Then, neither the chemical nor the water could flow in either direction if the injection device is stopped.

Normally closed, solenoid-operated valves (to be located on the intake side of the injection pump) may not be readily available, and they don't always operate reliably in a vacuum.

(Box B shows suction line valves that EPA allows as alternatives.)

Figure 1.—Minimum requirements for
antipollution devices and arrangement of
equipment for applying chemicals through the
irrigation system *(engine drive)*
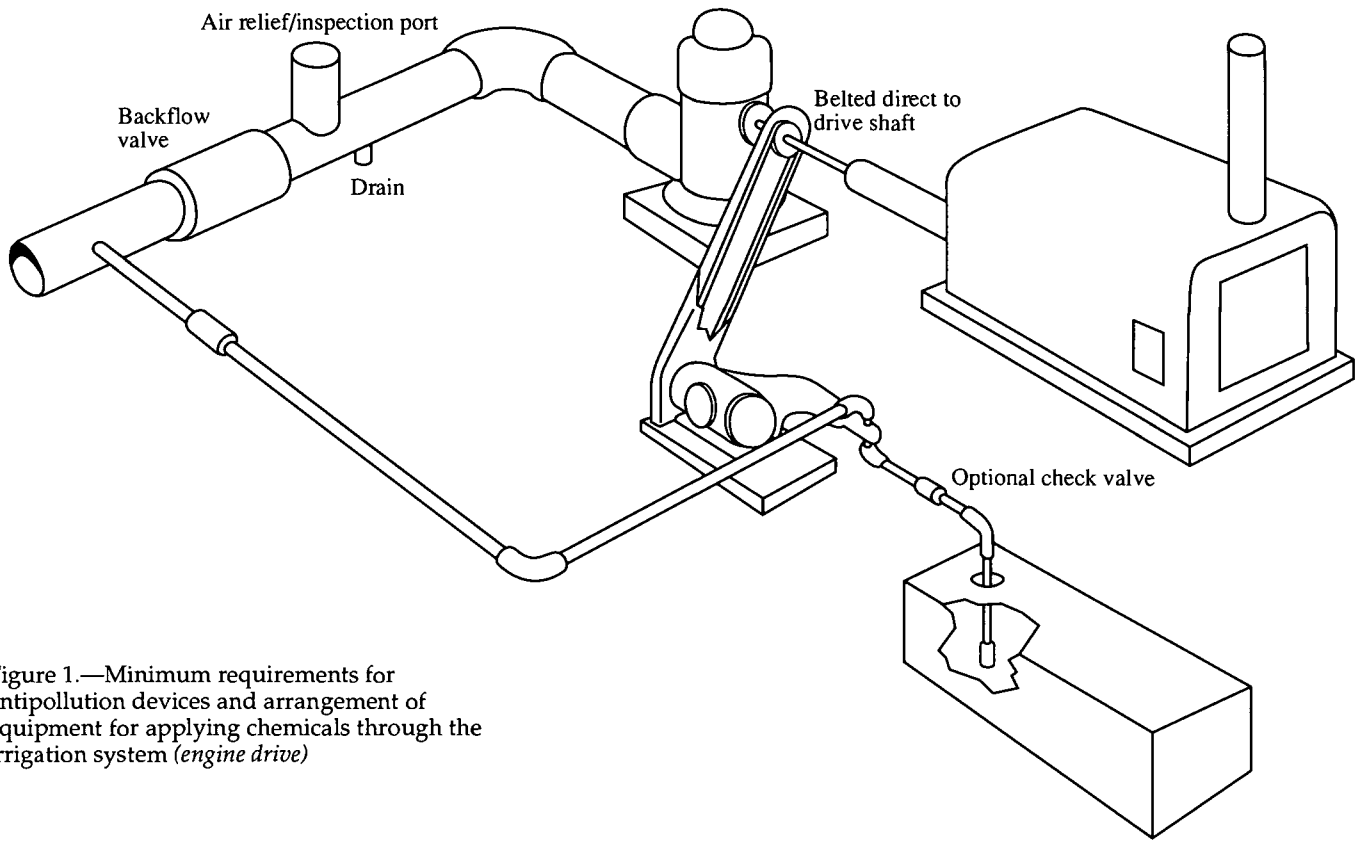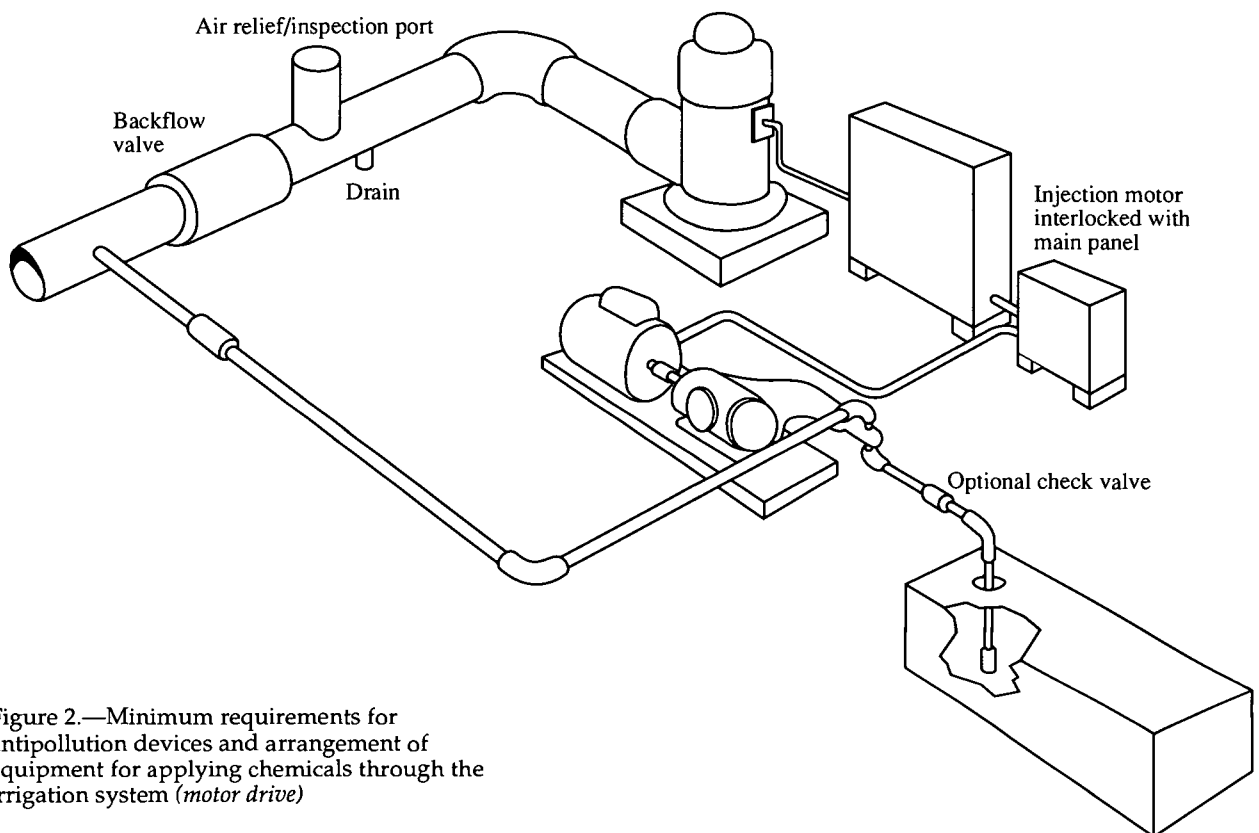

Figure 2.—Minimum requirements for
antipollution devices and arrangement of
equipment for applying chemicals through the
irrigation system *(motor drive)*

Figure 3.—Cutaway of check valve

Figure 4.—Check valve assembly

Extra protection

While they're not required for protection, some other fittings can contribute to safely operating the chemigation system:

- A strainer on the chemical suction line prevents clogging or fouling of the injection pump, check valve, or other equipment.
- A valve installed upstream of the backflow prevention assembly will provide a clean water source.
- The proper fittings and the means for checking injection rates, such as a clear calibration tube, installed on the outlet side of the injection device.

