Chemigation and Fertigation Basics for California

by

Dr. Charles M. Burt
Irrigation Training and Research Center (ITRC)
Cal Poly State University
San Luis Obispo, CA 93407
cburt@calpoly.edu
www.itrc.org

for

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Definition of Chemigation

Chemigation is the application of any chemical through an irrigation system. Examples of chemicals include insecticides, fungicides, fertilizers, water amendments, soil amendments, and compounds used to reduce plugging of drip emitters. Proper chemigation reduces energy consumption (less fertilizer, chemicals, and tractor travel) and improves crop quality and yields.

Safety and Pesticides

The application of ***pesticides*** through irrigation systems requires strict adherence to label instructions. Both the USEPA and the California Department of Pesticide Regulation have issued hardware requirements for chemigation with pesticides.

Figure 1 below comes from the California Dept. of Pesticide Regulation (DPR) enforcement letter 01-28 (June 7, 2001) entitled “Chemigation Safety Devices: Pesticide Label Requirements and Allowable Alternative Equipment”. The complete document, as well as a modified “user-friendly” version by CIT in Fresno, can be downloaded at: www.itrc.org/reports/chemigation/chemigation.htm.

GENERIC CHEMIGATION SYSTEM DIAGRAM

1) MAIN WATER LINE:

- **Backflow prevention device**
  - Located between water source and point of pesticide injection
  - Prevents contamination of water source
  - Shown: Functional check valve, vacuum relief valve, low pressure drain
  - ALTERNATIVE EQUIPMENT ALLOWED BY LABEL OR POLICY

2) PESTICIDE INJECTION PIPELINE:

- **Automatic, quick closing check valve**
  - Located between main water line and pesticide injection pump
  - Prevents flow of fluid back towards pesticide injection pump
    - NO ALTERNATIVE EQUIPMENT ALLOWED
- **Normally closed, solenoid-operated check valve**
  - Located between pesticide injection pump and pesticide container or mix tank
  - Check valve connected to system interlock
  - Prevents pesticide from being withdrawn when irrigation systems shuts down
    - ALTERNATIVE EQUIPMENT ALLOWED BY POLICY

3) PESTICIDE METERING PUMP:

- **Positive displacement injection pump**
  - Connected to system interlocking controls and pesticide injection pipeline
  - Assures proper rate of pesticide injection
    - ALTERNATIVE EQUIPMENT ALLOWED BY POLICY

4) INTERLOCKING SYSTEM CONTROLS:

- Located between the pesticide metering pump and the water pump motor
- Automatically shuts off pesticide metering pump when water pump motor stops
  - NO ALTERNATIVE EQUIPMENT ALLOWED

5) IRRIGATION LINE OR WATER PUMP:

- **Functional pressure switch**
  - Located on irrigation pipeline
  - Stops water pump when drop in water pressure adversely affects pesticide distribution
    - NO ALTERNATIVE EQUIPMENT ALLOWED

