**Completed**

# Uniformity of Chemigation in Microirrigated Permanent Crops

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**Final Report – April 2001**

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## Objectives:

1. Develop physical relationships, based on field-gathered measurements, to relate water application uniformity and chemigation uniformity in microirrigated permanent crop.
2. Quantify, in the selected microirrigated orchards / vineyards, the chemical travel times, irrigation water chemical concentrations with time at various irrigation system locations, and total applied chemical distributions of a soluble material (potassium chloride) injected using a positive displacement pump.
3. Quantify, in the selected microirrigated orchards / vineyards, the chemical travel times, irrigation water chemical concentrations with time at various irrigation system locations, and total applied chemical distributions of a low solubility material (potassium sulfate) injected using a solutionizer machine.
4. Determine key, microirrigation system indicators (e.g. lateral line length, flow rate, etc.) which can be correlated to management strategies (e.g. injection period, clear water run times following injection, etc.) in order to achieve chemigation uniformity.
5. Develop written recommendations, in the form of an easy-to-use leaflet, for chemigation management to ensure uniform chemical application.
6. Conduct a series of educational workshops on microirrigation chemigation.

## Executive Summary:

Field tests were done on 6 commercial drip irrigation systems (3 orchards and 3 vineyards) to determine the travel time of water and chemicals through the underground pipelines and above-ground lateral lines. Total travel times of water and chemicals to the hydraulically most distant point in the drip systems ranged from 32 to 75 minutes in the orchards and 30 to 45 minutes in the vineyards.

Further field tests were performed on a 500-foot long drip lateral with 1 gallon per hour drip emitters spaced 5 feet apart. The travel time of water and chemicals through the 500-foot lateral was 25 minutes. It was found that the highest chemical application uniformity was achieved when the injection time was 50 minutes or more and the post-injection , clean water irrigation period was 50 minutes or more. A 25 minute injection period followed by 25 minutes of clean water irrigation was nearly as good. The worst chemigation application uniformity resulted from a short injection period (e.g. 13 minutes in this case) followed by no post-injection, clean water irrigation.

Two types of solutionizer injection machines were also evaluated. One machine uses a paddle-wheel system to keep the injection material (e.g. gypsum, potassium sulfate, etc.) in a slurry form. As the slurry is injected, more water is added to the tank. As second machine uses a small sprinkler mounted under a protecting shield in the bottom of a conical tank to wash down the dry injection material in the tank. The slurry from the tank is injected into the irrigation system via a venturi injector.

It was determined that, while the slurry concentration in the solutionizer machines varied over time, the rate of change was gradual enough so that it did not negatively impact the uniformity of chemical application through the drip irrigation systems.

The following steps should be followed to achieve a chemigation as uniform as the microirrigation system's irrigation uniformity.

Step 1: If it isn't already known, determine the length of time it takes water / injected material to travel from the injection point to the microirrigation emitter farthest away hydraulically. This can be done by injecting chlorine into the drip system and tracing its movement through the drip system by testing the water using a pool/spa chlorine test kit.

Step 2: Start the microirrigation irrigation system and allow it to come to full pressure before beginning injection.

Step 3: Inject the chemical over a time period at least as long as the time it takes for water / injected materials to reach the emitter farthest away hydraulically from the injection point (determined in Step 1). Longer injection periods will slightly improve the chemigation uniformity.

Step 4: Stop the injection, but continue running irrigation water for a time period at least as long as the time it takes water to travel to the emitter farthest away hydraulically from the injection point. An even longer post-injection irrigation period will further improve chemigation uniformity. It is important to have this post-injection irrigation period. Do not simply shut down the irrigation system when you stop injecting.

A University of California ANR publication, "Chemigation in Tree and Vine Microirrigation Systems" was prepared and includes many of the results of the study. In addition, the study results have been presented at over 15 workshops, training classes, and international professional conferences.

