Appendix II

Winegrape Management Practice Workbook 2010
DRAFT

California Department of Pesticide Regulation –
Pesticide Management Alliance Grant
Controlling Off-site Movement of Agricultural Chemical Residues in Winegrape Production

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Controlling Off-site Movement of Agricultural Chemical Residues in Winegrape Production

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Controlling Off-site Movement of Agricultural Chemical Residues in Winegrape Production

INTRODUCTION

WHAT’S IN THIS PUBLICATION?

The main goal of this publication is to provide winegrape growers with information to help reduce the occurrence of organophosphate and synthetic pyrethroid pesticides in surface waters, which include streams, lakes, ponds, rivers, and drainage ditches. An assessment of the potential risk of offsite movement as a result of an agricultural chemical application is performed using a flow chart for a specific crop, management practices, and field conditions. The risk self-assessment focuses on issues that affect either the number of pesticide applications containing these active ingredients, or the offsite movement of pesticides as drift, attached to sediment, or in water that carries pesticide active ingredients.

If a significant risk is determined, an array of science based management practices is then identified and discussed. Growers can implement these practices to mitigate the risk that pesticides will leave the site of application and enter surface waters.

WHY IS THIS PUBLICATION NEEDED?

The Central Valley occupies about 40 percent of the land area in California, and provides much of the State’s agricultural production. Maintaining this productivity has required the use of about 132 million pounds of pesticides annually, and water quality in the Valley’s rivers and streams have suffered as a result of pesticide movement from agricultural lands into these waters. The list of impaired water bodies recently proposed for listing under Clean Water Act Section 303(d) includes nearly a hundred water body segments in which the impairment is due to agriculture. Agriculture is identified more often than any other source in the State as the likely cause of impairment.

Agricultural pesticides reach surface water bodies directly as spray drift or indirectly through storm water runoff or irrigation run-off from treated fields, vineyards. Run-off waters may transport pesticides as dissolved or soil particle-adhering residues. Among the pollutants often attributable to agriculture is the organophosphate insecticide chlorpyrifos. California agriculture uses 1,425,000 lbs of chlorpyrifos annually, more than any other insecticide. Approximately half of the hundred 303(d) listed water body segments impaired due to agriculture in the Central Valley are impaired in whole or in part by chlorpyrifos. Its presence in surface water and its toxicity to aquatic life has been responsible for multiple Total Maximum Daily Load (TMDL) projects in California, including one for the San Joaquin River, another for the Sacramento-San Joaquin Delta, and many other TMDLs elsewhere in the State where the process is less developed.. Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. In one study, chlorpyrifos was responsible for mortality to the test organism, Ceriodaphnia dubia, in
seven of ten toxic samples (de Vlaming et al. 2004).

Pyrethroids are another group of compounds emerging as a concern. Pyrethroids are a cause for 303(d) listing of about 10 percent of agriculture-impaired water bodies in California. In a study of toxicity of sediments collected from agricultural waterways, 54 out of 200 sediment samples caused acute toxicity to the test organism, *Hyalella azteca*, and pyrethroids were responsible for the toxicity in 61 percent of those cases (Weston et al. 2008). Chlorpyrifos was the second most common contributor to toxicity, responsible for toxicity in 20 percent of the samples. Recent data has also shown pyrethroids to be present above toxic thresholds in irrigation tailwater samples as well. In a study just completed, the pyrethroid lambda-cyhalothrin was responsible for toxicity to the *H. azteca* in three out of six toxic samples collected at agricultural pump stations where tailwater was being returned to nearby rivers. Chlorpyrifos was responsible for toxicity in the remaining three samples (Weston et al. in review). As analysis of environmental samples for pyrethroids increases, it is likely that the water quality effects of pyrethroids will be even more broadly recognized in future years.

The continued use of these effective agricultural pesticides is dependent on measures to prevent offsite movement of residues into surface water sources. A table listing the active ingredient and trade name for insecticides commonly used in winegrape production can be found in Table 1.

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>Common Name</th>
<th>Trade Name</th>
<th>Lbs/Year</th>
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<td>Cygon</td>
<td>379</td>
<td>organophosphate</td>
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Source: Pesticide Action Network [http://www.pesticideinfo.org](http://www.pesticideinfo.org)

**CURRENT REGULATORY APPROACH TO SURFACE WATER PROTECTION**

All growers farm under the requirement not to pollute surface and ground water. Water leaving agricultural lands as irrigation or storm water runoff can contain pesticide residues, sediment, or nutrients. These discharges are regulated by the Central Valley Regional Water Quality Control Board (Water Board) under a program called the Irrigated Lands Regulatory
discharges

Types

General individual adhered some watersheds

The Water Water WATER irrigation

In Program. Federal

However, to was this end the board has:

• Established surface water quality standards in each watershed basin plan
• Enforced Waste Discharge Requirements

THE AG WAIVER

In 1982 the Board adopted a resolution “Waiving Waste Discharge Requirements for Specific Types of Discharge.” The resolution contained 23 categories of waste discharges, including irrigation return flows and storm water runoff from agricultural lands. The resolution also listed the conditions required to comply with the waiver, hence the term ‘Conditional Ag Waiver’. However, due to a shortage of resources at the time, the Water Board did not impose measures to verify compliance with these conditions.

