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Insectigation in Vegetable Crops: The Application of Insecticides Through a Drip, or Trickle, Irrigation System

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1. Introduction

Drip, or trickle, irrigation can be defined as a method of uniformly delivering water to a plant's root zone through point or line sources (emitters) on or below the soil surface at a small operating pressure (Dasberg & Or, 1999). Modern drip irrigation systems use low pressure (~34.48-68.95 kPa [5-10 psi]) to force water through plastic or metal tubing with emitters spaced at regular intervals down its length to deliver water to the plant's root zone, and can be either a surface system (tubing on top of the soil) or a subsurface system (tubing buried beneath the soil). Water savings with drip irrigation can be as high as 80% compared with other irrigation methods (Bogle & Hartz, 1986).

The basic concept of efficient irrigation using less water dates back centuries ago, but the idea of drip irrigation using tubing was used by crop producers as early as the 1860's in Europe for subsurface irrigation using perforated metal irrigation pipe (Ross et al., 1978). Modern day commercial drip irrigation was not possible until the development of plastics during World War II which enabled drip irrigation equipment and supplies to be economical for use by crop producers. During the late 1970's researchers were successful with injecting liquid fertilizers through drip irrigation systems, followed soon thereafter with other agrichemicals including insecticides and fungicides. Today, many agricultural chemicals are labeled for application through various irrigation systems, including overhead, sprinkler, and drip/trickle, in vegetable and other crops.

2. History of drip chemigation

Although researchers experimented with drip irrigation systems before the 1950's, the first use of a modern drip irrigation system was conceived by Symcha Blass (Blass, I. & S. Blass, 1969), a retired British Water Agency worker. His ideas of micro-tubing for irrigation included special low volume water emitters that overcame the clogging of drip holes by particles carried in the water. He patented his plastic emitters in 1959 with Kibbutz Harzerim in Israel under the trade name 'Netafilm Company', producing the first practical surface irrigation drip emitters.

The initial use of drip tubing in conjunction with a plastic row cover, together called 'plasticulture' (Lamont Jr., 2004) was conducted in a cucurbit field at Old Westbury Gardens, Long Island, NY in 1963 by R. Chapin of Chapin Watermatics, Inc, and N. Smith, a Nassau County Agricultural Agent (Ayars et al., 2007). Over the next decade, plastic row covers and drip tape improved, and inexpensive, consistent emitters with a constant discharge rate were quickly developed. Commercial drip irrigation rapidly expanded to >54,000 ha in the USA by 1975, being used on various crops for water management in 35 different states, and between 1982 and the late 1990's drip irrigation increased in the United States 650% (Anonymous, 2000).

As drip/trickle chemigation quickly became adopted by growers, research investigations on the injection of agricultural chemicals through the same system rapidly increased. Fertilizers were first injected into a drip irrigation system in 1979 to tomatoes and eggplant in New Jersey (Paterson, 1980), and to cucurbits and other vegetables in California (Hall, 1982). Insecticides were first injected into a drip irrigation system in bell peppers in New Jersey for the control of European corn borer (*Ostrinia nubilalis* Hubner) in 1980 (Ghidiu & Smith, 1980), and the following year in lima beans for control of the Mexican bean beetle (*Epilachna varivestis* Mulsant) (Ghidiu, 1981). However, the insecticides were not effective against these pests when applied systemically and neither trial resulted in insect pest reduction. The first successful drip application of an insecticide for insect pest reduction was conducted in 1985 (Wildman & Cone, 1986), where asparagus aphid (*Brachycorynella asparagi* [Mordvilko]) numbers in asparagus were significantly reduced using disulfoton (Di-Syston 6E, Miles Inc., Elkhart, IN) as compared with the untreated. Ghidiu (1992) used a small ¼ hp electric pump to inject carbofuran (Furadan 4F, FMC Corporation, Philadelphia, PA) and methomyl (Lannate 1.8L, E. I. DuPont de Nemours & Co., Wilmington, DE) through a drip irrigation system under black plastic mulch for European corn borer control in bell peppers, but reported no reduction in borer damage and significant phytotoxicity to the pepper plants, demonstrating that injected materials must not only be efficacious but must also be safe to the plants. Successful insectigation trials were reported with entomopathogenic nematodes for the control of spotted cucumber beetles (*Diabrotica undecimpunctata howardi* [Barber]) in 1986 (Reed et al., 1986), followed by the effective control of aphid (Aphididae spp.) populations by chemigating imidacloprid in vegetables in Arizona in the mid-1990's (Kerns & Palumbo, 1995; Palumbo, 1997), and effective control of spotted cucumber beetles in melons in Virginia with drip-applied imadclorpid and thiamethoxam (Kuhar & Speese, 2002). In a 3-yr field trial starting in 2004, chlorantraniliprole was shown to be highly effective against the European corn borer in bell pepper when applied through a drip irrigation system (Ghidiu et al., 2009). Further, chlorantraniliprole applied through a drip irrigation system significantly reduced armyworms (*Spodoptera* spp.) and fruitworms (*Helicoverpa zea* [Boddie]) in tomatoes in field tests in both Virginia (Kuhar et al., 2009) and Florida (Schuster et al., 2009). And Ghidiu (2009) reported that chlorantraniliprole and thiamethoxam injected via a drip irrigation system significantly reduced damage to eggplant foliage caused by flea beetles (*Epitrix* spp.) and leafminers (*Liriomyza* spp.).