## Introduction

Chemigation, the injection of chemicals through an irrigation system, is common among permanent crop (trees and vines) growers using microirrigation systems. Advantages to chemigation include: (1) flexibility in timing fertilizer applications, (2) reduction in the labor required for applying chemicals, and (3) the potential increase in the efficiency of chemical use; thus reducing the cost of chemical use. Some chemicals (e.g. chlorine) and some fertilizers (e.g. numerous nitrogen sources) readily dissolve in water and are injected via venturi or positive displacement pump injectors. Other chemicals (e.g. gypsum, potassium sulfate), seeing recent chemigation use, are not readily soluble and are being injected using "solutionizer" machines.

Uniformity - equal distribution - of chemical application via injection through the irrigation system is crucial from plant nutrition, economic, and environmental viewpoints. Microirrigation systems, with their high water application uniformity, have the potential for uniform chemigations, but injected chemicals do not simply begin to be uniformly discharged from all emitters as soon as injection begins. Injected materials are subject to "travel time" delays as the materials travel from the injection point to the closest discharge emitter and then to the farthest emission point in the microirrigation system. This, in itself, may lead to non-uniformity of chemical application.

This project was undertaken to develop field-based information on which to base a Best Management Practice recommendation for chemigation through permanent crop drip irrigation systems.

## Work Description

*Task 1: Field evaluation of permanent crop microirrigation chemigation systems.*

Field evaluations were completed on 6 commercial orchards and vineyards. The evaluations provided information on typical irrigation system designs and valuable information on travel times of water and chemicals through the drip systems. Additional field work on injection uniformity along a 500-foot drip lateral was done to further refine the impact of various chemigation strategies. Field evaluation was also done on two types of solutionizer injection machines to determine the impact their use had on chemigation uniformity. Finally, a series of laboratory photographs of dye movement through a clear drip irrigation lateral were taken and refined so that they could be used as an educational tool.

*Task 2: Analysis of field-gathered chemigation data and draft preparation of a leaflet on recommended practices for chemigation.*

The field data on chemigation in 6 commercial orchards and vineyards was evaluated along with the multiple tests run on the 500-foot drip lateral. The results of those tests were incorporated into the draft leaflet which was submitted for peer review and publication.

*Task 3: Organize and conduct a series of microirrigation chemigation workshops.*

Over 15 workshops and presentations on the results from this study have been presented (see Outreach Activities Summary). Most have been done for growers in California but the study results have also been presented at an international irrigation conference in Australia (Irrigation 2000) and at a chemical/irrigation technical meeting in

Mexico City. Three additional presentations to growers and consultants in Mexico are scheduled during the next few months.

*Task 4: Final preparation and publication of a Best Management Practices leaflet on chemigation through permanent crop drip systems.*

A University of California ANR leaflet ("Chemigation in Tree and Vine Microirrigation Systems" - Publication 21599 – attached) has been published by the project PI's.

**Results**

*Commercial Orchard/Vineyard Evaluations*

Six commercial grower operations (3 vineyards and 3 orchards) were evaluated during the summer of 1998. Their selection was based on the desire to test operations with typical irrigation systems, but also to evaluate some which were unusual in design. This would give us the best idea of what range of chemigation uniformities and water / chemical travel times could be expected in commercial operations.

Test Procedure

The test procedure for the commercial operations included monitoring chemical travel times to multiple, critical points in the drip irrigation systems. Examples of critical points included the head and tail of the drip lateral line closest to the injection point, and the head and tail of the drip lateral farthest from the injection point. Other critical points were monitored and sampled if it was felt that they would provide useful information. Monitoring these critical points provided us with excellent information on travel times in the mainline / submain system and travel times in the drip lateral lines.

The monitoring was done using chlorine as a tracer. Both sodium hypochlorite (liquid) and calcium hypochlorite (granular) were used and both worked equally well. A pool / spa test kit was used to monitor when chlorine reached critical locations in the drip irrigation system following initiation of injection, and when chlorine disappeared from critical locations following cessation of injection. This technique worked well. It is a simple technique which is safe and would be easy for a manager of a drip irrigation system to do. It has the added benefit of being a good drip system maintenance procedure for preventing drip system clogging by organic matter (algae, bacterial slimes, etc.).