The waiver, set to sunset in 2003, was amended by adopting two conditional waivers for discharges from irrigated lands. One was for coalition groups of individual dischargers that comply with the California Water Code and Water Board (check plans and policies. The other was for growers to comply as individual entities. To be covered by the waivers, the coalition or individual must have filed with the Water Board by November 1, 2003 a Notice of Intent and General Report that contained specific information about their farm, and then must have adhered to a plan and timeline that includes, among other things, a farm management plan and surface water monitoring plan.

WATER QUALITY COALITIONS

Water quality coalitions are generally formed by growers on a sub-watershed basis, although some are based on a specific commodity. The San Joaquin County and Delta Water Quality Coalition, for an example, encompasses all of San Joaquin County and portions of Contra Costa and Calaveras Counties. The coalition includes about 500,000 acres of irrigated lands and 4500 individual members. The coalition monitors and analyzes the water quality of sub-watersheds and facilitates the implementation of management plans. They provide outreach and support to growers in response to water quality exceedances at sub-watershed monitoring sites, in order to enhance the water quality of those water bodies.

Water Quality Monitoring

The coalition currently monitors water quality at numerous sites in both large and small sub-watersheds within the coalition watershed. Water samples are collected monthly, and sediment samples are collected twice per year. During 2008, water quality standards were exceeded many times. At some locations, as many as 40 percent of the samples exceeded water quality standards for pesticide residues (Management Plan, San Joaquin County Delta Water Quality Coalition, Karoski 2008). When more than one exceedance of water quality limits occurs for any contaminant, a management plan must be developed by the coalition to address it. In addition, any single exceedance of either chlorpyrifos or diazinon triggers the requirement for a management plan.
Management Plans

The overall goal of water quality management plans, whether developed by individuals or coalition groups, is to reduce agricultural impacts on water quality in the plan area. Management plans evaluate the frequency and magnitude of exceedances and prioritizes locations for outreach.

To achieve the goal of improving water quality, a management plan must include:

- Source identification of constituents causing poor water quality.
- Outreach to growers about irrigation and dormant season management practices.
- Evaluation of water quality improvements achieved by monitoring and management practices.

Under the management plan landowners/growers must:

- Help the coalition succeed by participating in efforts to solve problems identified through water monitoring.
- Staying informed – read mailings and updates, respond as necessary.
- Attending grower water-quality information meetings.
- Implementing management practices that address the identified water quality concerns.

HOW TO USE THE WORKBOOK

This workbook is designed to be used in a two-step process. The first step is to identify specific vineyard conditions or operations that increase the risk of off-site movement of pesticides. To aid in doing this, a series of “flow-charts” are presented. When followed systematically from beginning to end, these will guide you through a series of considerations of your vineyard operation and help identify potential problem areas. The second step is to understand and implement management practices aimed at addressing problem areas you have identified. For the purposes of this workbook, these practices focus on organophosphates and pyrethroids, the two pesticide groups of greatest current concern for water quality, and can be divided into three broad categories:

Use integrated pest management practices, select pesticides with the lowest risk of off-site movement, and follow good pesticide handling practices

Integrated Pest Management is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment. Control materials are selected based on efficacy, economics, worker safety and runoff potential. Mixing and loading are key times to prevent high
concentrations of pesticides from being released for potential off-site movement.

**Use practices that reduce off-site movement of pesticides** Drift is the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site. Spray drift from ground or aerial pesticide applications can be reduced or eliminated by adhering to established guidelines on application equipment, conditions, and pesticide and adjuvant product selection. Off-site movement from storm water runoff and irrigation runoff can be controlled using vineyard floor and irrigation management techniques that reduce or eliminate run-off.

**Capture and recycle or treat runoff waters**

When IPM and run-off control practices do not address the problem, consider the feasibility of capturing and reusing runoff or treating fields or waters with products that chemically degrade pesticide residues before discharge waters leave the vineyard.

Lastly, a case study is presented to illustrate the process of evaluating the risk of off-site movement and discussions of and/or implementation of management practices to minimize it. The case study begins with a set of sample conditions, and then uses the flowcharts to help us assess the risk of a treatment’s off-site movement potential.
FC1
Assessing the Risk of Offsite Movement of Ag Chemicals to Surface Waters

Follow each shaded boxes below using your field conditions to assess the risk - if the risk is significant continue on to view management practices to reduce the risk of off site movement. If the risk is low return to the next shaded box.