3. Effectiveness of insectigation

During the mid-1990's, researchers reported effective control of beetles, aphids, whiteflies, and several other insect pests using foliar applications of a newly-developed class of

insecticides, the neonicotinoids. These new-chemistry insecticides are especially suited for application through a drip irrigation system because they are highly soluble, they are root systemic and essentially non-phytotoxic to most plants, they are highly effective against specific pests, and they are considered by the USEPA to be reduced-risk pesticides. Felsot et al. (1998) examined the distribution of imidacloprid in soil when applied through a drip irrigation system and concluded that it is a good candidate for insect control via drip irrigation systems.

More recently, another new class of insecticides, the anthranilic diamides, has been shown to be highly toxic to numerous caterpillar pests (Lahm et al., 2005). One of these insecticides, chlorantraniliprole, is xylem-mobile through root uptake and controls caterpillars and other leaf-feeding pests (Lahm et al., 2007). Like the neonicotinoid-class insecticides, chlorantraniliprole is also highly soluble, root systemic, and effective against specific insect pests, especially caterpillars, leafminers, and beetles. Because both of these materials are selective against certain insect pests, they are ideal materials for a pest management program.

Currently, the USEPA has approved and labeled numerous insecticides of different classes for application through a drip irrigation system in fruits and vegetables for the control of a wide variety of insect pests:

<u>Common name</u>	<u>US Brand name</u>	<u>Insecticide class</u>
azadirachtin	Aza-direct	limonoid insect growth regulator (neem)
chlorantraniliprole	Coragen	anthranilic diamide
clothianidin	Belay	neonicotinoid
dimethoate	Dimate	organic phosphate
diazinon	Diazinon	organic phosphate
dinotefuron	Venom	neonicotinoid
imidacloprid	Admire PRO	neonicotinoid
malathion	Malathion 8 Aquamul	organic phosphate
methomyl	Lannate	carbamate
oxamyl	Vydate	carbamate
rosemary+peppermint oils	Ecotec	botanical
thiamethoxam	Platinum	neonicoinoid
thiamethoxam + chlorantraniliprole	Durivo	neonicotinoid

4. Advantages and disadvantages of insectigation

There are both advantages and disadvantages to injecting agricultural chemicals, including insecticides, into a drip/trickle irrigation system. Additionally, some states in the U.S. require that the irrigation operator register with a specific State Department (such as Department of Water, Natural Resources, Agriculture, or Environmental Control, etc.) before using any chemigation with overhead or drip/trickle systems. The irrigation operator may also be required to keep records of each chemigation application including the date, type and brand name of chemical, the field area covered by the injection, and the amount of material used.

4.1 Advantages of insectigation

1. The total insecticide input for control of targeted insect pests in most crops is significantly reduced when compared with that of traditional foliar applications, while at the same time essentially 100% protection of the plant is obtained because these materials are root systemic and translocate throughout the plant, resulting in a more even distribution of the pesticide within the plant. For some vegetable crops, 1-2 drip/trickle irrigation applications of an insecticide during the season result in equivalent control, or better control, of insect pests than that of multiple foliar sprays. Kuhar et. al. (2009) reported that a single injection of the high labeled rate of chlorantraniliprole (Coragen; E.I. DuPont de Nemours Inc., Wilmington, DE) into a drip system was as effective as 4 foliar applications of the pyrethroid lambda-cyhalothrin (Warrior II; Syngenta Crop Protection, Inc., Wilmington, DE) for control of caterpillar damage in fresh market tomatoes, and Ghidui et al. (2009) reported that 2 injections of chlorantraniliprole into a drip system was as effective as 7 applications of a standard grower foliar spray program consisting of 2 applications of acephate (Orthene 97; United Phosphorus, Inc., King of Prussia, PA) followed by 5 applications of indoxacarb (Avaunt 30WDG; E.I. DuPont de Nemours, Inc., Wilmington, DE) for control of European corn borer in bell peppers.
2. Less energy is required to transport water and insecticide solutions at the lower pressures and velocities in drip/trickle systems as compared with other irrigation systems. Also, because fewer applications are needed, less energy input is required than by tractor or other application methods, and no soil compaction occurs that results from heavy tractors or spray equipment being operated over the field. The fewer times a tractor goes over the field, the less potential for plant damage caused by the tractor operation.
3. Pathogen movement through the field via water flowing over the soil surface can be reduced through the use of a drip/trickle irrigation system if plastic mulch is used in combination with drip tubing. This is especially true for plant diseases such as *Phytophthora capsici*, a soil-borne fungus, which produces spores that are spread via water splashing up onto the foliage by rainfall, operation of field equipment and sprayers, etc.
4. Weather is not a factor during application, as injection of an insecticide into a drip/trickle irrigation system can be made in wind or rain, or when fields are too muddy or soft to operate ground equipment without getting stuck.

5. Applicator exposure, both in terms of physical contact and time of exposure, to insecticides during application is significantly reduced.
6. For many growers in areas that are experiencing urban encroachment, insectigation can be completed without spray drift, eliminating 'application visibility' that concerns these growers.
7. Plant growth may be enhanced through the use of drip irrigation systems because with frequent drip waterings, it is possible to maintain a more optimum balance between soil water, plant needs and aeration. Healthy plants are less susceptible to insect pest problems than unhealthy plants or plants under water stress.
8. And because many of these new-chemistry insecticides are selective to specific insect pests, they are generally less toxic or disruptive to non-target species and beneficial organisms, including insect predators, parasites and pollinators. The injection of insecticides through a drip/trickle irrigation system thus fits well into an integrated pest management program.