Monitoring of travel times using red dyes as tracers was also investigated. There are dyes available which are harmless and currently used as tracers in streams and creeks. Food coloring was also tried. The use of dyes as a travel time tracer will work well in small drip irrigation systems, e.g. drip irrigation system's with flow rates less than 50 gpm, but they become too dilute in larger flow rate systems. For example, one commercial orchard we tested had a flow rate of 600 gpm and a dye tracer would not work in such a large drip irrigation system.

Uniformity of chemigation - how much chemical was discharged at various locations within the drip system - was measured by collecting samples at critical locations in the drip irrigation systems. All the water (and chemical) discharged at the critical locations was collected during: (1) the period from the start of injection until the injected chemical reached the farthest discharge location in the drip irrigation system (advance time) , and (2) the period from the time injection stopped until testing showed that the injected chemical was substantially decreased in concentration at the farthest drip location ( recession time). At each of the sampling sites, total discharge volumes were measured and a representative sample collected for lab analysis.

During the initial set of system evaluations, chlorine was used both as a tracer for travel times and as the chemical to be analyzed to determine injection uniformity. Unfortunately, the chlorine in the collected samples lasted no more than a day or two; even when the sample bottle was filled completely and refrigerated. The chlorine is either volatilized, changes chemical form, or is depleted in oxidizing the organic matter in the water.

A second set of similar tests field evaluation tests were rerun at the orchards / vineyards, but potassium chloride (KCl) was injected in addition to the chlorine. The collected water samples were then sent to the UC DANR lab for potassium analysis. Potassium was chosen because it is normally quite low in irrigation water and it is not lost from the sample prior to its analysis. This methodology worked well.

Test Results

Advance times - the time it takes water / chemical to move from the injection point to the observation point - are important since they will likely limit the minimum injection period. Travel times in the mainline / submain system vary significantly depending on the drip irrigation system design (Table 1). In our field tests, the advance times to the head of the drip lateral closest (hydraulically) to the injection point ranged from 1 to 17 minutes. More dramatically, the advance times to the head of the drip lateral farthest hydraulically from the injection point ranged from 8 to 65 minutes. Thus, travel time in the underground pipeline system could be as long as 65 minutes. We believe this 65 minute time provides us with an excellent upper bound for mainline / submain travel time.

The travel time of water / chemical in the drip laterals also adds to the total advance time to the farthest point (emitter) in the drip system. In our field tests, drip lateral travel times ranged from approximately 10 to 30 minutes. These times depend on the lateral line length and on the emitter flow rate and spacing.

Thus, total advance times, from the injection point to the end of the drip lateral farthest hydraulically from the injection point ranged from 30 to 75 minutes. If the situation were to arise where a long pipeline system were to be paired with a long drip lateral line, the total tail-of-last-lateral advance time could be 95 minutes. [pipeline (65 min travel time) + drip lateral (30 min travel time)].

Recession times (time for chemical to dissipate at a site following injection stopping) are consistently longer than advance times for the same site location. It takes longer for the injected chemical to dissipate completely than it does for it to advance to a location, and the chemical concentration change is gradual for recession while it is abrupt during advance.

The test injections consisted of injection until chemical reached the tail of the farthest lateral followed by clear water until the chemical had substantially dissipated at the tail of the farthest lateral. A normal, commercial injection would likely consist of injection continuing after chemical has reached the end of the farthest lateral. Continuing to inject following complete advance through the drip system would essentially add the same amount of chemical to all locations in the orchard / vineyard (assuming equal discharge from all emitters). Drip irrigation system uniformity plays an important role here because it is the upper bound on injection uniformity.

At sites 1, 4, and 6, the amount of chemical collected at the tail of the lateral farthest from the injection point was less than at other points in the system (Table 2). This was due to the fact that the water collection stopped when the chlorine concentration at the tail of the far lateral was significantly decreased. Undoubtedly, there was still some chlorine and potassium in transit through the system.

*UCD-LAWR Field Station Tests*

Although not part of the FREP contract, the PI's felt that a series of injection tests under controlled field conditions would provide valuable information. A drip lateral assembly was installed which consisted of 500 feet of conventional, 5/8" diameter, polyethylene drip tubing with 1 gallon per hour (gph), pressure-compensating (PC) drip emitters installed at 5-foot intervals. Filters, flow meter, valves, etc. were all installed to monitor and control the chemigation and irrigation system.

