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Drip Chemigation of Insecticides as a Pest Management Tool in Vegetable Production

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ABSTRACT. Drip, or trickle, irrigation was used as early as the late 1800s, although it was not until the development of modern plastics during World War II that drip irrigation became economically possible. Developed initially to reduce or prevent moisture stress in the plant, drip irrigation systems also offer an excellent method to apply agrichemicals to the root zone of plants. The application of insecticides through a drip irrigation system was first attempted in the 1980s by using various carbamates and organophosphates, although success was limited. Currently, several newly-developed insecticides such as the neonicotinoids and anthranilic diamides are drip-injected for the control of many vegetable insect pests. The advantages of drip-injection of insecticides over ground application methods include a uniform distribution of insecticide throughout the plant; a reduction in pesticide application inputs, including manpower and vehicle or tractor fuel; and a reduction in soil compaction, plant disturbance, and applicator exposure to pesticides. Insecticides applied through a drip irrigation system can replace or reduce the number of foliar insecticide sprays, reducing the risks to nontarget species.

Key Words: chemigation, drip irrigation, imidacloprid, thiamethoxam, chlorantraniliprole

Drip, or trickle, irrigation is a method of uniformly delivering water and nutrients to a plant's root zone in the precise amounts required to meet the needs of the plant (Roberts 2004). Drip irrigation was used in Europe as early as the 1860s when a type of trickle irrigation system was developed for subsurface irrigation in Germany by using perforated irrigation pipe (Ross et al. 1978). However, modern-day commercial trickle irrigation systems were not possible until the development of plastics after World War II.

The first use of trickle tubing in conjunction with a plastic film row cover, together called 'plasticulture' (Fig. 1), 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 Extension Agent (Ayars et al. 2007). As irrigation-line filters improved and consistent emitters were developed over the next decade, trickle irrigation increased to >54,000 ha in the United States by 1975, being used on various crops in 35 different states. By 2000, trickle irrigation was used on >200,000 ha in California and the Pacific Northwest region of the United States alone (Anonymous 2000).

'Chemigation' is a term defined as the application of agricultural chemicals, including herbicides, insecticides, fungicides, and fertilizers through a center pivot system (Chalfant and Young 1982, 1984) (i.e., an overhead sprinkler line that rotates continuously around a pivot point at the center of a field). However, other terms that have been used to denote the application of agricultural chemicals through an irrigation system have been confusing, including 'pestigation' (Larsen 1982); 'insectigation' (Owens 1981); 'fertigation' (Hall 1982); 'herbigation' (Johnson et al. 1987); 'fungigation' (Potter 1981, Johnson et al. 1987); 'drip chemigation' (Wildman and Cone 1986); and 'drip trickle chemigation' (Certis USA 1999).

In the United States, overhead irrigation systems first were used for the application of fungicides and insecticides in the mid-1970s (McMaster and Douglas 1976, Raun 1979), and drip irrigation systems first were used to deliver fertilizers to vegetable crops in the late 1970s (Paterson 1980, Hall 1982). However, the first reported application of an insecticide through a drip irrigation system in the United States was made by Ghidiu and Smith (1980), who injected the carbamate oxamyl (Vydate 2L, E.I. DuPont de Nemours & Co., Wilmington, DE) for control of European corn borer, *Ostrinia nubilalis* (Hübner), in bell peppers. They reported that damage caused by European corn borer in the chemigated plots was not significantly different than damage in the untreated plots. Other carbamates and organophosphates including disulfoton, carbofuran, and methomyl were measured in drip irrigation systems in vegetables throughout the 1980s; however, results regarding insect control efficacy were mixed (Ghidiu 1981, Overman and Price 1983, Wildman and Cone 1986) and, in some instances, problems with phytotoxicity were observed (Ghidiu et al. 1992). In addition, Reed et al. (1986) successfully applied entomopathogenic nematodes through a drip irrigation system for control of spotted cucumber beetles, *Diabrotica undecimpunctata howardi* Barber, in cucurbits. Ghidiu et al. (1992) concluded that any insecticide applied through a trickle system would need to be safe to the crop (nonphytotoxic), highly soluble (to prevent clogging the drip emitters and ensure movement to the root zone), xylem mobile (to travel upwards from the roots to the upper plant portions), and effective against specific insect pests that attack the crop.