4.2 Disadvantages of insectigation

1. The initial capital expenditures for a complete drip system and additional injection equipment can oftentimes be greater than that for sprinkler, overhead or other irrigation systems. However, the more the system is used, the smaller the costs per hour of operation. And most drip systems have many re-useable components (pumps, filters, tubing, hoses, injectors, etc).
2. Drip/trickle systems generally require consistent maintenance and monitoring of all equipment for constant pressure, leaks in any part of the system, plugged emitters, etc. Specific safety equipment is required, and additional safety precautions must be followed.
3. Water carries particulates that can clog the emitters if the filters malfunction or are not maintained properly (backwashing, cleansing, etc). If plastic mulch is used in combination with the drip/trickle system, clogged emitters are sometimes difficult to locate, resulting in uneven distribution of the insecticide when pumped into the drip system. Also, if plastic drip lines and tubing are not properly rinsed after each use, it is possible that emitters may become clogged with residue.
4. Drip line repairs can sometimes be time consuming and costly. Bright, direct sunlight may affect some plastic tubing used for drip irrigation, shortening their useable life span. Also, small rodents (mice, rabbits, chipmunks, etc) and certain soil insects (crickets, wireworms, ground beetles, others) may chew on drip hose, especially in droughts, causing small leaks that subsequently result in loss of pressure and uneven distribution of the insecticide. Oftentimes, such small leaks are difficult to detect under row covers such as black plastic until the row becomes saturated and wet spots appear.
5. After the final harvest, clean-up costs of drip/trickle systems may be higher than with other irrigation systems. Costs may include removal of plastic row covers, all drip lines and tubing, and injection and safety equipment. The disposal cost of used plastics (plastic mulches, drip lines) continually increases.
6. Top-dressed fertilizers and some herbicides may need additional sprinkler application for activation, especially if a plastic mulch is not used over the row.

7. Salts can accumulate as a result of inadequate flushing of the drip/trickle irrigation system (Dasberg & Or, 1999), particularly at the perimeter of the wetted area.

5. Drip chemigation system requirements and operation

Drip chemigation systems that will have insecticides injected into them must be properly engineered, installed, and maintained over the season to ensure a uniform distribution of outflow (Ross, 2004). Chemigation requires that two separate hardware systems be joined together, operating as a single system. The components of the first system, a typical drip/irrigation system, include:

- main water source (well, irrigation pond, etc). Public water supplies cannot be used.
- main water pump
- water filter system (with sand screens, screen filters, flush valve or drain)
- backflow prevention valve/backwash controller
- pressure gauge
- low pressure shutoff valve
- low pressure sensor/shutoff switch
- pressure relief valve
- various diameter hoses and polytubing to carry water to the plant roots (main lines, lateral and drip lines, etc). Drip lines are available with a wide range of emitter spacings, and can be found with spacings of 4", 8", 12", 18", or even 24", with flow rates of 12 to 64 gallons or more per 100' /hour.

Most growers that currently use some form of drip/trickle irrigation as a water-management tool can easily, and inexpensively, add the necessary equipment to properly inject agrichemicals. The components of the second system, in addition to the typical drip irrigation system equipment listed above, include the following pieces of equipment that are needed before injecting any agricultural chemical into the system:

- chemical mix tank, such as a 19 L [5 gallon] plastic jug, preferably with an agitator and an outlet filter to prevent clogging of emitters by the chemical solution
- containment tray or pan to catch any chemical solution leakage or spillage
- positive displacement pump or other reliable solution metering device which provides a consistent flow rate at low pressures
- backflow prevention valve to prevent backflow of solution into the mixing container
- low pressure shutoff valve to shut the injection system off should a loss of pressure occur

A basic drip/trickle irrigation system with an additional insectigation system using a positive displacement metering pump for injection of an insecticide is shown in Figure 1.

6. Injection pumps

The injection pump is a critical component of a chemigation system, and must be properly installed and maintained to ensure an even flow of the chemical solution to every emitter in the irrigation system. Injection should be on the downflow side of the main pump filters to

avoid potential site contamination as a result of the filter back-flush operation. Two basic types of chemical injection pumps are available for the application of agrichemicals (insecticides, fertilizers, etc) through low-pressure drip/trickle irrigation systems: the volumetric water flow pump and the positive metering pump. Regardless of type used, it should be a pump that provides consistent flow rates at low pressures. For agricultural use, both should be made of materials that are resistant to corrosion by fertilizers, acids, chlorine, etc., and both should have adjustable injection rates at various pressures. Both types of pumps have models that may deliver a flow rate as little as 11.4 liter/h (3 gal/h) at operating pressures of 20 kPa (3 psi) or more.