A series of 9 injection tests were done to determine travel times and injection uniformities. Initial tests using dyes and chlorine as tracers were done to determine travel time of water / chemicals along the drip lateral, but most importantly, to the end of the drip lateral (500-foot mark). For this drip lateral configuration, it took 25 minutes for injected chemical to reach the end of the drip lateral (see Table 3). Note that the injected chemicals quickly travel along the beginning of the drip lateral, and that the incremental time to reach each 50-foot increment increases with distance along the lateral. This is particularly true of the last 50 feet (450' to 500'). Table 4 lists the tests done as well as the amount of injected chemical (potassium) reaching 50-foot interval sampling sites along the lateral. All results have been normalized based on the amount of potassium collected at the 50-foot sampling site.

Test Results

Looking at Table 3, it is evident that the last 100 feet and particularly the last 50 feet of the drip lateral, are the sections which contribute substantially to the total travel time to the lateral end. If the lateral line were only 400 feet long, it would still take the same length of time for water / chemical to travel the last 50 feet. The total advance-to-lateral-end time would be less for a 400-foot vs. a 500-foot lateral though.

The recession time (Table 3) is longer than the advance time for each location along the lateral. Injected chemical does not clear from the system as quickly, nor as abruptly, as it advances through the drip lateral. Chemical clearing, after injection is stopped, is a gradual process.

Analyzing the chemical uniformity results in Table 4 leads to the conclusion that as long as the injection period is at least as long as the travel time to the farthest emitter (designated as "X" in Table 4), and at least an equal time period of clear water is run after injection (test X / X in Table 4), the application uniformity will be quite good.

Injecting for only a time period of half the travel time to the far emitter (0.5 X) can give fairly acceptable results as long as the clear water operation time is equal to or greater than the travel time (X). This would be test 0.5X / X in Table 4. Allowing no clear water operation time after a half-travel-time injection (0.5X / 0X) gives very poor distribution uniformity with almost no chemical reaching the 500-foot point.

Table 1. Advance / recession times for the injections at the commercial field tests evaluated.

| Site | Time (minutes) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Head of Near Lateral | | Tail of Near Lateral | | Head of Far Lateral | | Tail of Far Lateral | |
| | Advance | Recession | Advance | Recession | Advance | Recession | Advance | Recession |
| 1A | 5 | 5 | 15 | 18 | 29 | 31 | 39 | 43 |
| 1B | 5 | 5 | | | 65 | | 75 | |
| 2 | 14 | 18 | 22 | 27 | 22 | 25 | 32 | 37 |
| 3 | 10 | 15 | 35 | 45 | 13 | 17 | 40 | 50 |
| 4 | 1 | 1 | 23 | 32 | 8 | 12 | 30 | 37 |
| 5 | 17 | 15 | 45 | 42 | 16 | 15 | 45 | 42 |

Table 2. Uniformity of applied chemical for the injections at the commercial field tests evaluated.

| Site | Relative Amounts of Applied Chemical[a] | | | |
|---|---|---|---|---|
| | Head of Near Lateral | Tail of Near Lateral | Head of Far Lateral | Tail of Far Lateral |
| 1A | 100 | 120 | 124 | 116 |
| 2 | 100 | 108 | 98 | 93 |
| 3 | 100 | 110 | 96 | 91 |
| 4 | 100 | 126 | 118 | 118 |
| 5 | 100 | 84 | 88 | 68 |

[a] All injected chemical amounts normalized to the amount applied at the head of the near lateral (= 100).

