INFLUENCE AND USE OF DRIP IRRIGATION IN NEMATODE MANAGEMENT- A REVIEW

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ABSTRACT

Water shortages have increased growers interest in drip irrigation. The use of drip irrigation in agriculture has increased rapidly during the past 25 years. The drip irrigation has been used to deliver fertilizers and pesticides and there are increasing number of studies on the application of nematicides or other pest control agents via drip irrigation. The results of the experiments conducted so far for the management of nematodes through chemicals and bioagents; insect pests through entomopathogenic nematodes using drip irrigation system are encouraging and it is inferred that the application of nematicides through drip irrigation is simpler, safer and more cost effective than conventional nematicides application methods. In the following we summarize the results of experiments conducted for the management of nematodes and certain insect pests with other details relevant to drip irrigation system. The information should aid future assessment of drip irrigation system in the management of wide range of nematodes in various crops.

Key words: Drip irrigation, Nematode management.

Water availability is one of the most important parameters regulating biological activities in soil. Changes in water availability will influence soil organisms through complex interactions with nutrient conditions, soil temperature, pore size distribution and soil atmosphere.

The relationship between moisture stress and nematode induced damage to crop plants is reasonably well established and some researchers have demonstrated the influence of irrigation on nematode population dynamics and plant growth. The drip irrigation alone reduced population of nematodes viz., Xiphinema americanum and Pratylenchus penetrans associated with peach root (Funt et al., 1982). Similarly the incidence of lettuce drop caused by Selerotinia minor and corky root caused by Rhizomonas suberifaciens occurred at a lower rate under subsurface drip irrigation than under conventional furrow irrigation (Subbarao et al., 1997). Further drip irrigation is less conducive than sprinkler irrigation to stem rot disease of potato (Brown et al., 2002).

1. Drip irrigation

The use of drip irrigation technology in crop production is widely regarded as the most promising irrigation system. The drip irrigation system designed to provide frequent low volume irrigation to crops, conserve energy and labour in addition to conserving water and minimizing environmental contamination (Bahme et al., 1987a).

Drip irrigation serves to provide the plant with optimal water conditions, thus reducing the influence of nematode stress (Funt et al., 1982). It is considered that surface drip irrigation which can maintain a relatively dry soil surface while maintaining crop water requirements would be less conducive than conventional system of irrigation to plant diseases and nematodes (Brown et al., 2002).

Currently the drip irrigation system has been used to deliver fertilizers, pesticides including biopesticides (Bucks et al., 1982; Burelle et al., 2002, Davies and Bucks 1983; Johnson et al., 1986, McIntosch et al., 1984; Shoji 1977 and Solel et al., 1979) and there are increasing number of studies on the application of nematicides or other pest control agents via drip irrigation (Apt 1981; Bahme

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et al., 1987b; Garabedian and Van Gundy, 1985, Keng et al., 1985; Overman 1982 & 1987; Radewald et al., 1985; Roberts & Mathews, 1987; Schenick and Apt, 1987 and Van Gundy & Garabedian, 1984) and it resulted in the suppression of pest and diseases in many crops (Overman et al., 1979; Overman 1977; Overman and Price, 1983).

It is also reported that the crop yield in this system is higher compared to crops irrigated through conventional system under similar situation (Apt and Caswell, 1988; Brown et al., 2002; Hartz 1993; Phene, 1995; Sausmis, 1980; Scherm & Van Bruggen, 1995).

1.1 Methods of drip irrigation

Drip irrigation can be implemented in various ways including surface, subsurface, bubbler, sprays (Davis and Bucks, 1983), or traveling drip systems (Phene et al., 1985). The objective is to provide the plant root zone with sufficient water to meet evapo-transpiration demands (Davis and Bucks 1983 and Phene et al., 1985).

2. Concepts and history

Drip or trickle irrigation delivers relatively low volumes of water as drops, streams, or sprays through holes or emitters located at intervals along plastic water delivery lines (Davis and Bucks, 1983; Shoji, 1977). The basic concepts involved in drip irrigation can be traced back to experiments on subirrigation and drainage in Germany in the 1860s (Soffer, 1971). Since that time many developments and refinements have occurred, the most important being the development of the plastic industry after World War II (Shoji, 1977). Drip irrigation was introduced to the United States in the 1960s and currently is used for growing many crops in different countries.