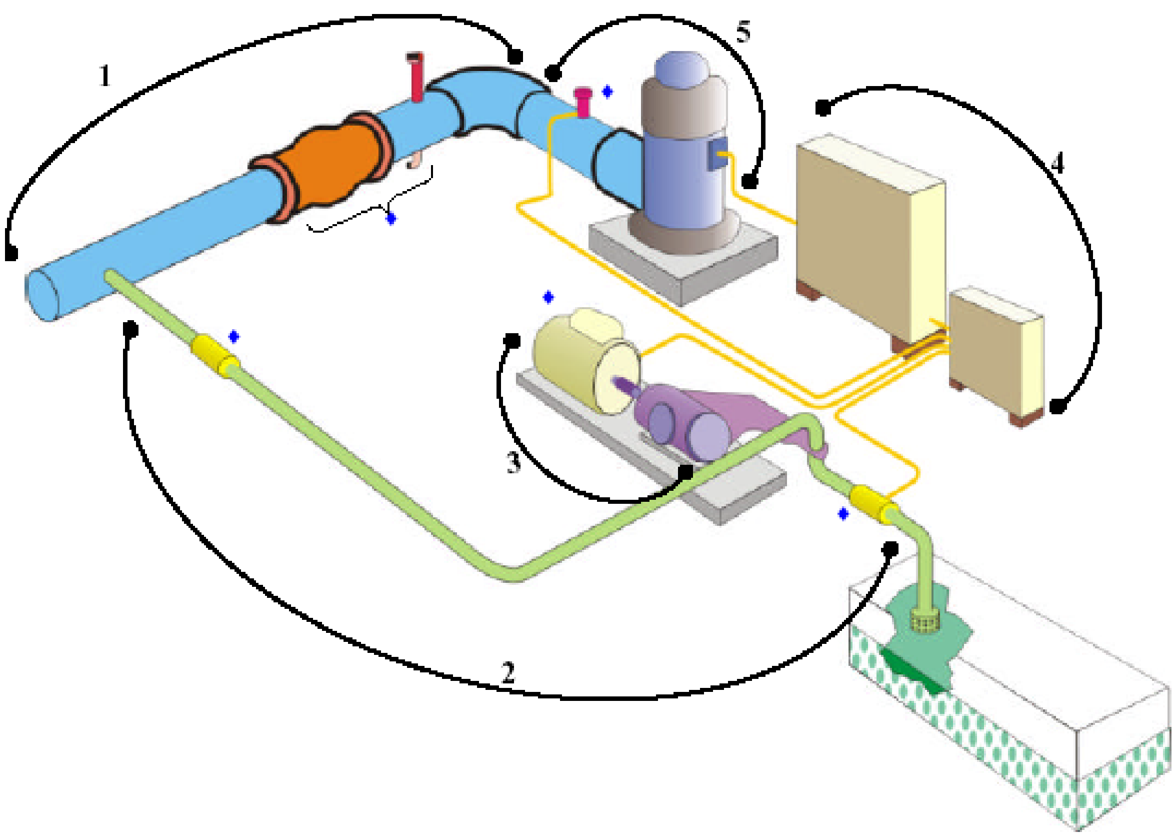

Figure 1. Pesticide safety equipment required by Calif. Dept. of Pesticide Regulation.

Most fertilizers, water amendments, soil amendments, and some chemicals used to reduce drip/micro system plugging do not present the same potential health hazard as pesticides. Containers of these substances are not typically labeled, and the rules governing their application vary throughout the U.S. However, the rules which apply to safe pesticide injection "make sense" regardless of the type of chemical being injected.

Following are some basic answers to common questions related to chemigation with pesticides in California agriculture.

Question: Who enforces the safety regulations of the Calif. Dept. of Pesticide Regulation?
Answer: The County Agriculture Commissioner (CAC)

Question: What is the fine or penalty for non-compliance with requirements?
Answers: There are really 3 answers:

a. Individual counties determine the appropriate action.
b. If someone is hurt because the legally required equipment is not in place, the existence of these laws clearly leaves the owner/applicator in a poor legal position.
c. The requirements make practical sense both from the standpoint of protecting the groundwater quality and from a personal safety standpoint, so ITRC sees this as more an issue of awareness than one of "who is to blame" or "penalties".

Question: Are the chemigation safety requirements the same if the irrigation system is supplied by a public water system rather than by a well?
Answer: No. The backflow prevention devices required for public water systems are more complex. When connected to a public water supply, pesticide labels require handlers to use a reduced-pressure zone backflow preventer. Alternatively, the water may be discharged into a reservoir tank as long as an air gap is maintained between the public water source and the top of the reservoir.

Question: What is a "public water system"?
Answer: A "public water system" means "a system for the provision to the public of piped water for human consumption if such system has at least 15 service connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year" (DPR's ENF 01-28: http://www.itrc.org/reports/chemigation/ENF01-28.pdf).