Irrigation Runoff
- Pressurized System
  - Runoff to Surface Waters
    - No
      - Low Risk
        - Go To FC2
    - Yes
      - Go To FC3
- Gravity Surface System
  - Runoff to Surface Waters
    - No
      - Low Risk
        - Go To FC3
    - Yes
      - Go To FC3

Storm Water Runoff
- Runoff to Surface Waters
  - No
    - Low Risk
      - Go To FC4
  - Yes
    - Low Risk
      - Go To FC4

Application Near Water Surfaces
- No Adjacent Surface Water Areas
  - Yes
    - Low Risk
      - Go To FC5
FC2
Reducing the Risk of Offsite movement of Ag Chemicals in Pressurized Irrigation Systems

Runoff to Surface Waters Occurs

YES

Integrated Pest Management

Selecting Pesticides to Reduce Water Quality Risks

Mixing and Loading Near Surface Waters

Irrigation System Management

Irrigation Scheduling

Runoff Water Capture or Treatment

Improve Water Infiltration

Improve Irrigation Uniformity

Turn system off before runoff

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FC3
Reducing the Risk of Offsite movement of Ag Chemicals in Gravity Surface Irrigation Systems

Runoff to Surface Waters Occurs

YES

Integrated Pest Management → See pg19

Selecting Pesticides to Reduce Water Quality Risks → See pg19

Mixing and Loading Near Surface Waters → See pg22

Capture Runoff

Reduce Runoff Volume

Irrigation Scheduling

Runoff Water Capture or Treatment

Vegetated Filter Strips

Modify Cul-Off Point

Improve Water Infiltration

Recycle Runoff

Convert to Pressurized Irrigation

Organophosphate Pesticides

Landguard

Sediment and Pyrethroids

Polyacrylamide (PAM)

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FC4
Reducing the Risk of Offsite movement of Ag Chemicals in Storm Water Runoff

Runoff to Surface Waters Occurs

YES

Integrated Pest Management
See pg 19

Selecting Pesticides to Reduce Water Quality Risks
See pg 19

Mixing and Loading Near Surface Waters
See pg 22

Avoid Application at Times of Risk

Plant cover crops
See pg 17

Protect Soil Surface

Organic Matter Management
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Improve Water Infiltration

Runoff Water Capture or Treatment

Organophosphate Pesticides

Sediment and Pyrethroids

Polyacrylamide (PAM)

Sediment Basin
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Vegetated Filter Strips
See pg 46

Landguard
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Till Orchard / Vineyard Floor (flat ground)
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When Rain is Predicted

See pg 17

Evaluate and institute a chemical solution
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When Soils are Saturated

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See pg 39
FC5
Reducing the Risk of Offsite movement of Ag Chemicals Near Water Surfaces in Drift Situations

Ground Applications

Application Conditions

Application Equipment

Product Choice

Buffer Zones

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RISK ANALYSIS CASE STUDY

In any risk analysis there are a number of site and pest conditions as well as the management options of pesticide choice, timing, and climate to consider. Let’s begin with a set of sample conditions, and then use the flowcharts to help us assess the risk of a treatment’s off-site movement potential:

Crop: Mature Cabernet Sauvignon  
Site: Undulating topography 0-4 percent slope  
Soil: San Joaquin Sandy Loam soil  
Irrigation system: Drip  
Drainage: runoff moves to a drain at edge of field; then, on to a larger creek  
Surface Water Sources: edge of field drain contains water from irrigation runoff from neighboring lands.  
Pest: Vine mealybug  
Pest Detection: mid- late season—pre harvest  
Mixing and loading area: within 50 feet of the surface water ditch

Step 1 . EMPLOY IPM PRACTICES  
(The following was adapted from the UC IPM Guidelines available at:  
[http://ucipm.ucdavis.edu](http://ucipm.ucdavis.edu))

Identifying and Understanding the Ecology and Dynamics of the Pest

Vine mealybugs are small (adult females are about 1/8 inch in length), soft, oval, flat, distinctly segmented, and covered with a white, mealy wax that extends into spines (filaments along the body margin and the posterior end). The adult male is smaller than the female, has wings, and flies short distances to mate. There are three to seven generations a year.

All or most life stages of the vine mealybug can be present year-round on a vine depending on the grape-growing region. During the winter months, vine mealybug eggs, crawlers, nymphs, and adults are under the bark, within developing buds, and on roots.

As temperatures warm in spring, vine mealybug become visible as they move from the roots and trunk to the cordons and canopy. By late spring and summer, vine mealybugs are found on all parts of the vine: hidden under bark and exposed on trunks, cordons, first- and second-year canes, leaves, clusters, and roots. Ants may transport vine mealybug from the roots to above ground plant parts where they continue to tend vine mealybugs throughout the remainder of the growing season.