Chemical injection devices

Active and passive

A wide variety of approved chemical injection devices are available; they're classified as either active (an outside power source is required) or passive (no outside power is needed).

Active injection devices include positive displacement pumps such as diaphragm, piston, roller, and gear pumps. Injection pumps can typically be adjusted over a range of different injection rates to provide a continuous and relatively uniform concentration of chemical in the irrigation water. They should be mechanically rugged with internal and external components made of chemically-resistant, noncorrosive materials.

Passive. The primary passive injection device operates on the venturi principle, where, under the proper conditions, a flow constriction in the pipeline creates a vacuum because of the increased velocity of flow. Another less common passive device is the batch tank system.

Chemical injection rates

Chemigation is being used to apply a wide variety of chemicals to many different crops through varying types

---

Box B.—EPA alternative suction line valves

1. **A spring-loaded check valve with a minimum of 10 psi (70 kPa) cracking pressure.** This single device can substitute for both the solenoid-operated valve and the automatic, quick-closing check valve in the pesticide injection line when it has a minimum 10 psi (70 kPa) opening pressure.

2. **A normally closed, hydraulically operated check valve.** The hydraulic control line is connected to the main water line, and the valve opens only when the main water line is pressurized.

3. **A vacuum relief valve located in the pesticide injection line between the positive displacement pesticide injection pump and the injection line check valve.** This alternative is appropriate for only chemigation systems that use a positive displacement injection pump—don't use it with venturi injection systems.

   Locate this valve at least 12 inches (0.3 m) above the highest fluid level in the pesticide tank—it must be the highest point in the injection line to function properly. The valve should open at 6 inches (15 cm) water vacuum or less, and it must be spring-loaded or otherwise constructed so it doesn't leak when you close it.

Figure 5.—Diaphragm-type injection pump

Figure 6.—Piston-type chemical injection pump and tank

of irrigation systems. The required rate of chemical injection is depends very much on each of these factors; and it ranges from 1 pint per acre (1.18 L/ha) for foliar-applied materials like insecticides to more than 30 gallons per acre (281 L/ha) for liquid fertilizer solutions like nitrogen.

No single injection device can accurately cover this entire injection range. In this case, at least two injection devices, one with a low and one with a moderate injection rate range, might be required for chemigation.

Your type of irrigation system may limit your choice of injection device. Some, such as set move sprinklers, solid set sprinklers, and drip irrigation, are batch systems. The chemicals can be mixed and applied in batches.

Moving irrigation systems such as center pivots, linears, and travelers must have chemicals injected continuously at uniform rates based upon the water application rate, rate of travel, and area covered. Injection pumps used with moving irrigation systems should be accurate to within 1% of the maximum injection rate.

Diaphragm pumps

Diaphragm pumps can be accurately calibrated to provide the continuous, uniform injection rates required with moving irrigation systems. They have two distinct advantages over other injection units. First, they have few moving parts, and only a limited area of their components is exposed to the chemical being injected. This greatly reduces the potential for corrosion, wear, and leakage. Consequently, this reduces potential maintenance costs and the potential for the human and environmental safety concerns associated with leakage.

Second, you can easily adjust the injection rate while the pump is operating. For most of these pumps, you adjust the injection rate by simply turning a micrometer type adjustment device (see figure 5).

The main disadvantage: Diaphragm pumps are more expensive than other kinds of injectors.

Piston pumps

Piston pumps have been used extensively for chemigation. Their main advantage is their ability to inject at a constant rate against fluctuating pressure in an irrigation system (see figure 6).

Piston pumps, however, have two distinct disadvantages for chemigation:

Mechanically complex. Piston pumps have complex valves, pistons, and connecting linkages and a relatively large internal area exposed to the chemical being pumped. This creates corrosion and wear on internal components, increases maintenance cost, and reduces the useful life of these pumps—in addition, the worn seals can leak chemicals onto the irrigation platform and soil around the chemigation system, creating a safety hazard.

Difficult to calibrate. It's inherently difficult to calibrate the chemical injection rate by setting the pump stroke. You must stop the pump to adjust the stroke length and restart it to check the new injection rate.

Calibration of a piston injection pump is a time-consuming and frustrating process of stopping, adjusting, starting, and checking the pump over several cycles. Many irrigators don't accurately calibrate piston pumps because of this difficulty.

Other pumps

Other types of chemical pumps such as roller or gear pumps and even chemically-resistant nonpositive displacement centrifugal pumps can be used on batch-type irrigation systems (wheel-lines, hand-lines, solid set sprinklers, drip/trickle) that don't require the high accuracy needed by moving irrigation systems.

Venturi units

Chemical injection units based upon the venturi principle inject chemicals by generating a differential pressure across a venturi device. The venturi creates a vacuum, sucking the chemical into the irrigation system.

Box C lists the additional fittings that are required for venturis to be EPA-approved alternatives to positive-displacement pumps.

Venturis can be inserted directly into the main water line, installed in a bypass system, and in bypass systems boosted with an auxiliary water pump. A differential pressure can be created by a pressure-reducing valve installed in the mainline of the irrigation system in parallel with the venturi injection device.

Reducing system pressure to operate a venturi can adversely affect the performance of the irrigation system. When this is a problem, you can install a small auxiliary pump (usually centrifugal) in series with the venturi device to create differential pressure across the venturi device. This is called a *boosted venturi system*, and it requires an outside power source.

The primary advantage of the venturi-type injection unit is its relatively low cost compared to either piston or diaphragm pumps.

A major disadvantage is that the venturi unit's chemical injection rate depends on the available differential pressure.

Variations from the calibrated pressure significantly change the chemical injection rate, resulting in nonuniform chemical concentration in the irrigation water. For this reason, venturis are generally not recommended for use on moving irrigation systems. For batch-type irrigation systems, this variation isn't important.

Batch tanks

As the name implies, a batch of chemical is mixed into an auxiliary tank. The batch tank is plumbed into a pipe loop parallel to the mainline, and a portion of the mainline flow is diverted through the tank containing the chemical to be applied.

The batch tank and fittings must operate safely at the mainline operating pressure (see figure 7). The flow is diverted by valves on the mainline and pipe loop, creating a pressure differential on the mainline. Irrigation water flows through the tank, and water and chemical solution reenter the mainline downstream of the pressure differential device.

The main disadvantage of these systems is that you have little or no control of the chemical injection rate.
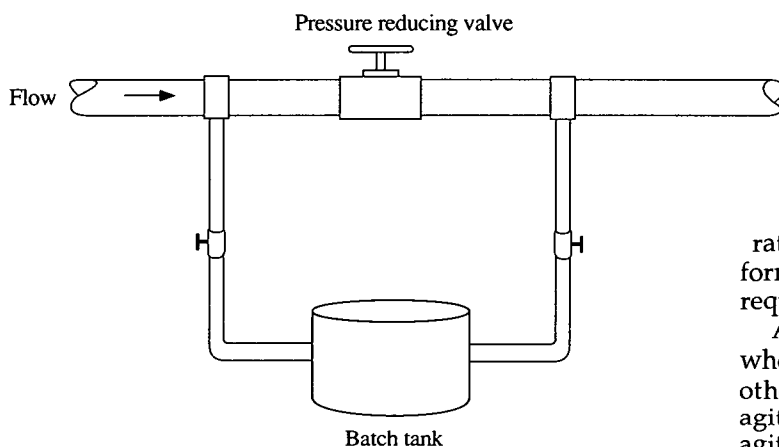

Pressure reducing valve

Flow

Batch tank

Figure 7—Connecting a batch tank injection system

Chemical concentration in the irrigation water starts high and declines rapidly.