Question: Can an irrigation district or other local agency have more stringent chemigation requirements than California DPR?
Answer: Yes. For example, some irrigation districts require double check valves and others require reduced pressure zone backflow preventers, instead of the single check valve, vacuum relief valve, and low pressure drain combination.

Question: What if pesticides are applied to a non-pressurized irrigation system that has no possibility of backflow into a well?

Answer: Systems using a gravity flow pesticide dispensing system must meter the pesticide into the water at the head of the field and downstream of a hydraulic discontinuity such as a drop structure or weir box to decrease the potential of water source contamination from backflow if water flow stops. (http://www.epa.gov/PR_Notices/pr87-1.html)

Question: Are there other safety measures that some growers take?

Answer: Yes. For example, some growers limit the amount of chemical that can possibly be applied in any given day by only injecting from small tanks. Other growers have had problems with fittings leaking, and install their chemical tanks inside containment tanks.

Figure 2. Chemical tanks placed inside larger containment tanks.

General Chemigation Rules

In addition to the legal requirements for safety, several other points should be considered by anyone who plans to inject chemicals. These include:

1. For some chemicals, a filter may be needed between the injector and the chemical supply tank.

Figure 3. Chemical tanks with precipitate in the bottom. This will plug the injector pumps if no filter is installed between the tanks and the injectors.

Always consider how this filter will be cleaned out without spilling the chemical on the ground. Figure 4 below illustrates a possible configuration that allows the chemical hose and filter to be flushed with fresh water before disassembly of the filter or other parts.

Figure 4. Recommended connection to a chemical tank. The chemical moves from the center tank through the filter and then through the chemical line to the injector pump. Fresh water can be supplied from the left hand side. The figure shows ball valves in positions that shut off the chemical and allow fresh water to flush the filter and injector.

2. Fittings (valves, hoses, elbows, etc.) should be properly selected to withstand:
    a. The chemicals they will be exposed to.
    b. The pressures they will be exposed to (assume the worst possible condition).
    c. Sunlight damage.

3. Use more than one pump if you plan to inject more than one chemical. Reasons include:
    a. Each chemical probably has a different optimum rate of injection. Injection pumps and chemical flow meters are usually ideally suited for a rather narrow range of flows.

Figure 5. A small injector pump is all that is needed to add some specialty products to drip systems to minimize plugging.

b. Installation of multiple pumps at a site eliminates the need to constantly take apart hoses and reconnect them to different tanks. This helps to avoid:
    i. Dirty hose ends.
    ii. Adverse chemical reactions between residuals in the hoses.
    iii. Personnel contact with the chemical.