Present Day Drip Chemigation of Insecticides in Vegetable Crops. In the early 1990s, the first neonicotinoid insecticide, imidacloprid, was introduced. Several years later, other neonicotinoids, including thiamethoxam, dinotefuran, and clothianidin also would be registered. Since that period, these chemicals have been widely used on vegetable crops to control leaf-feeding beetles and sucking insect pests such as leafhoppers, psyllids, aphids, thrips, and whiteflies. Neonicotinoids are neurotoxins that target the nicotinic acetylcholine receptor acting as agonists (Maienfisch et al. 2001). Although they are effective as contact insecticides, it is the ability of these chemicals to be taken up by the roots from the soil as systemic insecticides and transported to the foliage that has been one of the primary reasons for their success. These insecticides are particularly suitable for application through a drip irrigation system because they are effective against specific insect groups, they are soluble and have systemic properties, they are relatively nonphytotoxic, and they are considered reduced risk pesticides under the U.S. Environmental Protection Agency (USEPA) Federal Reduced Risk Pesticide Program (http//:epa.gov/opprd001/workplan/reducedrisk.html). Felsot et al. (1998) examined the distribution of imidacloprid in soil when applied through a drip irrigation system, and

Fig. 1. Staked bell peppers with drip irrigation and a black plastic mulch row cover, NJ.

concluded that imidacloprid was a good candidate for drip chemigation. Imidacloprid and other neonicotinoids applied through a drip system have been shown to provide effective control of whiteflies and aphids in desert vegetable crops (Kerns and Palumbo 1995, Palumbo 1997, Palumbo et al. 2001) as well as cucumber beetles in cucurbit crops (Kuhar and Speese 2002). A single application of these insecticides through a drip irrigation system provided similar control as multiple foliar sprays.

More recently, a newly developed class of insecticides, the anthranilic diamides, has been shown to be highly toxic to virtually all lepidopteran pests (Lahm et al. 2005). Chlorantraniliprole, an anthranilic diamide, is xylem-mobile through root uptake, moves systemically throughout the plant's green tissue, and controls many leaf-feeding pests (Lahm et al. 2007). Schuster et al. (2009) reported that a single or double drip application of chlorantraniliprole effectively reduced both leafminer, *Liriomyza trifolii* (Burgess); and armyworm, *Spodoptera* spp., damage in tomatoes (*Solanum lycopersicum* L.). Ghidiu et al. (2009) injected chlorantraniliprole for European corn borer control in bell peppers over a 3-yr period and reported significant reduction of damaged fruit. Further, they reported that two injections of chlorantraniliprole were as effective for European corn borer control as multiple (up to nine) foliar applications of a standard insecticide program by using a ground sprayer. Kuhar et al. (2008) achieved similar levels of European corn borer control with soil applications of chlorantraniliprole in pepper. Kuhar et al. (2010) further reported that two drip applications of chlorantraniliprole significantly reduced the percentage of tomatoes damaged by tomato fruitworm, *Helicoverpa zea* (Boddie), as compared with that typically achieved using multiple foliar applications of insecticides. Palumbo (2008) reported that two drip applications of chlorantraniliprole during stand establishment provided excellent residual control of *Trichoplusia ni* (Hübner), *Spodoptera exigua* (Hübner), and *Liriomyza* spp. in romaine lettuce (*Lactuca sativa* L. var. *longifolia*), with no significant marketable yield loss. In addition to chlorantraniliprole, there are additional new-chemistry systemic insecticides such as cyantraniliprole (an anthranilic diamide) soon to be registered in vegetables for control of an even greater pest spectrum (Ghidiu 2009; Kuhar et al. 2011a,b; Palumbo 2011).