Chemigation power sources

Chemigation pumps of the piston and diaphragm designs are available as water-, electric motor-, or engine-powered units. Most piston and diaphragm pumps are powered by either electric motors or engines that provide a constant rate of oscillation/rotation of the injection components and a stable rate of chemical injection.

Some oil-based chemicals present an explosive hazard—these require special, explosion-proof motors and wiring. Consult a licensed electrician to wire the injection system correctly, as defined by the National Electric Code 70.

In a hazardous zone, isolate the injector unit and chemical tank as shown in figure 8 (from the National Fire Protection Association, NFPA 497).

There are water-powered alternatives when other power sources are unavailable. You can use a variety of water-driven turbines, pump jacks, and diaphragms to drive the injector. A water-powered injector is shown in figure 9.

These units must be driven by a water source upstream from the backflow prevention device as they "waste" water to gain the energy to drive the pump. In addition, clean water is usually required because these devices are prone to malfunction in water that contains sediment or debris.

Materials of construction

All injection device components that come in contact with chemicals must resist all formulations of agricultural chemicals that you're applying—including the active ingredient and any emulsifiers, solvents, or other carriers.

The materials suggested for appropriate components of an injection pump are stainless steel, polypropylene, polyethylene, EPDM, EVA, Teflon, hypalon, and viton. In general, components that contain PVC, neoprene, butadiene, or styrene butadiene rubber are not satisfactory for many agricultural chemicals.

Supply tank, hoses, and valves

Selecting a supply tank or reservoir for chemigation is similar to selecting a tank for conventional chemical applications. The supply tank should be large enough to contain enough chemical to treat the entire chemigated area without refilling.

For insecticides and other applications at low rates, a smaller reservoir may be desirable, but some formulations of pesticides and plant nutrients may require a very large reservoir.

Agitation in the chemical supply tank is required when you use wettable powders, dry flowables, or any other suspended formulation. Mechanical and hydraulic agitation are the two most common types. Mechanical agitation usually works best. Both types of agitation require a separate power source.

Box C.—EPA requirements when you use a venturi

For venturis to be EPA-approved alternatives to positive displacement pumps, some additional fittings are required:

1. The line from the pesticide supply tank to the venturi must contain an automatic, quick-closing check valve to prevent the flow of liquid back toward the pesticide supply tank.
2. This valve must be located next to the venturi pesticide inlet.
3. This main supply line must also contain either a normally closed, solenoid-operated valve connected to the system interlock or an approved alternative device, as shown here:

Venturi system inserted directly into the main water line (section 7A.5)
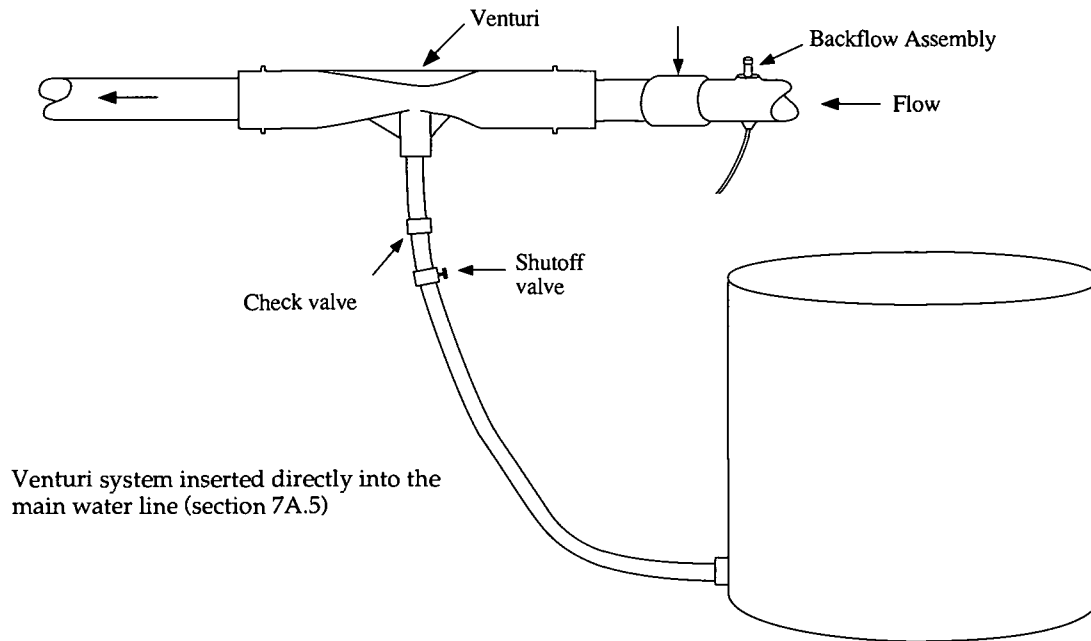
4. In bypass systems, an alternative to placing both valves in the line from the pesticide supply tank is to place a check valve in the bypass line immediately upstream of the venturi water inlet and either a normally closed solenoid or hydraulically operated valve immediately downstream of the venturi water outlet, as shown here:

Venturi system with a bypass system (section 7A.5)
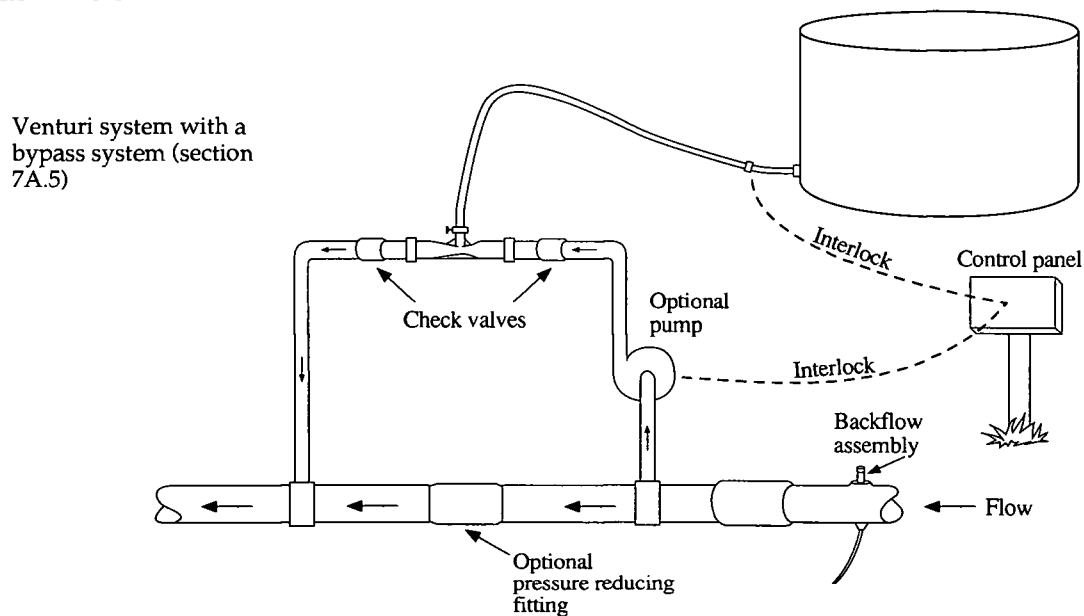
5. Booster or auxiliary water pumps must be constructed of materials resistant to pesticides.
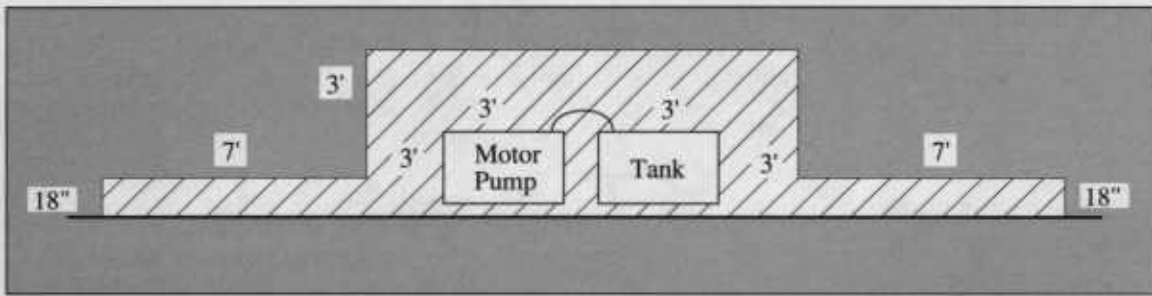
Figure 8.—Hazard zone when injecting flammable chemicals (from the National Fire Protection Association, NFPA 497)
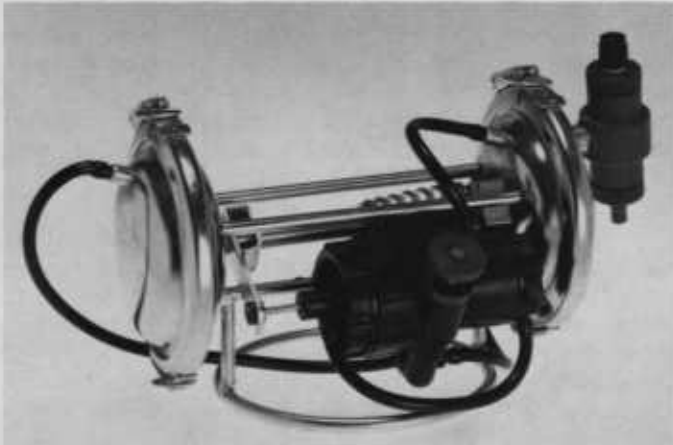