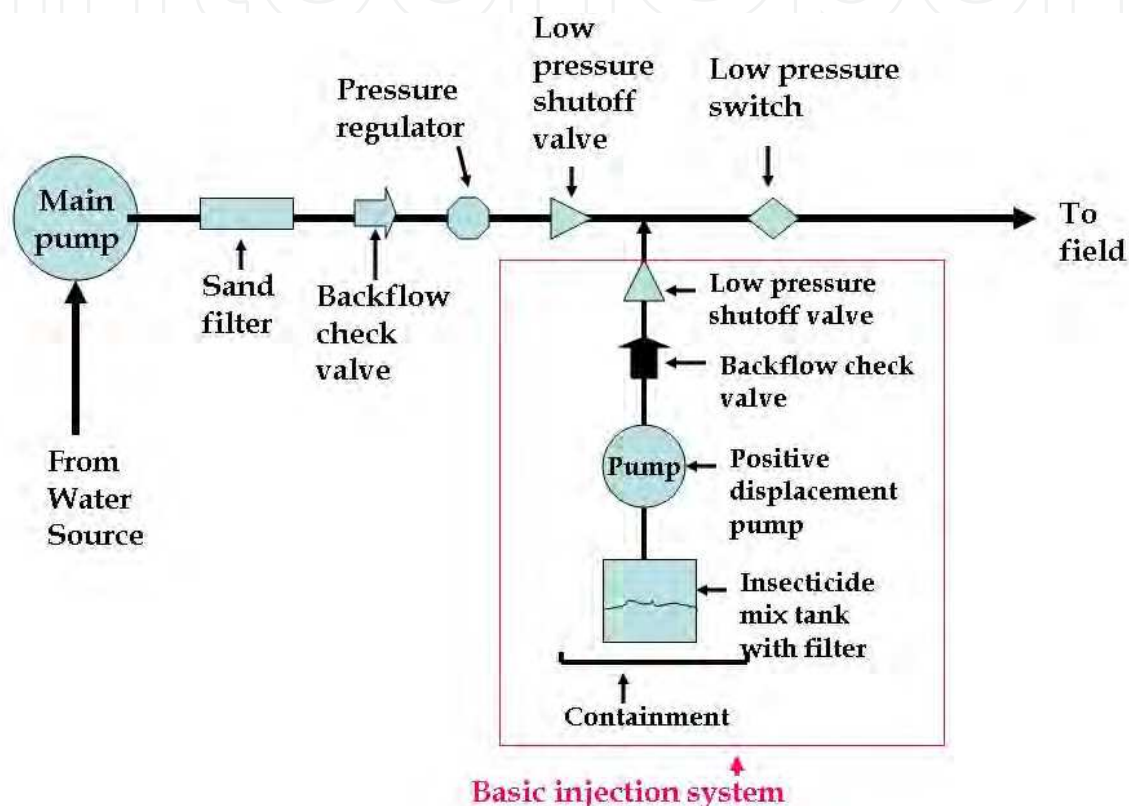


Fig. 1. A basic drip/trickle irrigation system with chemigation capabilities using a positive displacement injection metering pump.

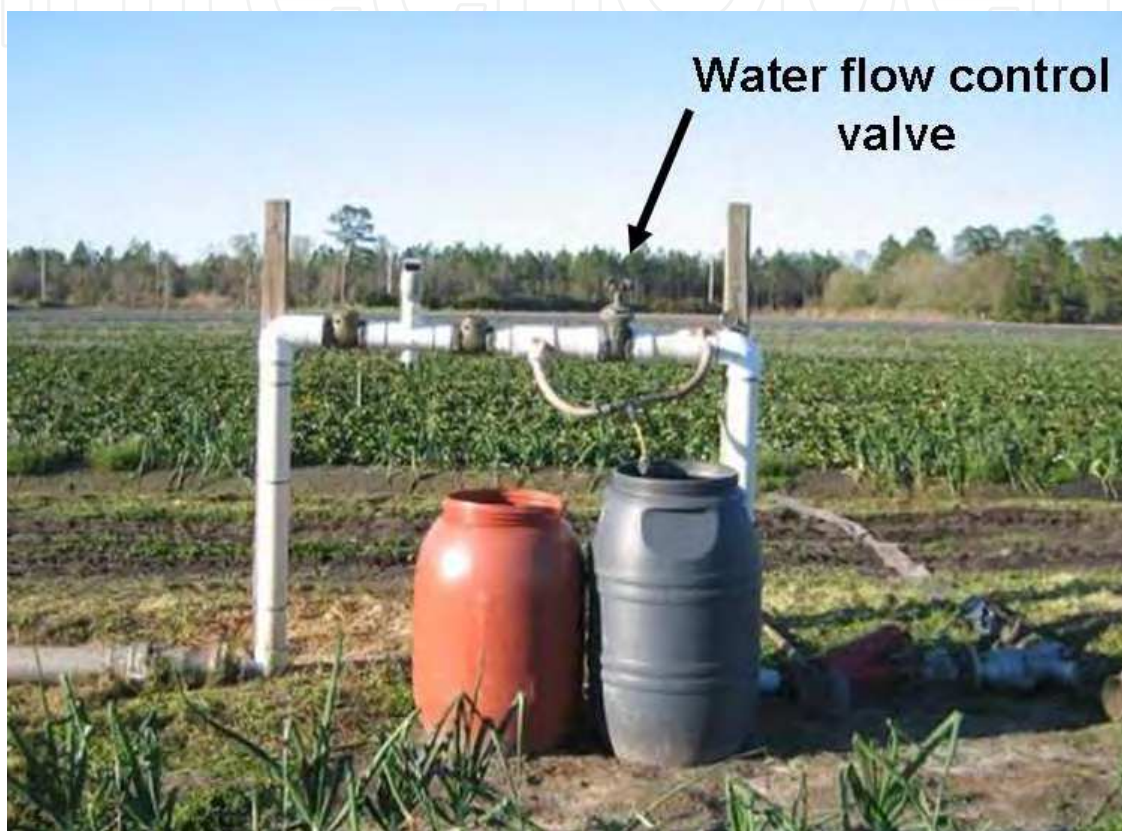
6.1 Volumetric pumps

There are two types of volumetric water flow pumps available. Both operate on the flow of water through the pump to suction out the chemical solution in the mixing tank.