Discussion

The application of insecticides through a drip irrigation system has been used successfully for the control of a variety of vegetable insect pests. Because many vegetable growers already use a drip irrigation system for water management, the injection of a pesticide can easily and inexpensively be achieved with the addition of an injection pump and the required safety equipment (switches, check valves, drain valves) for the injection of soluble pesticides (Fig. 2). The current availability of novel, systemic insecticides that are labeled under the EPA Reduced Risk Pesticide Program such as neonicotinoids (including imidacloprid, clothianidin, thiamethoxam, and dinotefuran) or anthranilic diamides (including chorantraniliprole and cyantraniliprole), as well as additional future insecticides under development, have advanced the opportunities for drip chemigation as an effective and environmentally sound pest management tactic.

The advantages of drip chemigation are numerous. The total insecticide inputs for control of insect pests in most crops is reduced using drip chemigation when compared with that of traditional foliar applications, whereas essentially the entire plant is protected. In many trials with vegetable crops, 1–2 drip applications of an insecticide per season resulted in equivalent, or better, control of specific insect pests as compared with multiple foliar applications (Palumbo 2008; Ghidiu 2009; Kuhar et al. 2008, 2010). With fewer applications needed, less total energy inputs are required (either by tractor or by large horsepower overhead irrigation system pumps), and no soil compaction occurs as a result of heavy spray equipment being operated within the crop. Also, certain plant diseases, such as *Phytophthora capsici* Leonian, a soil-borne fungus, which produces spores that are spread via water splashing onto the foliage by rainfall, tractor wheels, and other factors, may be reduced because foliage is not wetted and the soil moisture can be better controlled (Ristaino and Johnston 1999). Drip chemigated fields also reduce potential worker exposure to pesticides by eliminating the application of insecticides to the plant foliage.

Fig. 2. Chemigation of staked tomatoes under black plastic with trickle irrigation, VA.

Weather is not a factor during or after application, as drip chemigation is not affected by wind, and application can be made when fields are too muddy to operate ground equipment. Also, drip chemigation allows for flexibility in application timing when injections can be made virtually any time during the season from stand establishment until harvest. For many growers, where urban encroachment is rapidly taking place near their fields, drip chemigation can be completed without spray drift, eliminating 'application visibility' that concerns many growers and their residential neighbors. This is especially true when considering the visibility of mist applicators and air blast sprayers. In addition, because many of the newer insecticides such as the neonicotinoids and anthranilic diamides are selective to certain insect pests, they are generally less disruptive to nontarget species and beneficial organisms.

Drip chemigation with insecticides has some disadvantages. There are initial capital expenditures for the chemical injection equipment, the costs being dependent on the type of system installed, equipment selection, and other expenses. However, much of this equipment can be reused over several seasons. Also, drip irrigation systems generally require a high level of maintenance and regular monitoring of the entire system for pressure fluctuations, leaks in the system, plugged emitters, and other potential problems, all of which are even more important when insecticides are injected. And because some of the new compounds have exhibited long residual activity after chemigation, caution should be taken not to overapply the products to sustain insect susceptibility.

Considerations for Drip Chemigation with Insecticides In Vegetable Crops. Optimal application timing of a root systemic insecticide through a drip irrigation system depends on the ability to efficiently deliver the compound to the actively growing roots. Several agronomic and operational factors should be considered before insecticides are applied through any drip or trickle irrigation system.

Crop Growth Stages and Root Types. Plant size at the time of chemigation may determine how an insecticide is applied (Syngenta 2009). Early in crop establishment, seedling plants and transplants generally occupy a small root zone as compared with the well-developed and expanded root zone of larger, more mature plants. In either case, insecticide efficacy will occur only if the soil in the root system has adequate soil moisture for plant growth and insecticide uptake. Root type also will influence the results of chemigation. For example, broccoli tends to have a relatively shallow and fibrous root system, and will have different irrigation requirements than would a deep, tap-root crop like watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai].