Figure 9.—Water-powered diaphragm chemical injector (photo courtesy Filtration, Irrigation & Fertigation, Reseda, CA)

Chemical supply tanks should be totally self-emptying, such as those with conical bottoms on the tanks. Likewise, you should minimize the length and size of interconnecting hoses, to reduce the amount of material retained in the system when you complete chemigation.

Chemical supply tanks must be constructed of materials that will withstand the corrosive action of agricultural chemicals. Stainless steel, fiberglass, nylon, and polyethylene are common construction materials. Avoid iron, steel, copper, and brass. Check the pesticide label for any suggestions or restrictions.

Hoses, clamps, and fittings. Hoses, seals, gaskets, etc., in contact with the chemical or chemical mixture, from the strainer to the point of injection on the irrigation pipeline, should be made of polypropylene, polyethylene, EPDM, EVA, Teflon, Hypalon, Viton, or other chemically resistant materials.

Hoses and connectors should be designed to withstand the pressure generated by the chemical injection device. Quick-disconnector fittings on hoses are really convenient. Keep all hoses, clamps, and fittings in good repair; inspect them at least annually.

Injection port. The main function of the injection port is to disperse the injected chemical into the flow of the pipeline to provide a uniform chemical concentration.

Soluble chemicals. A simple fitting on the side of the pipe can be adequate because turbulence in the pipe can adequately mix the chemicals.

A side-injection port works best when the irrigation water flows through a length of pipe and a few fittings (such as elbows) to create turbulence to mix the chemical before it reaches the irrigation system.

In installations where the flow is divided, the injection ports should be at least 10 pipe diameters upstream of the dividing fitting to ensure adequate mixing. If you can't fulfill this space requirement, install special turbulence-inducing fittings to mix the chemicals adequately.

Nonsoluble chemicals like wettable powders or oil-soluble chemicals require better mixing. The injection port should extend to the center of the pipe where the chemicals will be more quickly dispersed. When properly dispersed, wettable powders will be more likely to stay in suspension.

Two or more chemicals. Usually, you can inject two or more chemicals simultaneously, but incompatibility problems can occur (chemical precipitation, etc.). If chemicals are incompatible when you mix them in a tank, problems are also likely when you inject two or more incompatible chemicals through a common injection port, even with separate injector pumps.

Under these circumstances, inject each chemical through a separate injection port located at least 6 inches (15 cm) from any other port.

Foliar applications. The injection port has a significant effect on the efficacy of oil-formulated pesticides intended for foliar applications. An oil-formulated pesticide must be well mixed at injection. Both the flow velocity within the irrigation mainline and the sprinkler design can significantly affect chemical distribution and efficacy:

1. sprinkler orifice diameter significantly affects the sizes of oil-insecticide droplets;
2. sprinkler design (spray nozzle versus impact) can significantly affect the uniformity of chemical distribution and efficacy;
3. the irrigation system pressure (high versus low pressure) can cause the distribution uniformity of chemical concentrations and chemical volumes to be substantially different from the distribution uniformity of the irrigation water; and

4. the efficacy of oil-formulated insecticides may be erratic and unacceptably low when applied by chemigation in an irrigation system with an initial mainline flow velocity of less than 4.5 ft/sec (1.5 ms⁻¹).

Operating chemigation systems

The goal of operating a chemigation system is to apply the proper amount of chemical safely, and as evenly as possible.

To achieve this goal, take these precautions:

- assure both personal and environmental protection;
- calibrate chemigation equipment to inject the desired quantity of chemical;
- apply only the right amount of water at the right time, to reduce the possibility of runoff, drift, or deep percolation, all of which carry chemicals from the field; and
- use a well-designed and maintained irrigation system—you can't distribute the chemical more evenly than the water.

Calibration

To get the most value from the chemicals you apply through an irrigation system and to avoid environmental and health problems, you must properly calibrate the chemigation system.

A University of Nebraska study showed only about 40% of chemical application equipment checked was calibrated to apply the chemical within ±10% of the intended rate—and some equipment in the survey was 83% off! *Successful Farming* called this a billion dollar blunder.

Calibration of chemigation systems is relatively straightforward, but it recquires time, equipment, and accurate calculations to arrive at the correct chemical application rate.

Calibration involves six basic steps:

Step 1. Determine the area to be irrigated (treated) in acres.

Step 2. Determine the desired amount of chemical to be applied per acre by carefully reading label directions.

Step 3. Determine the total amount of chemical required: Multiply the area to be treated (step 1) by the chemical application rate (step 2).

Step 4. Determine the length of time in hours during which injection will take place. This will depend on such factors as the length of the irrigation set or the time to cover the field, irrigation water application rate, and the desired amount of water to be applied with the chemical. Take into account the transit time for the chemical to move through the irrigation system.

Step 5. Determine the proper chemical mixture.

Step 6. Set the injection device to the proper flow rate.

Two categories. Calibrating chemigation equipment must take into account the type of irrigation system. Irrigation systems can be divided into two broad categories—batch systems and moving (continuous application) systems.

Batch mode. Irrigation systems such as set move sprinklers (side rolls, hand lines), solid set sprinklers, and drip irrigation are operated in batch mode. This is because these systems irrigate a block of land at a constant rate for some period of time. A batch of chemical can be mixed and applied to this block during irrigation.

Continuous application. The second category is continuous injection of chemicals into moving irrigation systems such as center pivots, linears, and travelers. These machines cover irrigated land at a constant rate, and the rate of injecting chemicals must be matched with the rate of travel.

Setting the injection rate. In either case, you must adjust the injection device under the same conditions as those under which the system will normally operate. You can make coarse ajustments by injecting clean water; you set the device by estimating the percentage of full flow based on the manufacturer's nominal recommendations. Don't rely on flow rates labeled on the equipment's controls.

You must make the fine adjustments by calibrating the equipment *yourself.* Install a tube or tank with accurately marked increments of volume, inline on the suction side of the injection device.

Adjust the injection device after measuring the volume of the chemical pumped per unit of time while injecting against normal pressure. Use a stopwatch to time the flow rate and allow at least 5 minutes pumping time for the final check. You must make the final ajustment while you inject the properly mixed chemical solution.

Changes in viscosity and density may change the injection rate.