6.1.1 Venturi pumps

Venturi pumps (Fig.2) are powered by water that flows through a constriction (Fig. 3) in the pump tubing, creating a change in water flow velocity, which creates a pressure differential that forms a vacuum. The vacuum pulls the chemical solution out of the chemical solution tank through a small diameter hose and injects a precise amount of chemical solution into the irrigation system in proportion to a certain volume of water. However, the injection rate varies with the pressure differential, and an accurate regulating valve and flow meter are

needed for calibrating the system if a precise metering of the chemical solution is necessary. The advantages of Venturi pumps are that these pumps are relatively inexpensive and very simplistic in that they essentially have no moving parts (except for the solution moving through it). All the suctioning activity is completed by the vacuum created within the pump. A valve in the main line between the inlet and outlet of the Venturi pump assists in the control of the volume of water flow. As with all other injection pumps, a backflow check valve is required. Filters just before the pump to remove particulates in the water are not as critical in the Venturi pump as it is with other pumps, but they are still recommended to be installed to prevent any potential clogging of the system.



Courtesy of E. Simmone, UF-IFAS.

Fig. 2. Venturi pump with a flow control valve between the water in port and the water out port.

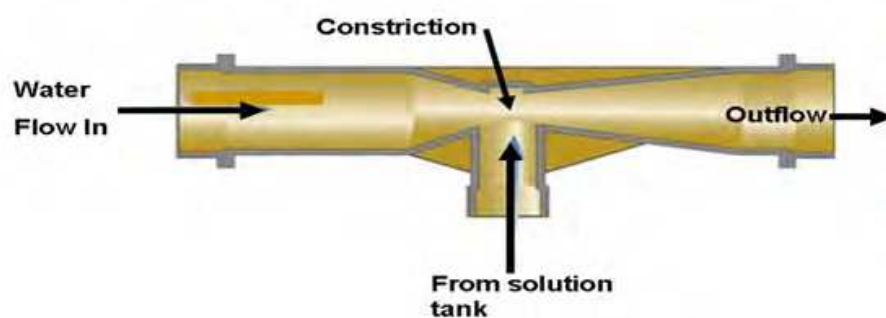


Fig. 3. Cross-sectional view of a Venturi pump. Note constriction in the center of the pump to create a suction to pull solution from chemical tank.

6.1.2 Proportional liquid injectors

A more complex water-driven pump than the Venturi pump is the proportional liquid injector (Figs. 4, 5). This pump injects a precise amount of chemical solution proportional to a volume of water, and operates with system flows of as low as 3.8 liter/hour (1 gal/hr). Water pressure is the power source (electric is not needed), as the water flow operates a piston inside the pump which takes up the required percentage of concentrate from the chemical solution tank, and in-line water pressure forces the solution downstream through the irrigation system (Fig. 6). The dose (concentration) of the chemical solution picked up is directly proportional to the volume of water entering the pump, regardless of variations in flow or pressure which may occur in the main water line. A bypass valve allows clean water to be supplied without operation of the pump, and also allows the pump to be easily dismantled while the irrigation system is operating. Proportional liquid injectors have moving parts within the pump, and these units cost significantly more than the Venturi pumps. In-line filters (300 mesh– 60 microns, depending on water quality) to remove particulates in the water supply are critical to the trouble-free operation of the pump. As with other chemigation injection units, a backflow check valve is required for proportional liquid injectors.



Fig. 4. A Chemilizer[®] volumetric injection pump.



Fig. 5. A Dosatron[®] injection pump injecting a pesticide in bell pepper, Bridgeton, NJ.

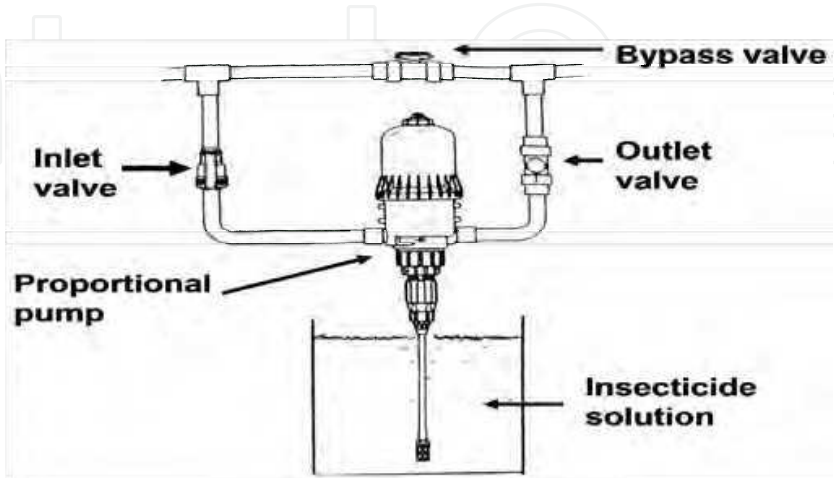


Fig. 6. Diagrammatic sketch of a proportional liquid injector pump connected to a drip/trickle irrigation system with a chemical solution mix tank.

6.2 Positive displacement metering pumps

Several types of positive displacement metering pumps are available, including both electric (Fig. 7) and gasoline-operated metering pumps (Fig. 8) and hydraulic metering pumps. The positive displacement pump has an expanding cavity on the suction side of the pump where a liquid solution is sucked in from the insecticide mix container, and a decreasing cavity on the outlet side of the pump where the solution is forced out into the irrigation system as the cavity collapses. The volume of liquid discharged is always constant for each cycle of operation by the pump, hence the term 'positive displacement'. These pumps can be easily and quickly transported between fields.