Soil Properties. Movement of insecticides through the soil during chemigation will depend partially on the soil texture and the amount of organic matter in the soil. Irrigation water moves at higher flow rates in coarse-textured sandy soils than in fine-textured clay soils, which tend to hold water longer. Consequently, soil texture will determine drip irrigation frequency and duration as well as when an insecticide is applied via drip chemigation. Furthermore, soils with high organic matter may actually reduce the availability of an insecticide for root uptake, depending on the chemical properties of the insecticide.

Physiochemical Properties of the Insecticide. The water solubility and partition coefficient of an insecticide will influence movement of the insecticide in soil and determine how the insecticide is best applied via drip chemigation. For example, because of the low water solubility and low partition coefficients of imidacloprid, clothianidin, and chlorantraniliprole, insecticides that contain these active ingredients have little mobility in soil. Thus, when applying a compound such as chlorantraniliprole through a drip irrigation system, it should be injected at the beginning of the irrigation event followed by a long period of irrigation to push the compound into the root zone (DuPont 2008). In contrast, insecticides with a higher water solubility and high mobility in soil, (e.g., oxamyl, thiamathoxam) should be applied near the middle third of the irrigation cycle to avoid leaching the compound out of the effective root zone (DuPont 2008, Syngenta 2009). Currently, many insecticide labels that permit drip chemigation recommend an optimal injection time during the irrigation cycle for that particular insecticide.

Type of Drip/Trickle Irrigation System. The type of drip tape used can influence the performance of a drip chemigation treatment. The flow rate and emitter spacing on the drip tape, coupled with the crop irrigation requirements, largely will determine irrigation frequency and how the insecticide is delivered to the root system. Ideally, emitter spacing should match up with plant spacing whenever possible to maximize delivery to plant roots. Drip tape placement relative to the roots may also influence application timing. Drip application of insecticides with low soil mobility (e.g., chlorantraniliprole) in subsurface drip tape buried >12.7 cm (5 in.) below the plants should be applied after the root system has become established near the tape. Drip chemigation in crops where the drip tape is placed on the soil surface at the base of plants is more flexible.

Another important factor for optimal insecticide activity with soil systemic compounds is to ensure that the correct amount of irrigation water is applied through the drip system during and after the insecticide injection. Insufficient amounts of water can prevent the insecticide from being adequately available to the roots for uptake, and, conversely, too much water may result in the compound being moved or leached out of the root zone. Either of these events can delay insecticide uptake by the plant and reduce efficacy. It is critical that the water–insecticide mixture be applied as uniformly as possible across the entire field during drip chemigation. Depending on the irrigation system, the amount of time to uniformly distribute the insecticide will depend on type of drip tape used, the insecticide pumping system, the length of time of the insecticide injection, and the length of time the irrigation system is allowed to operate after the injection. Ghidiu (2012) discusses and lists the benefits and disadvantages of various drip chemigation pumping equipment. Growers should be aware of these factors before making insecticide applications through drip irrigation systems.

Recommendations. Drip chemigation offers growers a sound option to traditional foliar sprays of insecticides as well as new opportunities for integrated pest management (IPM) in conventional vegetables that may not have been available since the widespread use of synthetic insecticides. It enables growers to apply 1–2 applications of an insecticide directly to the plant roots for control of specific insect pests, including aphids, whiteflies, leafhoppers, beetles, leaf miners, and lepidopteran larvae. Many growers of vegetable crops currently use drip irrigation systems for water and nutrient management. The use of such a system for specific insecticide applications would result in an environmentally suitable and cost-effective IPM system with less total inputs (time, labor, insecticides) and with less effect on nontarget species as compared with multiple foliar sprays of more broad-spectrum pesticides. The impact on current IPM programs should be minimal as most drip-applied insecticides are effective within 24–72 h after injection, allowing growers to inject an insecticide into the irrigation system after thresholds are exceeded.

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