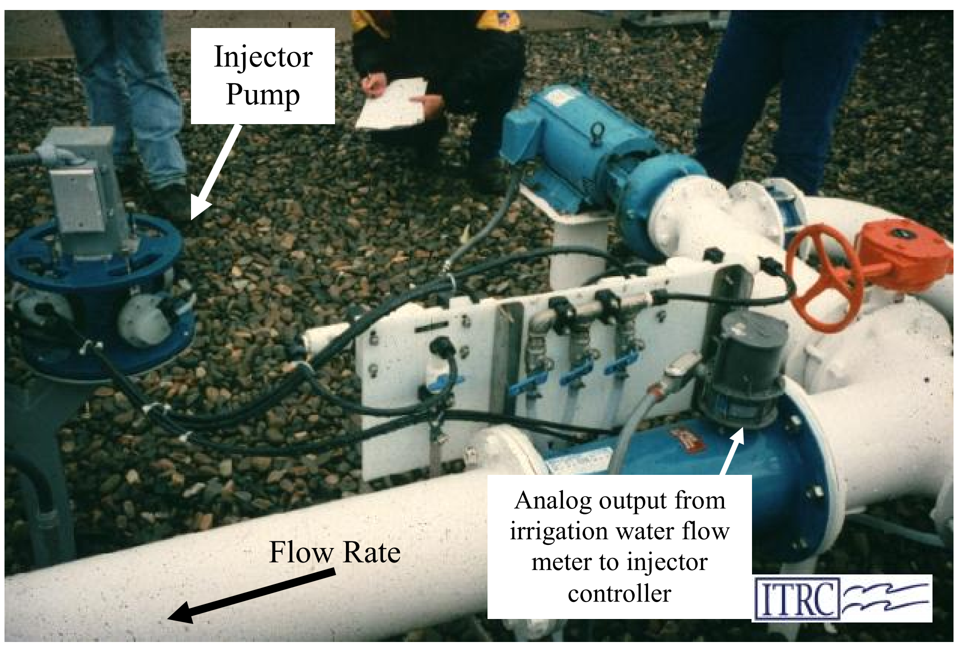

Figure 6. A pump (on the left hand side) that is configured to drive 4 independent pump heads simultaneously. Each pump head can be adjusted independently. The pump RPM can be controlled to inject proportionally to the flow rate through the irrigation system (notice the conduit leading to the propeller flow meter in the irrigation line).

c. A good chemigation program generally uses many different chemicals simultaneously. A chemigation system may need to inject several different types of fertilizers, plus chemicals to minimize emitter plugging, plus pH control, plus pesticides. That is difficult, if not impossible, to achieve with only one or two injector pumps without having adverse chemical reactions, and if one wants to have the proper dosage.

4. The distribution uniformity of the chemical through the field is only as good as the distribution uniformity of the irrigation water.

   Distribution Uniformity ("DU") is a ratio that indicates how evenly water is applied to different plants throughout a field.

$$DU = \frac{\text{Average of the low-quarter depths of irrigation water received by plants}}{\text{Average depth of irrigation water received by plants}}$$

   A DU of 1.0 indicates that all plants receive the same amount of water.

   No irrigation system is capable of delivering water with a DU of 1.0.

   Non-uniformity is caused by factors such as:
   - Pressure differences between sprinklers and emitters.
   - Worn sprinkler nozzles.
   - Wind with sprinklers.
   - Uneven soils in furrows and border strips.
   - Differences in “opportunity time” (how long the water sits on the soil surface at different points within a field) with furrows and border strips.
   - Plugged drip emitters.

   Figures 7 and 8 show the concept of non-uniformity and the DU index, graphically.

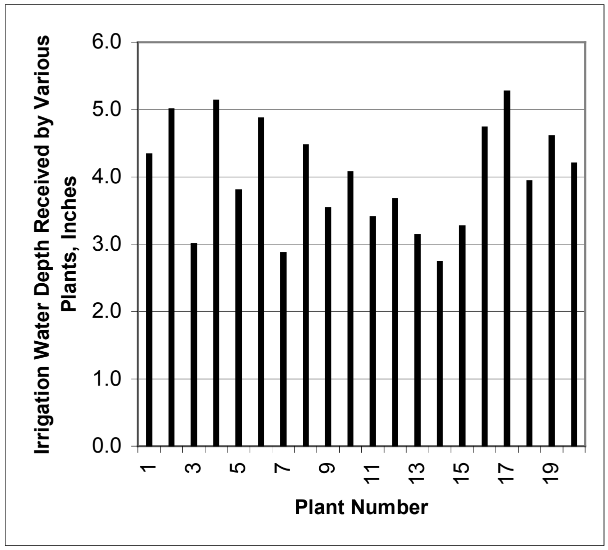

Figure 7. Example depths of irrigation water to different plants, measured in a transect across a field.