Fig. 7. A positive displacement electric (1/3 hp) metering pump with a 5-gallon jug for the concentrated insecticide solution and a containment tray beneath to catch all drips, spillage, etc. In the center of the picture is a flush valve to quickly and completely rinse all solution from within the pump.

Hydraulic drive metering pumps are positive displacement pumps that use the water pressure in the irrigation main lines from the irrigation well to power the pump instead of electric or gasoline power. Pumping cylinders can be mounted in parallel for large volume applications, or for injection of two non-compatible materials. Some models of hydraulic metering pumps have an adjustable piston stroke length to quickly change the precise flow of chemical solution to be injected, while other models change the injection rate by using a variable frequency drive on the pump which can vary the speed of the pump with the water flow rate.

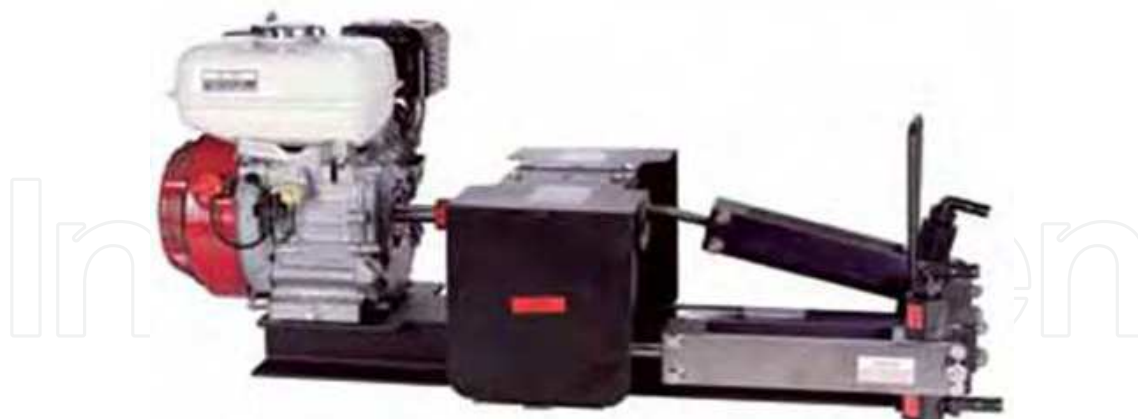


Fig. 8. A John Blue[®] E-Z meter injection pump. This pump is operated by a gasoline-operated engine.

7. Insectigation and water management

- Underwatering during injection will prevent the insecticide from uniformly reaching the root zone of all plants, reducing the systemic uptake and thus its effectiveness against the targeted insect pests.
- Overwatering (excessive watering during or after injection) increases the potential of the injected agrichemical to leach or move away from the root zone. Agrichemicals applied via a drip/trickle irrigation system are highly soluble, and too much water may reduce their effectiveness. Some insecticides, such as methomyl (Lannate L; E.I. DuPont de Nemours & Co., Wilmington, DE) and oxamyl (Vydate L; E.I. DuPont de Nemours & Co., Wilmington, DE), specify that best results are obtained when the product is applied at the end of the irrigation cycle, minimizing flush time to prevent the loss of efficacy. Other insecticides, such as rynaxypyr[®] (Coragen[®]), specify that best results are obtained when the product is injected at the beginning of the irrigation cycle (without over-irrigating). Thus it is important to carefully follow directions on the pesticide label.
- Uniform applications of the insecticide solution are necessary for consistent, effective control. Uniformity of application is controlled primarily by the duration of the injection period. Too short of an injection period will result in non-uniform distribution of the agrichemical, and not all plants will receive insecticide treatment alike. For very large fields, it may be best to establish irrigation blocks to reduce the size of the irrigated field which may result in a more uniform distribution of the injected material.
- After insectigation is complete, thoroughly rinse the irrigation system with clean water for the minimum injection time to ensure clog-free operation. It may take a considerable amount of time to completely remove all of the injected chemical from the drip/trickle irrigation system. For a thorough rinsing of the chemigation system, clean water should be pumped through the entire system for approximately twice the amount of time it takes water to leave the pump and reach the most distant emitter (the minimum injection time – see below).

7.1 Timing of insectigation applications

Injecting an insecticide via a drip/trickle irrigation system offers great flexibility in application timing. Depending on the presence of insect pests, the time required between root uptake and translocation throughout the plant needs to be considered. As a general rule, pest control is usually obtained within 24 hours after injection, depending on factors such as emitter spacing, length of time of injection, selection of insecticide, and plant growth stage.

- The overall objective of insectigation is to have an equal amount of insecticide released through every emitter in the system in order to have a uniform applicaiton to the root zone of all plants.
- The minimum injection time is the time needed for water to leave the injection pump and reach the most distant emitter in the field. To determine the minimum injection time, inject approximately 4 liters (about 1 gallon) mixture of water with a few drops of a household detergent soap, or with a few drops of a soluble food dye, through the system. Record the time beginning when the injection starts until the soap bubbles or dye reaches the furthest (very last) emitter – this is the minimum amount of time it takes for an injection to fill the system. Any injection time less than this will result in unequal application of the insecticide to the plants.
- Extending the length of time to complete the insecticide injection will improve uniformity of application delivery, especially in larger fields. Too short of an injection time will result in unequal application of the insecticide. As a general rule, the maximum injection time should last for no longer than 2 hours per irrigation block or zone (if the system is zoned).
- It is recommended that the injection of the insecticide be targeted to the middle third of an irrigation cycle. For example, if the irrigation cycle is 180 minutes, injection of the chemical should commence after the first 60 minutes.
- Run the drip/trickle irrigation system at the correct operating pressure for at least 30–60 minutes before injecting any insecticide. This will prime the system, wet the root zone of the plants, and ensure rapid, even uptake of the injected material.