Table 3. Advance / recession times for the UCD-LAWR, 500-foot drip lateral (1 gph PC emitters at 5-foot intervals).

| Location (ft.) | Advance Time (minutes) | Recession Time (minutes) |
|---|---|---|
| 0 | 0 | 0 |
| 50 | < 1 | < 1 |
| 100 | 2.0 | 2.5 |
| 150 | 3.0 | 3.5 |
| 200 | 4.0 | 4.75 |
| 250 | 4.5 | 5.25 |
| 300 | 5.5 | 6.25 |
| 350 | 7.0 | 7.75 |
| 400 | 8.0 | 9.75 |
| 450 | 12.0 | 13.75 |
| 500 | 25.0 | 38.0 |

Table 4. Uniformity of chemical injection for the UCD-LAWR, 500-foot drip lateral (1 gph PC emitters at 5-foot intervals).

| | Distance Along Drip Lateral - ft. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Test[a] | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | CV[b] |
| 0.5X / 0X | 100 | 102.4 | 93.0 | 88.7 | 79.8 | 80.9 | 72.2 | 52.4 | 31 | 5.2 | 0.45 |
| 0.5X / X | 100 | 108 | 105.8 | 101.9 | 98.9 | 105.8 | 105.0 | 99.5 | 96.7 | 98.1 | 0.04 |
| 0.5 X / 2X | 100 | 103.8 | 99.1 | 100.3 | 99.1 | 106.0 | 101.4 | 94.4 | 92.0 | ---[c] | |
| X / 0X | 100 | 105.5 | 103.8 | 96.4 | 75.6 | 90.9 | 86.9 | 80.2 | 68.8 | 30.0 | 0.27 |
| X / X | 100 | 109.8 | 111.5 | 109.1 | 104.7 | 107.6 | 109.2 | 109.1 | 104.3 | 106.4 | 0.03 |
| X / 2X | 100 | 109.0 | 108.0 | 101.2 | 103.2 | 108.2 | 104.3 | 102.2 | 95.2 | 99.10 | 0.04 |
| 2X / 0X | 100 | 99.7 | --[c] | 101.3 | 92.0 | 96.3 | 93.1 | 90.5 | 80.3 | 66.9 | 0.12 |
| 2X / X | 100 | 99.2 | 100.5 | 99.5 | 112.0 | 98.0 | 101.1 | 98.9 | 101.5 | 102.0 | 0.04 |
| 2X / 2X | 100 | 96.9 | 98.7 | 100.7 | 99.3 | 104.0 | 101.7 | 98.6 | 93.0 | 101.6 | 0.03 |

[a] Test designated as X = time to advance to the end of the lateral = 25 minutes for this lateral configuration. e.g. X / X = injection time = 25 min. / Clear water following injection = 25 minutes.

[b] Coefficient of variation = Standard deviation ÷ Average.

[c] Sample still being analyzed.

The clear water operation period following an injection is quite important to ensuring a uniform chemical application. Having no clean water period following injection (tests X / 0X and 2X / 0X) results in unacceptable chemical application.

The results were also categorized as to their chemigation uniformity relative to each other (Table 5). The CV of each test was calculated and compared. The 2X / 2X injection test had the lowest chemigation variability (as measured with CV) between emitters and it was assigned a relative uniformity of 100. All other tests were ranked according to the CV's relative to the 2X / 2X test.

It should be noted that the UCD-LAWR tests are only for a drip lateral. The provide valuable insight, but the travel time, and particularly the recession time, contributions of the mainline / submain system needs to be considered also.

Table 5. Chemigation uniformity in a drip lateral (500 feet long with 1-gph drip emitters installed at 5-foot intervals) for various injection times and post-injection clean water irrigations. (The water and injected chemical travel time to reach the end of the drip lateral was 25 minutes.)

| Test | Injection time (min) | Post-injection irrigation time (min) | Relative uniformity (%) |
|---|---|---|---|
| 2X / 2X | 50 | 50 | 100 |
| 2X/X | 50 | 25 | 98 |
| X / X | 25 | 25 | 95 |
| X / 2X | 25 | 50 | 90 |
| 0.5X / X | 13 | 25 | 81 |
| 2X / 0X | 50 | 0 | 25 |
| X / 0X | 25 | 0 | 11 |
| 0.5X / 0X | 13 | 0 | 7 |

*Laboratory Test*

A laboratory experiment was done to gain further information on chemigation in drip irrigation laterals (not required by the FREP contract). To visually evaluate what was happening during injection and chemical movement in a drip lateral, a test was set up in which a red dye's movement was followed along a 10-foot length of clear tubing of the same dimensions as commercial drip tubing. Two, 1-gph PC emitters were installed at the 5-foot and 10-foot points. The dye's advance along the tubing, following the start of injection, was monitored, and recession of the dye after injection stopped was also monitored.