3. General advantages

A major advantage of the system is that it supplies only the volume of water required by the plant directly to the root zone. Hence it is an economically sound method for applying water because costs are minimized. This is quite important in areas where water costs are rising rapidly. Additional general advantages (Davis and Bucks, 1983; Shoji, 1977) include the following:

- It makes maximum beneficial use of the available water.
- The grower controls water infiltration rates.
- Water is supplied to plants on the basis of phenological requirements.
- Drip irrigation systems can be easily adapted to automated control.
- Saline water may be used.
- Disease incidence is reduced through decreased wetting of plant leaves.
- Weed growth is reduced by decreasing the area of soil supplied with water.
- The system provides a vehicle for application of fertilizer and pesticides.

3.1 Advantages to Nematological Science

It is hypothesized that the system includes the following advantage with reference to Nematological Science (Davis & Bucks, 1983; Shoji, 1977). The passive movement of nematodes usually occurred in conventional system of irrigation is completely prevented in drip irrigation system. Generally the mobility of nematodes is much restricted in nonrhizosphere area in this system and it leads to natural suppression of nematodes to some extent. Also, the nematodes present in the rhizosphere became active on drip irrigation and easily susceptible to nematicides applied through this system. Suppression of weed growth in drip irrigation system helps to avoid the weeds acting as alternate/collateral hosts to nematodes during cropping/offseasons. Besides the system facilitates the placement of nematicides at target zone and provides chance to minimize the quantum of nematicides compared to conventional system (Davis and Bucks, 1983). Further the system has following merits over nematodes and their management.

3.1.1 Environmental contamination

The potential for groundwater contamination is a major concern with soil application of nematicides (Thomason, 1987). Many instances of groundwater contamination have been recorded earlier (Brennan, 1987). In 1980, ethylene dibromide (EDB) and 1,2-dibromo-3-chloropropane (DBCP) were discovered contaminating Hawaii’s groundwater (Brennan, 1987). Although the concentrations were low, the public outcry was vigorous. Similar situations have arisen with other nematicides in many regions of the United States.
(Thomason, 1987). The drip irrigation application of nematicides facilitating use of lower amount of nematicides can minimize environmental contamination by facilitating precise control of nematicide placement and quantity of nematicide delivered (Funt et al., 1982)

3.1.2 Nematode resistance and nematicide degradation

The potential for nematodes developing resistance to nematicides is still largely unknown. Recent studies have demonstrated, that exposing populations of nematodes to nonfumigant nematicides may result in behavioral changes as observed with Xiphinema index or decreased sensitivity to a nematicide as in the case of Meloidogyne incognita and Pratylenchus vulnus. The development of resistance to nonfumigant nematicides in the field with X. index and M. incognita has also been observed (Yamashita and Viglierchio, 1987).

Application of nematicides over long periods at relatively low concentrations in repeated applications via drip irrigation is a potentially strong selection pressure for resistance. Application of nematicides through drip irrigation results in root systems and nematode populations being confined to limited soil volumes and there is a smaller portion of the nematode gene pool “escaping” the nematicide by residing in nontreated areas, as does occur with other methods of application (Thomason and Caswell, 1987). This may enhance the development of resistance because there is a limited nonexposed gene pool to dilute the increasing frequency of resistance genes. This may not be a problem in deeply rooted crops where soil moisture is adequate for nematode movement throughout the soil profile.

Frequent application of nematicides at low concentrations via drip irrigation is also a strong selection for populations of micro-organisms capable of degrading specific nematicides (Thomason and Caswell, 1987). The increasing frequency of such micro-organisms in the root zone will decrease the concentration and hence efficacy, of the nematicide in the soil profile.

3.1.3 Activation of quiescent nematodes

Water applied via drip irrigation apparently induces quiescent nematode eggs to hatch, resulting in active susceptible juvenile stages being present in the soil when a nematicide is applied (Apt and Caswell, 1988).

3.1.4 Maximization of pesticide efficacy

Additionally when drip irrigation is used as a delivery system for fertilizer, nematicide or other pesticides the efficacy of the pesticides is often maximized in relation to dosage, allowing the effective use at lower rates (Keng and Vander Guilk, 1984; Keng et al., 1985)

4. Nematode management

The application of nematicides through drip irrigation, mentioning considerations that are important for successful application, problems, disadvantages and future directions are discussed below.