7.2 Calculation of rates of insecticides (amount to inject)

To calculate the rate or amount of an insecticide to inject in a drip/trickle irrigation system, it is necessary to first determine the effective wetting zone. The wetting zone can be modified by changing the placement of the drip tape, the drip tape emitter spacing, the drip tape flow rate, or the frequency of water applications (the time the irrigation system is operating).

Example 1 (crop grown on bare ground). Crop is on beds 1.5 m (5 ft) wide planted to bare ground (drip irrigation but no plastic mulch). After applying enough water to wet the root zone of the plants, determine the width of the wet zone. The width of the wet zone X the total length of the rows under irrigation will yield the area (squared) of the wet zone. The rate should be based on this area. For example, if the total length of the rows is 8,712 row ft and the wet zone covers 2.5 ft wide, the total area to be treated is 8,712 ft X 2.5 ft = 21780 sq ft, or 0.5 acre (since there are 43,560 sq ft per acre). Refer to the insecticide label for the application rate/acre (amount of product per acre) and inject $\frac{1}{2}$ of that amount to the crop, since the area to be treated is only $\frac{1}{2}$ acre. In this example, if the label states 3.0 fl oz per acre (88.7 ml of product per hectare) per application, then inject 1.5 fl oz (44.4 ml) of product through the irrigation system.

Example 2 (crop grown on geds covered with plastic mulch). Crop is a single row on beds 1.5 m (5 ft) wide on black plastic mulch row cover with drip irrigation under the plastic. The mulched row (after plastic is laid) is now 0.91 m wide (3 ft) under the plastic, and this represents the wetting zone. As in Example 1 above, the width of the wet zone X the total length of the rows under irrigation will yield the total area (squared) of the wet zone. The rate should be based on this area. If the total length of the rows is 8,712 row ft and the plastic mulch covers 3.0 ft wide, the total wetting area would be 8,712 ft X 3.0 ft = 26,136 sq ft, or 0.6 acre (since there are 43,560 sq ft per acre). Refer to the insecticide label for the application rate/acre (amount of product per acre), and inject 0.6 of that amount to the crop. In this example, if the label states 3.0 fl oz per acre (88.7 ml of product per hectare) per application, then inject 1.8 fl oz (53.2 ml) of product through the injection system.

The amount of product injected for both examples remains the same whether the crop is single row per bed, double rows per bed, or more. The amount of product injected is always based on the area of the irrigation wetting zone, and not on the crop width or number of rows per bed. Many of the newer insecticide labels now have tables that list the amount of product per row foot to be injected based on different wetting zones.

Dilute the appropriate amount of insecticide as calculated for injection with water in a dedicated mix tank or poly jug. It is recommended to use a dilution rate of at least 5 parts water to one part of the insecticide. As a general rule, the greater the dilution rate, the better potential for increased uniformity of application. Mix the solution thoroughly before injection (an agitator in the mix tank may be necessary for some insecticides). The insecticide solution should be injected into the irrigation system at a point before the final filters, or have a filter on the chemical solution tank, to prevent any particulate matter from reaching and clogging the emitters.

7.3 Additional safety equipment for chemigation

The U.S. Environmental Protection Agency requires that the water source be protected from contamination by chemical solutions in case of unscheduled system shut down. It is important that the agrichemical injection pump be completely interlocked with the irrigation system so that the chemical injection pump will quickly shut down if the main irrigation pump were to stop, or if there was a loss of pressure in the irrigation system. This will prevent a free flow of chemical solution if there is a pressure drop or loss (resulting from a power loss, a break or hole in the drip lines, etc), and it will also prevent the irrigation and drip lines from filling up with the chemical solution if the main water pump stops for any reason.

A flow sensor installed downflow from both the injection pump and the main pump should be interlocked with the shutoff valves of both the main pump and the injection pump to shut down both the irrigation system and the insecticide injection system if water pressure at any point in the irrigation system drops or ceases. A two-way interlock between these pumps will also shut down both systems if one of the pumps stops or malfunctions (pump breakdown, power outage, etc.).

It is important to tightly seal leaks throughout the system, especially at the end of the drip tape where leaks often form puddles. Sealing these leaks will reduce or eliminate exposure of the injected insecticides to pollinators and other beneficial organisms and will result in a

more uniform distribution of the insecticide to the plant roots. It is also important to seal all hose joints and connections to prevent leaks which may contaminate the environment. And a containment tray or pan under the injection pump will catch any insecticide solution leakage that may occur during injection. This material can be re-injected at the end of the injection period.

Pay particular attention to the directions and restrictions on the pesticide label, as many products are permitted for use only in overhead or sprinkler irrigation systems but cannot be applied via a drip/trickle irrigation system. Only products specifically labeled for application through a drip/trickle irrigation system can be applied in this manner.