The injection rate accuracy for moving irrigation systems should be as high as possible. The accuracy of batch injection is only as critical as the timing requires. For example, if injection is to be over a 2-hour period in an 11-hour irrigation set, an error of 10 minutes will have little effect.

Mixing the chemical. In either batch or continuous application, mix the chemical before you start (Step 1 through Step 3). Determine the total chemical that you should mix by multiplying the rate at which you'll apply the chemical by the area of land to be covered. Use accurate scales or volumetric measuring tools to mix the chemicals.

Example 1. Apply 40 lb nitrogen per acre to a 4-acre field using ammonium sulfate, $2(NH_4)SO_4$ (see appendix 1). Find the weight of the material and the minimum tank size. Ammonium sulfate is 20% N.

$$\text{Total Material} = \frac{\text{Application rate x Area}}{\%N}$$

$$= \frac{40\ \text{lb/acre x 4 acres}}{0.20}$$

$$= 800\ \text{lb 2(NH}_4)\text{SO}_4$$

When water is 50F (10C), the solubility of ammonium sulfate is 6.5 lb/gal.

$$\text{Minimum tank volume} = \frac{\text{Total material}}{\text{solubility}}$$

$$= \frac{800}{6.5} = 123\ \text{gal}$$

Batch applications. Batch application is straightforward as far as determining the amount you should apply. The timing of the application, however, involves two key factors, type of chemical and duration of the chemigation.

Type of chemical is of major importance. Some chemicals must be incorporated when applied to be effective. Incorporation requires applying enough water to carry the chemical into the soil.

Batch application offers the opportunity to move the chemical into the soil with clean water. For example, the herbicide Eptam requires incorporation, and it has been shown to be significantly more effective when injected during the first 4 hours of an 8-hour set.

Other chemicals, such as nitrate nitrogen, are soluble in water and are highly mobile. These chemicals should be left near the surface to avoid potential groundwater contamination problems, but they must be incorporated to avoid volatilization losses.

Therefore, inject nitrate nitrogen in the last half of an irrigation set, but continue the irrigation at least an hour after you inject the fertilizer to allow some incorporation.

Some chemicals are intended to be used as foliar applications. You must apply foliar-applied chemicals at the very end of the irrigation set, with a minimum of flushing. Consider the type of chemical and coordinate the application time relative to the irrigation, to provide maximum benefit from the chemical.

Duration of the chemigation is the second consideration. Batch application is less sensitive here than continuous injection, but it's still a consideration. Sprinkler irrigation, especially impact sprinklers, must be operated at least 15 minutes before the application can be considered uniform—30 minutes is better.

The next five sections show specific examples of Calibration Step 1 for batch-type systems.

Set-move sprinkler systems (siderolls, wheelines, hand move pipe). When you calculate the amount of chemical to be injected on one set of a side roll or hand line

system, the area covered is the length of the lateral times the lateral spacing.

Water and chemical are applied outside this corridor, but you expect the same volume of water from the next set to come back across the border.

Example 2. A side roll is 1,200 feet long and moves 50 feet between sets. The sprinklers are spaced 40 ft apart. What's the area covered by one set?

$$\text{Area} = \frac{\text{Length x Lateral spacing}}{43,560\ \text{ft}^2\ /\ \text{acre}}$$

$$= \frac{(1200)\ \text{x}\ (50)}{43,560}$$

$$= 1.38\ \text{acres}$$

Solid-set sprinkler systems irrigate blocks of land controlled by a single valve. The area covered by a block is the number of laterals times the lateral spacing times the length of each lateral.

This is similar to the area of coverage of a set move system, but it can be more complicated to calculate. Again, the amount of chemical to be mixed is the area covered times the desired chemical application rate.

Example 3. A solid set irrigation system has sprinklers spaced on a 40 x 30 ft grid. The shape is irregular, but there are 100 sprinklers total. What's the area covered?

$$\text{Area} = \frac{\begin{array}{c}\text{No. sprinklers x spacing between sprinklers}\\ \text{x spacing between sprinklers}\end{array}}{43,560\ \text{ft}^2\ /\ \text{acre}}$$

$$= \frac{100\ \text{x}\ 30\ \text{x}\ 40}{43,560}$$

$$= 2.76\ \text{acres}$$

Even if the actual field is larger, this is the area of the field covered by irrigation.

Drip systems. Drip or trickle irrigation systems are similar in most ways to solid-set sprinkler systems when it comes to chemigation. The area covered, however, is only the actual land covered by the crop. This is usually considered to be the area inside the drip line of a tree or bush or the width covered by a row crop.

Often, the amount of chemical applied will be calculated for an individual tree or for 100 feet of a row crop. Chemigation through drip irrigation systems can't control weeds in the unirrigated areas between rows because no water is applied there.

Chlorination is used to prevent algae or bacterial slimes from plugging an irrigation system, especially drip and microsprinkler systems. Surface water supplies are especially prone to algae growth and other microbial contaminants. Injecting chlorine solutions continuously or in slug doses can prevent plugging.

Continuous chlorine injection should provide 1 to 3 ppm free residual chlorine in the most distal part of the irrigation system. Slug doses of chlorine should provide

at least 40 ppm free residual chlorine at the end of the system for at least 30 minutes duration.

The frequency of slug doses and amount to be injected depend on various water quality factors (pH and the concentrations of iron and hydrogen sulphide). As a starting point, chlorinate the system at least once a month and after every fertilizer injection.

The amount of chlorine material needed for a desired dosage in parts per million chlorine (ppm) is calculated from the percent chlorine in the material, and the water flow rate in gallons per minute (gpm):

Gallons of liquid per hour =

$$\frac{0.006 \times \text{chlorine dosage (ppm)} \times \text{system flow rate (gpm)}}{\% \text{ chlorine in material}}$$

If the chlorine is to mixed in a batch:

Gallons of liquid material per 1,000 gal water (assuming liquid has same specific gravity as water) =
$$\frac{0.10 \times \text{chlorine dosage (ppm)}}{\% \text{ chlorine in material}}$$

Example 4. Chlorinate a drip irrigation system with 50 ppm liquid sodium hypochlorite (NaOCL) solution for 30 minutes with a 10-gal batch tank. The drip system has a flow rate of 10 gpm. The total flow in 30 mins. is 300 gal. From above, the gallons of chlorine per hour is

$$\frac{0.006 \times 50 \text{ ppm} \times 10 \text{ gpm}}{5\% \text{ (grocery store bleach)}} = 6 \text{ gph}$$

To maintain this rate for a half hour, place 3 gal of grocery store bleach in the batch tank and fill with water. When the drip system operates, release 0.3 gal per minute from the batch tank. The 10-gal batch tank will empty in about 30 minutes.

Surface irrigation systems. Chemigation is difficult to use with surface irrigation systems (furrows, rill, border, etc.). The main problem is poor water distribution of surface irrigation systems. In fact, don't chemigate surface-irrigated sandy soils because of the large potential for leaching to the groundwater.

If you'll use chemigation with surface irrigation, the area to be irrigated or chemigated by surface irrigated is the land area contained within a border dike system, or it's the irrigated furrow or rill spacing times the number of furrows per set, times the length of run for furrow irrigation.

The amount of water applied or the application rate requires that water be measured in the head ditch as it enters the field. For example, a given flow rate through a weir or flume at the head of a field divided by the area irrigated gives the gross average application rate.

Multiply the gross average application rate by the irrigation set time to find the average gross depth of application.

Moving irrigation systems. Accurate calibration of injection units is essential for chemigating on moving irrigation systems. Minor differences in delivery projected over extended periods can cause either excessively high or low application rates and, most likely, unsatisfactory results.

Center pivots. The injection rate of chemicals into a center pivot must be calibrated against the rate at which land area is covered. To determine the rate that land is covered, you must know or measure several factors, including:

1. circumference of the last tower wheel track,
2. acres to be treated, and
3. travel speed of the last tower.