During the past several decades, nematode control on commercial crops has been primarily chemical in nature and has consisted largely of soil fumigants applied by chisel injection. Although it is possible to have fumigant failures because of poor soil preparation, injection methods, or soil moisture or temperature conditions, the nature of the treatment – the diffusion of a volatile gas through soil pores has had a considerable margin for error. This margin allows fumigant application under less-than-ideal conditions by the researcher or grower.

Applying nematicides (volatile or non-volatile) by drip irrigation depends on water movement and hence is quite different from injecting volatile soil fumigants that diffuse as a gas. Awareness of factors influencing the success of a water application is essential because poor application technique will yield poor results.

4.1 Nematicide characteristics

All nematicides, regardless of application methods used, should be handled carefully and in accord with label instructions. Applicators should be aware of the mammalian toxicity of the nematicides applied and the symptoms of poisoning, and they should be familiar with emergency procedures and capable of performing them in case of accidents during application.

Nematicides differ chemically, and these differences are important in timing, application rates, and the design of application methods. Before considering application of a nematicides through
drip, it is desirable to know the parent compound, its chemical characteristics, its half-life in a particular soil, and its mobility in relation to the organic matter content and pH of the soil. Knowledge of the breakdown products, or metabolites, of the parent compound and their behavior in soil is also desirable.

For example, the half-life of fenamiphos in Hawaiian soils is 3-5 days; it adsorbs strongly to organic matter. Consequently its movement is limited. The nematicidal metabolite, fenamiphos sulfoxide, is highly mobile with a half-life of 45-70 days (Lee, 1987). Excessive water applied through irrigation or rainfall will quickly move this metabolite out of the top 30 cm of soil (Schnelder et al., 1988). Fenamiphos sulfone, the breakdown product of the sulfoxide, is less mobile. The data base on adsorption and penetration of various nematicides in different soil types needs to be developed further because such information will be important as a guide to application rates and frequency of irrigation.

4.2 Nematicide movement in soil

Critical factors determining the success of nematicides application in the field by drip irrigation are the wetted surface area and the wetting depth. Management of the wetting depth, which assures penetration of the compound to the root zone, requires knowledge of the physics of a particular soil. Simplified equations have been developed that allow estimation of distribution patterns of nematicides in relation to discharge rate, desired pesticide concentration, and irrigation time (Keng and Vander Guilk, 1984). Applying the equations requires knowledge of the soil hydraulic conductivity and soil sorptivity. Soil profile heterogeneity, due to cultivation or biological activity, was not included in the development of the equations. This is a problem when applying the equations to field conditions because soils contain macropores such as earthworm burrows or canals left by decaying roots, resulting in a wetting depth greater than that predicted (Keng et al., 1985). The equations represent an excellent starting point for estimating the parameters involved in applying nematicides through drip.

Two dimensional profile sampling, laterally and vertically from the drip tube beneath an emitter was made to assess the distribution of nematicides in pineapple beds. A nematicide that demonstrates good lateral movement in one soil type may be much more mobile vertically in a different soil. Depending on the depth and growth pattern of the root system being protected, differential nematicides mobility may be important.

If a soil fumigant, such as 1,3 – D, is applied as an emulsifiable formulation by drip irrigation, it moves through the soil pores in the water front, as opposed to movement as a gas when applied by chisel injection. The success of a water application of 1,3-D is influenced by the amount of water used in the application and the moisture content of the soil at the time of application. Injection of 1,3-D must be relatively quick and followed by a large amount of irrigation water – at least 1 acre-inch to move the nematicides into the root zone.

4.3 Period of protection

The critical period for protection of plant root systems by nematicides applied through drip irrigation varies with the crop plant. An important consideration is awareness of the characteristics of the root system with respect to rooting depth and root growth patterns.

In pineapple, the soil roots originate from the base of a vegetative seed piece, the crown, slip, or sucker. The primary roots maintain initial plant growth, establish the mother stem, and subsequently produce sucker growth and ratoon crops. The root system penetrates to a depth of approximately 45 cm, depending on soil conditions. The loss of these primary roots through nematode infection early in the season is highly detrimental to subsequent stem growth and yield. The protection of the initial root flush is important for the establishment of the crop. Specifically, maximum yields of pineapple are obtained in the plant crop and first and second ratoons (2.5-3.5 years) only if the initial root system is maintained in a healthy condition for 8-12 months (depending upon the nematode population density). Plant response from postplant nematode control is notably greater when 12 months of protection is provided, as compared with 6 months; however extending protection to 18 months does not improve the plant response (plant crop and ratoon yields) significantly (Apt and Caswell, 1988).