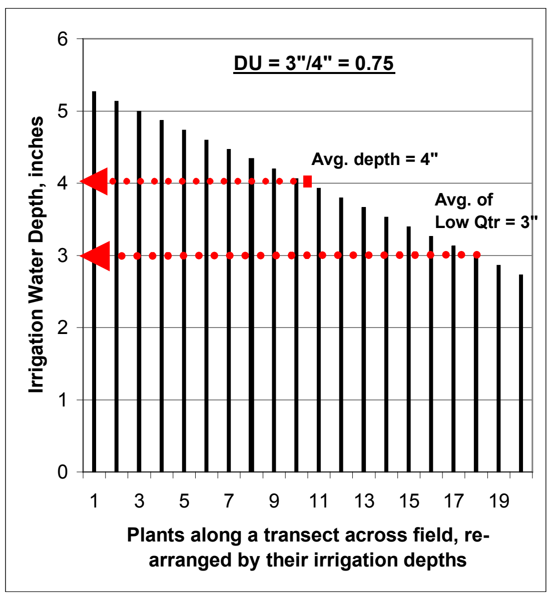

Figure 8. Irrigation depths from Figure 7, rearranged in order of magnitude. The "average of the low-quarter" values (3") is the average of the lowest 5 of 20 values. The ratio of 3" to the "average of all" (4") is 0.75, which is the Distribution Uniformity (DU) – a standard measure of irrigation performance.

The reason for this discussion of DU of irrigation water is that it has a huge impact on the efficiency of chemical injection through irrigation water. For example, the irrigation water DU of 0.75 illustrated in Figure 8 can also be interpreted as follows:

Maximum received by plants = 5.3"
Minimum received by plants = 2.7"

$$\text{Ratio of max/min} = \frac{5.3"}{2.7"} = \frac{1.9}{1}$$

In other words, with a DU of 0.75, ***some plants receive about 90% more water (and chemical) than others.*** Table 1 provides a similar interpretation of irrigation DU measures.

Table 1. Relationship between irrigation DU and maximum/minimum ratios of irrigation water throughout a field.

Distribution Uniformity, DU	Typical $\frac{\text{Maximum}}{\text{Minimum}}$ ratio of irrigation depths
0.70	2.2
0.75	1.9
0.80	1.7
0.85	1.5
0.90	1.3
0.95	1.1

Figure 9. Pattern of non-uniform sprinkler water distribution. This can be caused by improper sprinkler pressure, high winds, poor sprinkler head design, or wide sprinkler spacing. The variation between light and spots indicates that different amounts of water and different droplet sizes are applied throughout the field.

Figure 10. Hose-end flushing is important for proper maintenance of drip systems. The muddy water in this photo indicates infrequent flushing. Adequate filtration and chemical maintenance are also essential for drip/micro systems.

To achieve good pesticide/fertilizer/water application, you should obtain:

a. A guarantee of the new irrigation system DU for any new drip/micro or sprinkler system you purchase. An attainable value for most drip/micro systems is 0.90.

b. An evaluation of the irrigation system DU for any existing irrigation system. Evaluations are conducted by various private consultants, by personnel from irrigation districts, and by student teams from Cal Poly ITRC. Be certain that the evaluators have been trained at Cal Poly (short courses on evaluation have been taught for over 20 years there), and that they are using standardized Cal Poly ITRC evaluation procedures, computation procedures, and reporting formats.

Figure 11. Evaluation of flow rates for a microspray irrigation system evaluation.