One of the most important aspects of proper calibration is to determine the speed of travel as the pivot completes a full circle. While some of these factors are usually given in the instruction booklet that comes with the center pivot system, book values of speed at the various settings are usually not accurate enough for chemigation.

The actual travel speed (feet/minute) of the system should be determined by checking the time it takes for the outside tower to travel a measured distance.

Mark the end towers' progress with small flags and allow the system to move at least 50 ft (15 m). Measure the time between start of motion and start of motion with a stopwatch (see figure 10).

This measurement should be made while the system is operating at the same speed and pressure to be used during the actual chemigation process. A system running dry may travel faster than a system traveling wet. Check this distance per unit of time at several locations in the field if topography is rolling. Use an average value.

The rate at which the chemical is delivered by the injection pump can be calculated in several ways. The metering rate is *best* determined by using a calibration tube in line between the chemical tank and the injection pump (see figure 11).

The calibration tube is filled, the line from the tank is closed, and the material is pumped only from the

Figure 10.—Measuring the end tower travel speed

Figure 11.—Checking injection rate with a clear calibration tube

calibration tube for a specified time period. The calibration tube should be clear, unbreakable and graduated in ounces, pints or milliliters. Its capacity should be sufficient for a minimum of 5 minutes injection time in order to properly calibrate and monitor the application process.

This method is superior to pumping into a catch basin or container because pressure is maintained against the pump. Coarse adjustments can be based on 1-minute time checks. Make a final check over an extended time period (at least 5 minutes). Additional checks during the application process are advisable.

Example 5. A center pivot that is 1,280 feet long is to have an insecticide injected at the rate of 1 quart per acre. We'll need to use the six calibration steps (page 12), adapted to the special case of a center pivot.

Step 1: Calculate the circumference of the last wheel track (see figure 12)

Circumference = 2 x π x r, where r = distance in feet from pivot point to last wheel track and π = 3.1416.

In the example, r = 1,250 ft, so the circumference = 2 x 3.1416 x 1,250 = 7,854 ft.

Step 2: Calculate the area irrigated

If you plan to operate an end gun or end sprinkler intermittently, modify the calculations in this step to correctly determine the area to be irrigated. (The system will irrigate a greater area while the end gun or end sprinkler is on than when it's off.) See table 2.

If your calculations assume the end gun is running continuously, an overapplication will result when it's not running. If you don't consider the the additional throw while the end gun operates, underapplication will result.

However, if the resulting error in either case is minimal (less than 2 to 3%), continue your calculations; assume that the end gun or end sprinkler is off and allow either to operate.

Most likely, the resulting percentage error will be greater than 3%, and you'll need to make special calculations and separate calibration adjustments. You have two choices:

• Don't allow the end sprinkler or end gun to operate intermittently during the chemigation process and calculate accordingly.

Table 2.—Computing number of acres irrigated per revolution of center-pivot sprinklers *with various length systems*

Length (radius) center-pivot sprinkler (ft)	Areas irrigated/revolution		
	End sprinkler *off* all the time	End sprinkler *on* in corners	End sprinkler *on* all the time
400	12	14	16
500	18	20	23
600[a]	26	31	33
700	35	41	43
800	46	52	55
900	58	65	69
1000	72	80	83
1100	87	95	100
1200	104	114	117
1300[a]	122	130	136
1400	141	153	157
1500	162	175	180
1600	185	195	200
1700	208	221	227
1800	234	247	253
1900	260	275	282

[a]One-fourth section size; circle inside of 160 acres (Source: University of Nebraska *NE Guide* G75).

• Calculate two chemical injection rates—one when the end sprinkler or end gun is operating, the other when both are not operating—and manually adjust to the correct injection rate, coinciding with the on/off operation of the end sprinkler or end gun.

See your operator's manual to determine acres irrigated when the outside border of the irrigated circle is not continuous.

Assuming that the end gun is off, the calculation continues as follows:

$$Acres = \frac{\pi \times r^2}{43,560}$$

where r = distance from pivot point to last wheel track plus length of end boom.

So if

r = 1,250 ft + 30 ft = 1,280

$$\frac{3.1415 \times 1,280 \times 1,280}{43,560} = 118 \ acres$$

Step 3: Calculate the rate of travel

Calculate the rotational speed of the pivot by measuring the distance traveled (at the last wheel track) by the pivot while irrigating for at least 10 minutes. As we stated earlier ("Center pivots," page 14), check the rotational speed at several locations if the field topography is rolling. Use the averaged value.

60 feet/10 minutes = 6 feet/minute.

Step 4: Calculate the revolution time (see figure 12)

To find the time to complete a revolution, use this formula:

$$Time \ / \ revolution = \frac{Circumference \ in \ feet}{feet \ / \ minute}$$

$$\frac{7,854 \ ft}{6 \ ft \ per \ minute} = 1,309 \ minutes$$

Step 5: Calculate the acres treated per minute
Use this formula:

$$Acres \ treated \ / \ min = \frac{Number \ of \ acres \ treated}{minutes \ per \ revolution}$$

$$\frac{118 \ acre}{1,309} = 0.09 \ acres \ / \ minute$$

Step 6: Calculate the application rate

To find the amount of material to be pumped per minute, multiply the volume of formulated insecticide per acre times the acres irrigated per minute.

1 qt/acre = 946 milliliters/acre (946 ml/A)
         x (0.09 A/min)
       = 85.1 ml/min.

(Note: Conversion factors are given in appendix 2.)

The injector pump must be adjusted to inject the chemical solution at this rate.

Linears and travelers. The process for calculating injection rates are similar for linear move irrigation systems and travelers except for the calculation of area covered. The area covered is the width of the linear or the lane spacing of the traveler times the length of the field. The equation is:

$$Acres = \frac{Width \ x \ length \ of \ field}{43,560 \ ft^2 \ / \ acre}$$

Be sure to take into account the speed variations of these types of equipment. The travel speed of linears can vary when steering and travelers can increase speed as more cable or hose is wound on the winch drum. Both of these types of equipment have trouble uniformly covering the ends of the field.

Example 6: A linear move irrigation system is 1,250 feet long and travels 600 feet between hose changes. What is the area covered?
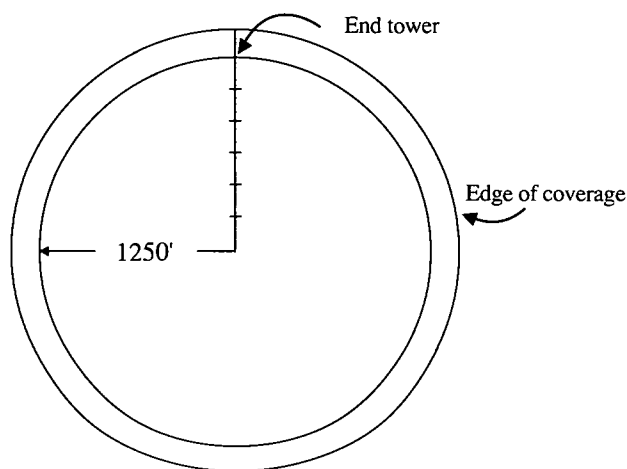

Figure 12.—Coverage of center pivot

$$\text{Acres} = \frac{\text{Width x length of field}}{43{,}560 \text{ ft}^2 / \text{acre}}$$

$$= \frac{1{,}250 \text{ x } 600}{43{,}560}$$

$$= 17.22 \text{ acres}$$

Proper application depends on exact calculations and an adequate system to calibrate the pump (a calibration tube).

Calibration is time-consuming, but it's absolutely necessary.

Time spent in calibration is a good investment from a control, environmental, economic and safety standpoint. After the proper equipment is installed and calibrated, it must be operated properly to complete a safe chemigation.

Management practices

Chemigation should be managed to assure safety and to make the applied chemicals work effectively. First, always read the label and follow all directions specifically applicable to the pesticide or chemical being used.