In contrast, roots of Protea (Protea spp.) penetrate deeper in the soil and have annual flushes of growth. A nematicide applied postplant by drip
irrigation to *Protea* will not affect existing infections of *M. incognita* as females and juveniles may remain inside galled tissue. Thus, original, infection sites provide inoculum indefinitely. Appropriately timed applications of nematicides may protect flushes of new roots, however, thus allowing the new roots to maintain plant growth. For *Protea* then, periodic postplant treatments are required for the duration of the plant’s life, which may be many years.

Maintaining low concentrations of carbosulfan, carbofuran, aldoxycarb, or oxamyl in the root zone of tomato through multiple applications via drip irrigation provided protection against *M. incognita* as measured by root galling (Garbedian and VanGundy, 1985). The application schedule determined the efficacy of the nematicides with respect to yield. Four applications of oxamyl, aldoxycarb, and carbofuran applied at 0.37 kg a.i./ha beginning at planting and 3, 6 and 14 days later (2.22 kg a.i./ha total) resulted in significant yield increases (Garbedian and Van Gndy, 1985).

In Hawaii oxamyl applied at 3.4, 6.7 and 13.4 kg a.i./ha through a biwall tubing with emitters 30.5 cm apart reduced populations of *Rotylenchulus reniformis* by 70.5, 76.3 and 91.5%, respectively, 4 weeks after a single application (Apt et al., 1987).

Four monthly applications of oxamyl at 3.4 kg a.i./ha reduced the average nematode population density in the soil profile by 99 per cent. Less effective control was obtained with a single application of 13.4 kg a.i./ha at planting. The estimated half-life of oxamyl applied through flood irrigation is 1-4 days, with penetration of about 152 cm deep (McIntosh et al., 1984).

Metham sodium can be applied successfully by drip irrigation. It should be applied throughout the irrigation period with no water applied postapplication. Overman (1982) found that a single preplant (14 days preplant) injection of methan sodium at the rate of 224 kg/ha through a drip irrigation system significantly reduced root galling and increased tomato yields. Incremental injections of metham sodium equally spaced over a period of 9 weeks significantly reduced root galling, but did not significantly increase tomato yields. Roberts and Mathews., (1987) found preplant application of metham sodium through drip irrigation is superior to conventional fumigation with 1,3-D in controlling *M. incognita* on tomato.

### 4.4 Duration of application

There are two basic approaches to the time allotted for nematicides injection during an irrigation run: the nematicide can be injected rapidly, followed by a determined amount of water; or the nematicide can be applied continuously during the irrigation run. In most cases nematicides applied over the irrigation run, allowing sufficient time after the injection period to clear the nematicide from the lines.

### 4.5 Control treatments

Experiments designed to assess the efficacy of nematicides applied through drip irrigation should include an irrigated control treatment. Drip irrigation by itself may have a substantial influence on plant growth and not taking this into account may result in erroneous interpretations of the efficacy of a nematicide. The nematicide may appear more effective than it is.

The importance of including an irrigated control treatment was shown when trickle irrigation alone reduced populations of *X. americanum* and *P. penetrans* associated with peach roots (Funt et al., 1982). Pineapple plants may tolerate a specific nematode density more readily under irrigated than under nonirrigated conditions. In a test of the efficacy of 1,3-D and fenamiphos as applied through drip irrigation, irrigation alone significantly increased pineapple yields (Apt and Caswell, 1988). If a nonirrigated control has not been included, the effect of the nematicide application would have been overestimated.

### 4.6 Nematode identification

Proper utilization of drip irrigation requires that the nematode target be correctly identified and its life cycle and ecology understood. Some nematode species have life history characteristics that can be used to advantage in a drip irrigation program. For example, the success of drip applications of a nematicide for control of *R. reniformis* is due in part to knowledge of the nematode’s life cycle and the influence of soil moisture thereon. For example water applied via drip irrigation apparently induces quiescent eggs to hatch, resulting in active, susceptible juvenile stages being present in the soil
when a nematicide is applied (Apt and Caswell, 1988).