8. Conclusion

Insectigation offers growers a sound option in place of traditional foliar sprays of insecticides for control of specific insect pests of vegetables produced using a drip/trickle irrigation system. Use of the drip/trickle irrigation system for application of insecticides allows for precise placement of systemic insecticides into the root zone of vegetable crops, eliminating the need for multiple foliar sprays of insecticides. Many growers currently use drip irrigation systems for water management, and the addition of an agrichemical injection system is a cost-effective method of pesticide application. It enables growers to apply an insecticide under virtually any weather condition for control of a wide range of insect pests, including aphids, whiteflies, leafhoppers, leafminers, beetles, caterpillars, and others while at the same time reducing the total insecticide inputs as compared with foliar sprays. The overall benefits of using chemigation include less application labor, less energy inputs, less time needed for application, less pesticide inputs, less worker and applicator exposure to the pesticide, less potential of soil-borne disease problems, a more even distribution of the pesticide, and less soil compaction. It suits a pest management program well because many of the new-chemistry insecticides labeled for drip/trickle irrigation system application are selective to specific insect pests and, because they are applied to the plant root zone, are generally less toxic to beneficial and non-target organisms. And in an urban state such as New Jersey, where urban populations border rural populations, insectigation can be conducted with no spray drift or misapplications, eliminating the ever important 'application visibility' that concerns both growers and the public.

Many University fact sheets are available on the internet that include information and instructions on how to inject agricultural chemicals into irrigation systems, including:

University of Florida IFAS Extension publication #BUL250, *Injection of Chemicals Into Irrigation Systems: Rates, Volumes, and Injection Periods* (<http://edis.ufl.edu/ae116>)

University of Florida Publication #HS980, *How to Conduct an On-Farm Dye Test and Use the Results to Improve Drip Irrigation Management in Vegetable Production* (<http://edis.ifas.ufl.edu/HS222>)

South Dakota State University Fact Sheet 862, *Chemigation Management* (<http://agbiopubs.sdstate.edu/articles/FS862.pdf>)

Washington State University Fact Sheet FS035E, *Calculating Chemigation Injection Rates* (<http://cru.cahe.wsu/CEPublications/FS035E/FS035E.pdf>)

Oregon State University Bulletin *Pacific Northwest Insect Management Handbook: Guidelines – Chemigation*. <http://insects.ippc.orst.edu/pnw/insects?31ADJV09.dat>)

In addition, there are several commercially-produced technical brochures currently available that thoroughly describe drip/trickle chemigation system requirements, equipment set-up, injection pumps, calibration, safety equipment, application timing, water use and maintenance, etc., including *Drip Chemigation: Best Management Practices* (2008 Technical Update K-14954 from DuPont Crop Protection, E.I. DuPont de Nemours and Company, Wilmington, DE) and *Best Use Guidelines for Drip Application of Crop Protection Products* (2009 Technical Bulletin, Syngenta Crop Protection, Greensboro, NC 27419). Although these brochures are oriented towards the injection of insecticides into a drip/trickle irrigation system, the information is applicable to other agrichemicals applied through a drip/trickle system.

Also, it is important to refer to the current manufacturer labels of specific pesticides that can be used for chemigation. These labels list pests controlled, pesticide rates, restrictions, use directions, suggested application timing, required safety equipment, and other information necessary for successful chemigation. The pesticide label is a legal and binding document, and the pesticide user/applicator must carefully read, fully understand and adhere to all directions, instructions and restrictions on the label.

9. Glossary

Backflow check valve – a safety device that prevents the flow of water backwards from the irrigation delivery system to the water source (main pump or the injection pump). Operation is automatic and quick closing to prevent contamination.

Chemigation – the application of agrichemicals (fertilizers, insecticides, herbicides, fungicides, etc.) to crops through an irrigation system (overhead, drip, etc).

Chemical tank agitator – a device within the chemical tank that maintains constant mixture throughout the chemical injection process.

Containment device – a pan, tray, or dike that will contain any chemical leaks or drips from the chemical injection pump.

Drip irrigation – also called trickle irrigation, the application of water to the soil using low pressure and low volumes through emitters in tubing or piping. Drip irrigation generally uses flow rates of >3 gallons per hour at >10 psi.

Emitter – delivers water from a pipe or tube to the plant root zone. Also called a “dripper”, flow rates are generally between 0.6 – 16 L/h (0.16 – 4.0 gal/h). A pressure compensating emitter discharges water at a constant rate over a wide range of drip line pressures.

Insectigation – the application of soluble insecticides through a drip irrigation system. A type of chemigation.

Interlocking controls – device that interlocks the chemigation pump with the well pump so if one pump fails the other is automatically shut off.

Laterals – pipes or tubing that go from the control valves to the drip emitter tubes.

Low pressure shutoff valve – a device that shuts off the pump when pressure in the delivery system suddenly drops. Can be installed in the irrigation pipeline or at the pump.

Low pressure sensor – a device that detects sudden drop in pressure in the delivery system and relays the signal to the shutoff valve.

Main lines – pipes or tubing from the water source to the control valves of an irrigation system.

Plasticulture – the application of plastics in agriculture for plant production, including row covers, drip irrigation, plastic tunnels, etc.

Positive displacement pump – a water pump that assures proper rate of injection of a liquid.

Pressure regulator – a device that maintains constant pressure downflow. It cannot increase pressure.

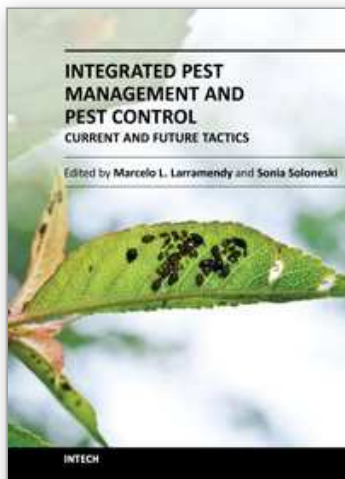
Subsurface irrigation (SDI) – drip systems that are buried beneath the soil surface, not recovered between cropping cycles. Some SDI systems are semi-permanent.

Vacuum relief valve – a device that prevents back siphoning, usually installed upflow of the mainline backflow check valve.

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