The basic management steps for chemigation are:

1. Apply only the water needed for the crop, as uniformly as possible.
2. Maintain all equipment in working order.
3. Flush the irrigation and injection system after injection is complete and after an automatic shutdown.
4. Take personal and environmental safety precautions.

The potential for groundwater and surface water pollution from chemigation is minimized when chemigation is one part of good water management for the entire irrigation system.

Depth of penetration. Use scientific irrigation scheduling to match the water applied with the crop's water requirements (see PNW 288). The average depth of irrigation should not penetrate deeper than the crops' roots.

The depth penetrated is determined by the application rate of the irrigation system, the duration of irrigation, the soil texture, and the soil moisture content before the irrigation. Table 3 shows the depth into the soil that 1 inch application of water penetrates for different soil textures and various soil moisture contents.

Soil moisture can be estimated by squeezing a sample of soil in your hand. Table 4 can be used to interpret the soil moisture fairly accurately.

Example 7: The fertilizer from example 1 is mixed in a 150-gallon tank. It is to be injected over 3 h in the 3rd through 5th hour of an 8-h set. The sprinkler system applies water at 0.3"/h, the crop's root zone is 3 ft deep, and the moisture in the loam soil is estimated to be 50% with a feel test.

A. What is the injection rate?

$$\text{injection rate} = \frac{\text{Volume}}{\text{time}}$$

$$= \frac{150 \text{ gal}}{3 \text{ h}} = 50 \text{ gal} / \text{h}$$

B. How deep does the irrigation penetrate?

Total application   = Rate x time

     = (0.3"/h) x (8 h) = 2.4"

Depth penetrated   = Total app. x (table 2 value)

     = (2.4) x (14") = 33.6"

This will be acceptable if the root zone depth is greater than 34". In the example, the root zone is 36 inches deep, so this would be an acceptable practice.

Operational precautions or procedures. Maintain all equipment in good working order:

- repair all leaks;
- tighten hose clamps;
- replace frayed hoses;
- inspect sprinkler nozzles to ensure they're the right size and not worn;
- clean debris from end gun shutoffs, check valves, vacuum breakers, etc., and be sure they're all working properly; and
- test switches and electrical interlocks.

Table 3.—Depth (inches) penetrated by 1-inch application

Texture	Sandy	Loam	Clay
Average water-holding capacity	(1.0 in/ft)	(1.7 in/ft)	(2.2 in/ft)
Moisture content			
75%	48	28	22
50%	24	14	11
25%	16	9	7

Table 4.—The "feel chart"

Degree of moisture	Feel	Amount of available moisture
Dry	Powder dry.	None
Low	Crumbly, won't hold together.	25% or less (critical)
Fair	Somewhat crumbly but will hold together.	25-50%
Good	Forms ball; will stick slightly with pressure.	50-65%
Excellent	Forms a ball, is pliable; sticks readily; a clear water sheen will come to the surface when ball is squeezed in the hand.	75-100%
Too wet	Can squeeze free water.	Over field capacity

Specific situations.
- Don't use chemigation on irrigated fields with runoff problems (see PNW 287).
- Remember: The edges of sprinkler irrigated fields are not covered with the same uniformity as the center of the field.
- Inspect sprinkler irrigation systems to assure high application uniformity by using proper nozzle sizes and design pressures, replacing worn nozzles, and fixing plugs and leaks.
- Proper water screening is essential for minimizing drip emitter and sprinkler system plugging.
- Laterals can drop in size as fewer sprinklers are served. When this is done, a screen is installed to filter debris larger than ⅜" diameter to prevent blocking underground pipes. Declining pipe sizes reduce the cost of pipe, but they increase design complexity and slightly increase pressure requirements.

Set move systems have a problem: The pipe is the same size throughout. This means the velocity at the end of the pipe is very low and some nonsoluble chemicals such as wettable powders can settle out. This material can accumulate and be flushed out when the system is drained, causing localized overapplication problems.

Solid set sprinklers can have all the problems of the set move systems. Some of the timing and precipitation problems can be minimized by laying out the lateral lines differently.

If chemigation is a primary concern, irrigated blocks can be laid out with a center feed submain (figure 13). The feed submain comes to the center of the block and then water is distributed around the block from there. This requires more pipe but reduces the travel time through the block.

Often in solid set systems, chemigation is only to be applied on one block when several blocks are usually irrigated together. Under this condition, the pressure in the system can be higher than normal and adversely

affect distribution. A pressure-reducing valve can maintain sprinkler pressures at the normal operating level.

Drip or trickle irrigation systems must be filtered, chemically treated, and carefully inspected to eliminate emitter plugging. High application uniformity with drip irrigation systems also requires use of proper emitter sizes, design pressures and distribution line sizes.

Drip systems have one characteristic that can cause problems—water temperatures increase substantially as water moves through the black plastic pipes. Temperature increases lower the critical pH at which carbonate precipitation occurs. Burying or shading laterals can help keep water temperature lower.

Surface systems should be designed and operated to obtain high levels of uniformity. This requires a careful balance between the inflow stream size, the length of run, the surface slope, and the soil type. Soil surface condition is important because it influences the rate of flow, amount of water applied, and the uniformity of distribution.

This is particularly true at the first irrigation of the season, when soil intake rates are typically higher due to drier soil conditions and the effects of tillage on soil structure. Land- and bed-forming machines that create a relatively smooth, clod-free surface are very helpful in obtaining uniform water applications. When chemigating, provisions should be made to collect and reuse all tailwater runoff.

The actual distribution of water applied by surface irrigation may vary considerably. When smaller application depths are attempted, it is possible that water may never reach the end of the field. To have some minimum level of chemical distribution, introduce chemicals into the water supply only after water reaches the end of the field.

Center pivot. If possible, always set a center pivot at a high rotational speed when injecting an insecticide. The longer it takes to complete the treatment, the more likely

18

Figure 13.—Solid set layout for chemigation

Source

Source

Conventional

Shorter duration center feed
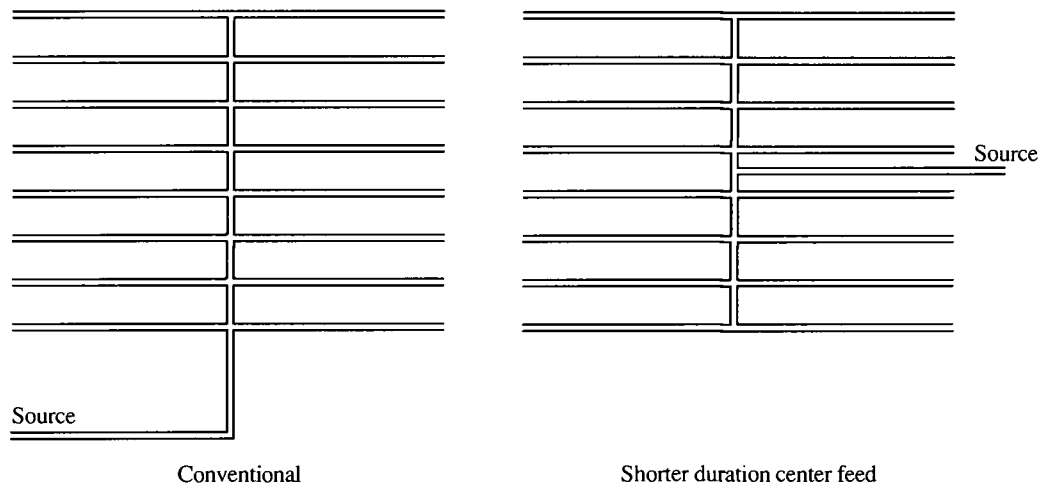
adverse weather conditions will affect the success of the application. *Read the label—it usually specifies the preferred amount of water for chemigation.*

Wait to start moving irrigation systems until the injected chemical has reached the end of the machine.