4.7 Determination of efficacy

Assessment of efficacy of nematicides is often taken for granted. Nematode extraction procedures that rely on nematode activity, such as Baermann funnels and mist chambers, and methods that extract passive nematodes, such as centrifugation-flotation, may yield different results, especially if a nematicide is nematostatic. A comparison of Baermann funnel counts with centrifugation-flotation counts may provide insight into the effect of nematicides on the activity of nematodes in the soil. Extraction efficiency also should be determined so that results can be compared by researchers investigating the efficacy of nematicides in different locations.

4.8 Influence of pesticides delivered through drip irrigation

Pesticides delivered to the plants by drip irrigation concentrate their effectiveness in the limited wetted area near the water emitters of the drip tube where the crop roots develop. In this restricted zone of maximum root growth, nematodes and microbial pathogens develop. Injection of pesticides to this area places the chemical in the zone of greatest edaphic pest activity and in the zone from which root absorb systemic materials for transport to above/below ground plant parts (Overman & Price, 1984).

4.8.1 Fumigants

Methyl bromide effectively controlled Meloidogyne spp. which is one among the most noxious pest in vegetable crops grown in tropical and sub tropical climate. One of the main methyl bromide alternative is the combination of the nematicide 1,3 dichloropropene (1,3-D) and the fungicide chloropicrin (Pic). This fumigant has shown to be an alternative means against soilborne diseases and nematodes (Gilreath and Santos 2008).

Plantpro an iodine based water soluble compound available commercially and applied through drip irrigation has potential as a methyl bromide alternative for root knot nematode control on tomato in Florida (Burelle et al., 2002).

Overman (1982) proved that a single pre plant injection of metham sodium @22.4kg/ha through drip irrigation system significantly reduced root galling and increased tomato yield and found to be superior over conventional fumigation with 1,3 - D.

Roberts et al. (1988) reported that drip application of metham sodium in strips on plant beds controlled in addition to M. incognita and M. javanica Pythium ultimum, Fusarium sp. on carrot and tomato.

The nematicide fosthiozate is a potential alternative to 1,3 - D for the control of Meloidogyne sp. in tomato and it could be applied through drip irrigation lines which could reduce the risk of personnel exposure (Leyes, 2006).

The fumigation programs that included the herbicides napropamide + Trifluralin in pre emergence and post directed trifloxysulfuran in combination with Pic and fosthiozate or 1, 3-D + Pic and methan sodium proved to be effective means to suppress root galling and weed Cyperus interference while maintaining high tomato marketable yield (Gilreath and Santos, 2008).

Overman and Price (1984) reported the overall level of root knot and lance nematodes and arthropod pest population reductions using cyromazine (Trigard; as injection @ 0.14 kg a.i. / ha / week) for 14 weeks.

4.8.2 Non fumigants

Application of ethoprop through drip irrigation at 4.6 kg a.i./ha reduced root galling on the cucumber crop but had no effect on the nematode population density in the soil at crop termination (Colyer et al., 1998).

Pinkerton et al., (1991) demonstrated through field experiments that in season application of ethoprop (900-1000 DDs) significantly reduced root knot nematode damage of potato tubers.

Fenamiphos emulsifiable concentrate (EC) reduced the severity of root rot caused by Radopholus similis in banana. The fenamiphos applied monthly (@ 375g a.i. /1100 m row/year) through drip irrigation was equivalent to the effect of the standard treatment of fenamiphos granules. Application of fenamiphos through micro irrigation is cost effective than conventional nematicide application methods (Schipke and Ramsey 1994 ).
In Hawaii, oxamyl applied at 3.4, 6.7 and 13.4 kg a.i./ha through a biwall tubing with emitters 30.5 cm apart reduced population of *R. reniformis* by 70.5, 76.3 and 91.5% respectively, 4 weeks after a single application (Apt *et al.*, 1987).

Four applications of oxamyl, aldoxycarb and carbofuran applied at 0.37 kg a.i. / ha beginning at planting and at 3, 6 and 14 days later (2.22 kg a.i. / ha in total) through drip irrigation provided protection against *M. incognita* as measured by root galling and resulted in significant increase in yield of tomato (Garabedian and Van Gundy, 1985).

4.8.3. **Biostatements**

Bahme *et al.* in the year 1987 itself speculated that application of biological control agents through drip irrigation has distinct possibility in the management of pests and diseases of crops.