A photo record (series of slides) was made of the test. This will be an excellent extension tool to use during next year's series of workshops. The photo record clearly shows that the dye clearing from the system after injection stops is slower and much less defined than is its advance through the tubing.

*Solutionizer Injector Evaluation*

Two solutionizer injection machines were evaluated during the project. One machine uses internal paddle-wheels to continually mix the not-readily-soluble injection material (usually gypsum or potassium sulfate) into a slurry which is pump-injected into the irrigation system. The second type of machine consists of a conical tank with a small "wobbler" sprinkler in its base, protected overhead by a small plate, which washed down the dry injection material in the tank. The slurry is then injected into the irrigation syste4m using a venturi injector.

It was found that both types of solutionizer machines injected material at a constant rate. While the paddle-wheel type machine continually adds fresh water to the tank during injection and this causes the slurry to become more dilute with time, the change in slurry concentration was slow enough not to impact the chemical application uniformity. The conical tank / sprinkler solutionizer machine was found to inject material at a very constant rate throughout the injection period (see attached report – "Diamond K Solutionizer Testing") and would result in a uniform chemical application as long as a period of clear water follows injection.

**Project Evaluation**

The project has been quite successful both in information development and outreach of the project results. We were able to gather some excellent field data upon which to base a best management recommendation for chemigation through permanent crop drip irrigation systems. Managers of orchard and vineyard drip irrigation systems have been very receptive to the study results. In many cases, the managers have simply not considered the implications of their chemigation practices. The common practice of injecting for a short period of time and then moving on to another injection location can lead to non-uniform chemical applications. Once this is pointed out to them, growers readily change their chemigation practices to improve their chemigation uniformity.

The 4-step procedure we developed and have been presenting to growers is simple, straightforward, and inexpensive. Determining the travel time of water and chemicals through a permanent crop drip irrigation system (Step 1 of procedure) is a one-time task, good for the life of the drip irrigation system. Armed with the chemical travel time to the farthest point hydraulically in the drip system, the grower has knowledge of the minimum injection time and the minimum post-injection clean water irrigation time necessary to achieve excellent chemigation uniformity.

**Outreach Activities:**

The following outreach activities have been done as part of the project. In addition to the meetings listed in Table 6, the leaflet (Chemigation in Tree and Vine Microirrigation Systems) prepared is also available to facilitate extension of the study results.

Table 6. Outreach meetings at which PI's have spoken on the study results.

| Date | Meeting Description | Attendees |
|---|---|---|
| 12/1/98 | Drip Irrigation of Vineyards – UC Davis | 80 |
| 12/3/98 | Drip Irrigation of Trees – UC Davis | 60 |
| 12/8/98 | Drip Irrigation of Row Crops - UC Davis | 40 |
| 11/17/99 | UC Irrigation Symposium – Kearney Ag Center | 70 |
| 2/22/00 | Drip Irrigation of Winegrapes – UC Davis | 95 |
| 3/22/00 | Bayer Chemical Co. Meeting – Brawley, CA | 35 |
| 3/22/00 | Bayer Chemical Co. Meeting – Indio, CA | 50 |
| 6/1/00 | Irrigation 2000 International Conf. – Melbourne, Australia (paper attached) | 70 |
| 11/7/00 | UC Pistachio Shortcourse – Visalia, CA | 95 |
| 11/9/00 | Pepper Shortcourse – New Mexico | 150 |
| 11/30/00 | Technical meeting of Bayer Chemical – Mexico City | 30 |
| 2/7/01 | American Assoc. of Agronomy – CA Plant & Soil Conf | 60 |
| 2/20/00 | Water Management meeting – UC S. Coast Field Station | 35 |
| 3/13/01 | Fresno State undergraduate class | 35 |
| 3/14/01 | Bayer Chemical Meeting – Fresno | 120 |
| 3/20/01 | Bayer Chemical Meeting – Stockton | 70 |