Time to move through the system. Keep in mind that injected chemicals do not instantly move through the irrigation system. The chemicals can take a surprisingly long time to make it through the pipeline and be applied. The time required can be calculated using the hydraulic design of the system.

A rough estimate of travel time is to divide the pipe length (in feet) the chemical will travel by 300 to find the number of minutes.

A better way to estimate transit time is to inject a food safe dye (red is a good visible color) and time the travel both to the irrigation equipment and how long it takes to move through the irrigation system. On batch type irrigation systems you should also note if the duration of injection is affected by velocity differences in the pipeline.

For example, a 15-minute injection of a foliar applied chemical may stretch to a slightly longer time due to dispersion in the pipeline. In most irrigation systems this effect will be minor.

You'll need to consider *all* these factors when you determine how long to run the system, when you can start a new set, or the time that you must allow for irrigation lines and laterals to be flushed (table 5).

If automatic valves switch before the slug of chemical has passed, the chemical can be misdirected, doubling applications or leaving the chemical in the pipeline. It can be difficult to coordinate these time requirements, especially if foliar application is desired.

Flushing equipment. Prevent the accumulation of precipitates in the injection equipment by flushing the injection system with clean water after each use. After injection is completed, operate the irrigation pump for at least 10 minutes to flush the irrigation system of the chemical. If the irrigation system was shut down automatically, flush the system as quickly as possible after

Table 5.—Irrigation system characteristics

Method	Uniformity	Type
Set move	Fair	Batch
Solid set	Fair	Batch
Drip	Good	Batch
Surface	Poor	Batch
Center pivot	Good	Moving
Linears	Good	Moving
Travelers	Fair	Moving

the shutdown is discovered, and extend the flushing period to 30 minutes.

Personal precautions. Because many chemicals used in chemigation are hazardous, take these personal safety precautions to protect yourself and others:

1. Always wear rubber boots, gloves, and other appropriate protective equipment at the injection site.
2. Exercise extreme caution when injecting any insecticide or nematicide into an irrigation system because they are so toxic.
3. For safety and application accuracy, use a separate system apart from that used for injecting liquid fertilizer to apply insecticides.
4. Consider identifying the field with a suitable warning sign that states *"Chemigation is in progress"* even if not required by regulation (it is required in Idaho).
5. Read the label to determine when it will be safe to re-enter the field after applying insecticide. Figure 14 shows a typical curve of the safety hazard declining over time after using (as an example) the oil-soluble insecticide Lorsban.
6. Keep the injection site clean and orderly.
7. On center pivots, plug the two nozzles outward from the pivot point so sprinklers do not wet down the injection site.
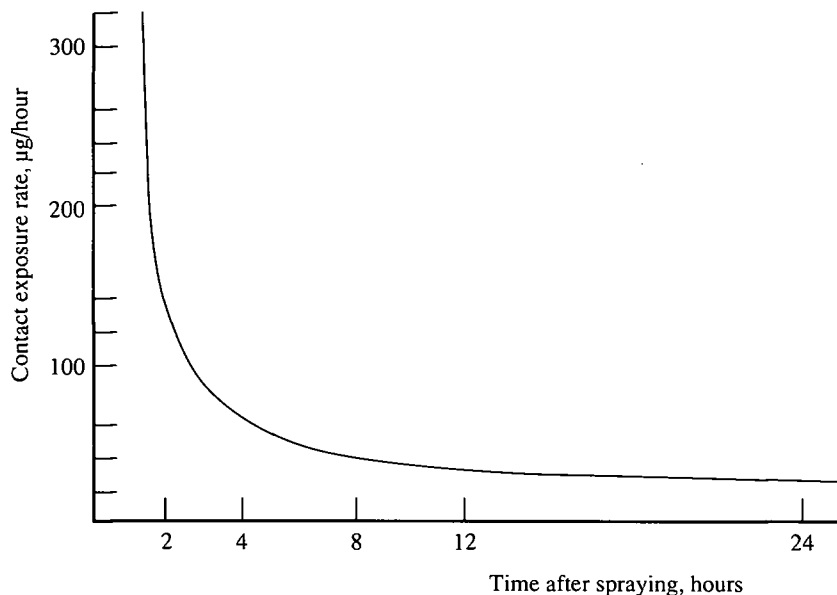
19

Figure 14.—Contact exposure rate (CER) of chlorpyrifos accumulation on the shoulders for various times of exposure after spraying, illustrating a typical reduction rate curve

Environmental precautions. Use the following precautions to protect the environment:

1. Don't leave chemigation equipment unattended. Monitor continuously.
2. Inject pesticide only when the irrigation system is running.
3. Don't apply when weather conditions favor pesticide drift from treated areas. Usually, this means shutting down when wind speeds exceed 10 mph.
4. Discontinue chemigating if significant rainfall occurs.
5. In the event of accidental well contamination, shut off the injection system and continue pumping water for several hours.
6. Avoid injecting pesticides through irrigation systems on those fields with permanent or semipermanent surface water areas, as it could harm wildlife and other nontarget plants and animals.

Summary

By following these guidelines, chemigation can be an effective means of applying agricultural chemicals. The chemicals can be applied uniformly and achieve their intended effect. This will maximize the economic benefits while minimizing the potential for pollution of our water supplies.

Glossary

Chemigation.	Injecting agricultural chemicals into an irrigation system.
Pesticide.	A chemical used to kill animal, insect, and plant pests.
Efficacy.	Degree to which a pesticide is effective in controlling the target pests.
Nemagation.	Chemigation with a pesticide to kill nematodes.
Fertigation.	Chemigation with fertilizer.
Herbigation.	Chemigation with an herbicide to kill undesirable plants.

For further reading

Hansen, Hugh J., and Walter L. Trimmer, *Irrigation Runoff Control Strategies*, Pacific Northwest Extension publication PNW 287 (Oregon State University, 1986). No charge.

Trimmer, Walter L., and Hugh J. Hansen, *Irrigation Scheduling*, Pacific Northwest Extension publication PNW 288 (Oregon State University, 1986). No charge.

These publications are available from Publications Orders, Agricultural Communications, Oregon State University, Administrative Services 422A, Corvallis, OR 97331-2119. Please include your charge for shipping and handling:

- For orders up to $2.50, include 25¢.
- For orders between $2.50 and $100, include 15%.
- For orders of $100 or more, or for 100 copies or more, call Agricultural Communications (503-737-2513) for a quote on reduced shipping and handling rates.

Appendixes

Appendix 1.—Composition, solubility, and residual acidity of some nitrogen and potassium fertilizers

Material	%N	%K2O	Solubility (lb/gal)		Lb calcium carbonate to neutralize acidity produced from 100 lb N
			0C	100C	
Ammonium nitrate	33.5		9.84	72.62	185
Ammonium sulfate	20-21		5.92	8.59	550
Calcium nitrate	15.5		10.09	31.35	−100 (basic)
Urea	45		8.34[a] (high)	158.0	
Potassium nitrate	13		11.11	20.59	−115 (basic)
Ammonium phoshate	21		10.92[b]		357
Potassium chloride		62	2.89[c]	4.73	
Potassium nitrate		44	1.11	20.59	
			2.63[c]		
Potassium sulfate		53	0.57	2.01	
			1.00[d]		

a 17C
b 15C
c 20C
d 25C

Appendix 2.—Metric conversion table

English	Multiply by	For metric equivalent
Foot (ft)	0.305	Meter (m)
Pound per square inch (psi)	6.895	Kilopascal (kPa)
Horsepower (hp)	0.746	Kilowatt (kW)
Acre (A)	0.405	Hectare (ha)
Mile (mi)	1.61	Kilometer (km)
Fluid ounce (fl oz)	29.57	Milliliter (mL)
Pint (pt)	0.473	Liter (L)
Quart (qt)	0.946	Liter (L)
Gallon (gal)	3.784	Liter (L)