Biological products such as Bioyield (a formulation of the plant growth promoting rhizobacterium *Paenobacillus macerans* and *Bacillus amyloliquefaciens*) and Di Tera (a concentrate killed fermentation beer of the fungus *Myrothecium verricoria*) as transplants mix delivered effectively through drip irrigation increased tomato yield significantly (Burelle *et al.*, 2002).

The use of avermectin (Avid) @ 0.146 to 0.584 kg a.i. / ha/ week for 13 weeks through drip irrigation reduced the nematode population in chrysanthemum (Overman & Price, 1984). However the authors opined that further evaluation on this line is necessary to achieve the potential of the drip irrigation system as a vehicle for successful pest management.

4.8.9. **Influence of entomopathogenic nematodes applied through drip irrigation**

More than 90% of insects including many pest species have at least one stage of their lifecycle in the soil along with the rapid mortality of hosts that span nearly all insect orders. Especially in cases where the stage is larval or pupal like weevil it offers an opportunity for an effective management programme to be developed, targeting specific host species where the ability of the target species to reallocate is much reduced.

Entomopathogenic nematodes (EPN) formulations applied directly to the soil offers a more environmentally friendly, chemical free, minimal cost possibility in the management of insect pests.

Andrew Brown (2003) experimented with EPN applied through drip irrigation for the management of pests on lettuce and strawberry crops. In the experiment on lettuce Nemaslug ® (*Phasemashabditis hermaphordita*) is applied to control slug pests; primarily *Dero ceras reticulatum*. On strawberry Nemasus ® (*Steinernema kraussei*) is applied for the management of blackvine weevil grubs (*Otiorhynchus sulcatus*).

Wennemann (2003) reported that drip irrigation lines have potential to deliver entomopathogenic nematodes viz., *S. carpocapsae*, *S. feltiae*, *S. glaseri* and *Heterorhabditis bacteriophora*.

The entomopathogenic nematodes, *S. riobrave*, *H. bacteriophora* and *H. indica* are being routinely used by many citrus growers in Florida as a component of IPM program to control the weevil *Diaprepes abbreviatus* (Duncan *et al.*, 2000).

4.9 **Problem in drip irrigation**

A potential problem in all drip irrigation systems is the partial or complete clogging of emitters. This leads to decreased and irregular application and can be a tremendous problem in experiments assessing nematicide efficacy. Filtering the water supply to the drip irrigation system is necessary to remove particulate contamination in the irrigation water and reduce clogging.

High salt content in water may lead to clogging. No visible plugging was found, but it was determined that salt was deposited around the emitter on the inside of the tube and was very slowly sealing off the emitters. The salt deposit was visible only when the tubing was dry. Periodic inspection of flow rates is advisable.

4.10 **Disadvantage**

Ants and rodents are often attracted to drip tubes, especially during dry periods. Ants may enlarge the emitters and rodents may cut the tubing. In either case, it is necessary to be alert for abnormal flow rates- a disadvantage of the drip irrigation system. A metered line will indicate an abnormally high or low flow rate.

In arid regions where water sources are somewhat saline, it is advisable to periodically apply
more water than will be used by the plants. This allows leaching of accumulated salts away from the root zone (Shoji, 1977).

5. Conclusion/Future directions

Application of nematicides by drip irrigation is being used more and more frequently; however, further research is required to optimize the efficacy of this system. An increased understanding of root growth in relation to plant growth and yield is required for many crops, as is the influence of nematode populations on root growth. Information on the dynamics of root growth in relation to nematode parasitism will allow additional refinement of application strategies for available nematicides, thereby increasing their efficacy.

The higher initial expense of drip irrigation systems compared with sprinklers is an important factor. Nevertheless at least some of the initial cost of drip irrigation can be offset by irrigation water savings and marketable yield increase (Brown et al., 1996). However comparative effects of pesticides/nematicides applied through drip irrigation on management of soil borne diseases and nematodes remain largely unexplored.

In the future, application of biological control agents through drip irrigation is also a distinct possibility. One of the problems preventing field application of biological control agents is obtaining a sufficient quantity of the agent and then delivering the agent to the rhizosphere. Application through drip irrigation could minimize the mass of the agent required and assure delivery to the rhizosphere. Consequently, drip irrigation can be used in integrated crop management systems to facilitate delivery of pesticides and biological control agents to the rhizosphere.

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