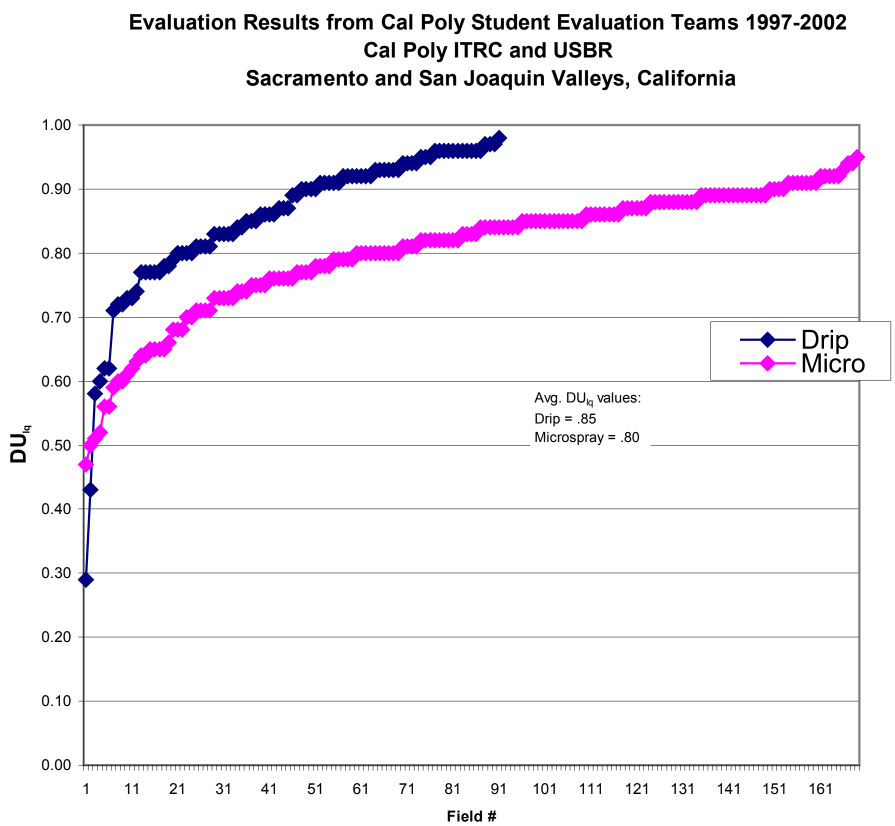

Figure 12. Measured DU values of California drip/micro irrigation systems by Cal Poly irrigation evaluation teams.

Questions and Hints for Fertigation

Fertigation accounts for the majority of chemigation. The sophistication of fertigation knowledge and practices is at about the same level as drip/microirrigation was in the mid-1970s. A lot of equipment and chemicals exist, and many farmers use fertigation, but only a relatively small percentage of those farmers are sophisticated users.

Below are a few of the common questions related to fertigation, accompanied by some very simplified answers and hints.

Question: How can one know how much fertilizer to apply?

Answer: Traditional fertilizer practices use information from a pre-plant soil test to determine how much fertilizer should be applied, perhaps combined with petiole analysis during the growing season. After lay-by (once the tractors can no longer move through the field), fertilizer can no longer be applied.

With fertigation, the rules should be different from traditional fertilizer practices if the benefits are to be achieved. A pre-plant soil analysis should still be conducted. However, lay-by is no longer a restriction to chemical application, and spoonfeeding can be done rather than application of just a few heavy dosages. Growers are using more "quick tests" to obtain weekly readings of plant sap (different from petiole analysis) and soil solution nutrient levels (different from soil tests which use dry samples), in addition to using petiole analysis. A key to any successful fertigation program, however, is maintaining good, consistent records of multiple tests over time.

A major challenge remains in how to interpret the numbers obtained from the different types of tests. While good correlations exist between some test results, better information is still needed on what nutrient levels are sufficient at various growth stages. Sophisticated growers develop rules for their own sufficiency levels based upon excellent record keeping and monitoring of crop yields.

Question: How many applications of fertilizer should be made during a season?

Answer: Spoonfeed, spoonfeed, spoonfeed. Spoonfeeding (adjusted according to continuous monitoring of indicators such as plant sap, soil water nutrient levels, and petiole analysis) has long since been shown to be good for optimum growth. Spoonfeeding also minimizes problems associated with over-application (and subsequent toxicity problems), irrigation system component corrosion, and plugging.

Question: Should the fertilizer be applied continuously or only during the middle of an irrigation set?

Answer: Classic advice on injection includes something such as a "third-third-third" rule. By allowing the system to pressurize before injecting chemicals (the first third of the irrigation set duration), uniformity is enhanced. By allowing the system to be flushed out before shutting down (the last third of the time), corrosion and plugging problems can be minimized. Of course, such a rule is difficult to use with center pivots, lateral/linear moves, and surface (furrow) irrigation (i.e., any continuous moving system) and a field will not receive a uniform application of fertilizer.

Figure 13. Furrow irrigation. Chemicals must be injected into the source water at a uniform rate as long as the source water enters the field.

Figure 14. Center pivot irrigation. Chemicals must be injected at a uniform rate, and at the correct rate, so that the proper dosage is applied in one revolution.

Most growers with drip/microirrigation have found that by spoonfeeding in low dosages, they can continuously inject fertilizers rather than needing to turn the injection on and off before and after each set change. The chemical dosages are so low that they do not cause problems with corrosion and plugging.

Figure 15. Drip and micro irrigation. Chemicals can be constantly spoonfed, or they can be applied rapidly in the middle of the set – as long as the correct amount is applied during a set.

Question: What types of nutrients (nitrogen [N], phosphorus [P], potassium [K], and/or micronutrients) should be applied through the irrigation system?

Answer: All of these can be applied as needed for drip systems on permanent crops (trees and vines), although some micronutrients can be applied as foliar sprays. In fact, because nutrients move into the root zone with water, most fertilizers on drip irrigated fields must be applied through the irrigation system. For field and row crops, it is generally recommended to apply at least 60% of the P and K fertilizer needs as a pre-plant application. Those nutrients do not leach during the season. Also, P is needed most during early plant growth, and if an irrigation must be made just to apply P, the cold wet soil (due to the irrigation) may actually inhibit plant growth and P uptake.

Question: If a nutrient such as nitrogen is applied, what form of the nutrient should be used?

Answer: This is not as simple as "the one with the cheapest cost per pound of N". Only a few points will be made here.

A high percentage of anhydrous ammonia will volatilize if injected into high pH water (either while in the water or later from the soil surface of a high pH soil). This is common in the southwestern U.S.

Figure 16. Furrows that are now covered with limestone as the result of injecting anhydrous ammonia into Imperial Valley irrigation water that has high concentrations of calcium salts and a high pH.

Ammonium fertilizers can cause water infiltration problems if the irrigation water is very pure (EC less than 0.3 dS/m).

Figure 17. Infiltration problems due to pure water on the east side of the San Joaquin Valley. Ponded water can be seen.

On the other hand, a diet of pure nitrate nitrogen is not best for plant growth. Plants may do best with a supply of about 50/50 Nitrate/Ammonium in the soil, both because of plant physiological needs and because this balance will enhance a good uptake balance of other nutrients (e.g., high nitrate uptake will compete against phosphorus uptake). Because all nitrogen compounds (including urea) undergo conversions in the soil to other forms, the plant uptake of various N forms will be dependent upon the conversion rates and the form of N being injected.

Question: What fertilizers are compatible – can multiple fertilizers be injected simultaneously?

Answer: There are no simple answers. The question must also be expanded to ask if the fertilizer is compatible with the irrigation water itself. A basic rule is that one should always conduct a "jar" test prior to injecting any fertilizer(s) – put the proposed fertilizer(s), at the desired concentration, into a clear jar of irrigation water and allow the jar to sit one or two hours. Any cloudiness or precipitate in the water indicates a potential problem.

There are some general notes. Urea-sulfuric (a.k.a. "N-phuric") fertilizers have limited compatibility with many fertilizers if applied in high dosages. Calcium (whether it originates in the water or in another fertilizer) will combine with phosphorus and sulfate (originating in another fertilizer or the water) to make an insoluble precipitate. Spoonfeeding minimizes or eliminates almost all such problems because the solubility limits (e.g., high concentrations of chemicals that cause precipitation) are typically not reached with the low dosages.

Question: Can gypsum injection through the irrigation system be beneficial?

Answer: Yes, it can be. But since gypsum is just a chemical, and it will only solve specific chemical problems. Gypsum is most commonly used alleviate irrigation water infiltration problems that are chemistry-related. **Continuous** injection can help remedy:

1. Infiltration problems caused by very pure water – such as on the east side of the San Joaquin Valley.
2. Infiltration problems caused by an imbalance of Calcium to Magnesium in the irrigation water – such as occurs on the Central Coast of California.

Figure 18. Large silo of gypsum powder with gypsum injection machine behind it.

Question: Are there potential hazards with gypsum injection?

Answer: Definitely yes. They include:

1. Injection of gypsum that does not dissolve quickly. This can occur due to:
    a. Injection at an excessively high rate, so that it doesn't all dissolve.
    b. Use of the wrong type of gypsum. Dihydrate gypsum dissolves much quicker than anhydrite.
    c. Use of impure gypsum. There is a wide variety of purity on the market.
    d. Use of gypsum that is not uniformly ground to pass through a 200 mesh or smaller filter
2. Injection of gypsum downstream of filters. If there is any un-dissolved gypsum, it will plug the irrigation system instead of the filters.

Gypsum that does not dissolve properly creates the following problems:

1. It can wear out microsprayer nozzles.
2. It can fill hoses and irrigation lines with gypsum.
3. It can plug filters.
4. It can plug emitters and microsprayers.

Question: Should chemicals be injected upstream or downstream of filters on drip/micro systems?

Answer: Pesticides and strong acids should be injected downstream of filters. All fertilizers should be injected upstream of the filters. This will protect the irrigation system from any precipitation caused by an adverse chemical reaction between chemicals, or between the chemicals and the irrigation water, or from dirty hoses, etc.

Figure 19. Chemical precipitate being flushed from drip tape. A yet-to-be-identified chemical was mistakenly injected downstream of the filters. The system plugged and needed to be replaced. This was considerably more expensive than cleaning a dirty filter.

Question: Won't injection of fertilizers upstream of the filters cause a loss of fertilizers when the filters go into a backflush cycle?

Answer: Yes….unless the chemical injection is turned off before the backflush begins. Several commercial automatic backflush controllers are available that can accomplish this. The controllers turn off the injectors, wait a user-specified time, and then begin the backflush cycle. At the end of the backflush cycle, they turn the injectors back on again.

Figure 20. When filters are backflushed, injected chemicals can be lost unless the chemical injection is temporarily suspended.

Other Information

The following will provide additional information regarding chemigation:

1. The Cal Poly ITRC publication (295 pages) "Fertigation". It can be purchased directly from ITRC by phone or via the web.
   Irrigation Training and Research Center
   Cal Poly State University
   (805) 756-2434
   www.itrc.org (select "Publications")

2. Resources are available on an ITRC web page dedicated to chemigation:
   www.itrc.org/reports/chemigation/chemigation.htm

   The web page is co-sponsored by the California Dept. of Pesticide Regulation. The resources that can be downloaded from the web site include:
   a. This article.
   b. A "Chemigation Grower Manual" written by CIT, Fresno. This is a "layman's guide" to the hardware that is required by law if pesticides are injected into agricultural irrigation systems.
   c. California Dept. of Pesticide Regulation's enforcement letter ENF 01-12, dated March 28, 2001. Entitled "Backflow Prevention Regulatory Requirements and Policy".
   d. California Dept. of Pesticide Regulation's enforcement letter ENF 01-28, dated June 7, 2001. Entitled "Chemigation Safety Devices: Pesticide Label Requirements and Allowable Alternative Equipment".
   e. A list of commercial vendors of various safety equipment for chemigation.