Damage by the vine mealybug is similar to that of other grape-infesting mealybugs in that it produces honeydew that drops onto the bunches and other vine parts and serves as a substrate for black sooty mold. If ants are not present, a vine with a large population of this pest can have so much honeydew that it resembles candle wax. Also, the mealybug itself will be found infesting bunches making them unfit for consumption. Like the grape, obscure, and longtailed mealybugs, vine mealybug can transmit grape viruses.
Instituting a Monitoring Program to Assess Levels of Pests and Their Natural Enemies

Pheromone traps for this pest are available for determining if a vine mealybug infestation is near or in your vineyard. The lure that is placed inside each trap contains the sex pheromone that female vine mealybugs use to attract winged adult males. Tent-shaped, red traps are recommended because the shape and color tend to reduce the number of non-target insects that are caught.

Place traps in and around the vineyard by April 1 in the southern San Joaquin Valley to May in areas further north and June in the North and Central Coasts:

- Choose two trap sites for each 20-40 planted acres.
- Put one trap in the center of the block and the other on the edge near a staging area.
  These traps can attract vine mealybug males from as far away as 1/4 mile.
- Attach traps to the trellis wires so that they are in the cluster area.
- Label the trap with the block name and row number of its location and the dates it remains in the vineyard.
- Check traps for the presence of male vine mealybug every 2 weeks through November.
- Follow the manufacturer's recommendations for storing and replacing pheromone lures.

Establishing an Economic or Action Threshold

After bloom, pull basal leaves to look for vine mealybug crawlers and honeydew in the canopy and look under the bark on the trunk and cordons. During bloom and veraison, treatment may be warranted for even a moderate population of nymphs on leaves (between 10 and 15 percent of the vineyard having mealybug present), but if possible it is better to wait until postharvest to treat in order to preserve natural enemies. Look for ant activity in vines and along drip lines. Also, the presence of ants moving up and down the vine may indicate the presence of Pseudococcus mealybugs, vine mealybug, or European fruit lecanium scale.

Vine mealybug produces more honeydew than other mealybugs, and this is particularly noticeable if there are no ants present. Thus, when searching for vine mealybugs during summer, look for honeydew exudates on the clusters, trunk, and cordons. These exudates will resemble melted candle wax, if the infestation is severe, and basal leaves will appear shiny and sticky. Sooty mold will grow on the honeydew, and permanent parts of the vine will appear black in fall and winter. Also look for fallen leaves beneath the canopy in July and August. To locate less severe infestations, it is necessary to look for all stages of the insect under the bark predominately at the graft union, on trunk pruning wounds, and below the base of the spur.

If vine mealybug is found in the vineyard, treatment is recommended. There are two approaches to managing mealybugs: eradication and yearly management. Eradication using chemical applications is most likely to be successful in young vineyards or in vineyards where only a few isolated vines are infested. In mature vineyards with heavy, loose bark, strip the bark off the trunk and cordons before a chemical application to increase chances of success. Eradication is most probable in areas where there are no nearby vine mealybug-infested
vineyards. If 2 years of effort do not eliminate vine mealybug from the vineyard, then switch to a yearly management program.

**Considering Available Control Techniques and Determining Which Are Most Appropriate**

**Biological Control**

The parasites that attack *Pseudococcus* mealybugs do not attack the vine mealybug, therefore two potential candidates for natural control have been imported and released in Riverside, Kern and Fresno counties. The most successful of these has been *Anagyrus pseudococci*. This species has provided up to 20 percent parasitism in some vineyards in the Coachella Valley and up to 90 percent parasitism in the San Joaquin Valley. It is extremely important to promote parasites because they are active late in the growing season and can reduce vine mealybug populations before the pest begins to move to the lower part of the trunk in October. To a limited extent, they can parasitize vine mealybug when it is located under the bark where chemicals cannot penetrate. Ants must be controlled to keep them from interfering with these natural enemies.

In the coastal regions a lady beetle called the mealybug destroyer, *Cryptolaemus montrouzieri*, attacks vine mealybug eggs and crawlers.

**Cultural Control**

The female mealybug is unable to fly so it must be carried by humans, equipment, birds, or be present on vines at the time of planting. Do not allow contaminated equipment, vines, grapes, or winery waste near uninfested vineyards. Movement of equipment that pushes brush or any over-the-row equipment can be a major source of infestations in new locations; steam sanitize equipment before moving to uninfested portions of the vineyard. Do not spread infested cluster stems or pomace in the vineyard. To reduce contamination, cover all pomace piles with clear plastic for several weeks, and avoid creating piles that consist predominately of stems.

**Organically Acceptable Methods**

Biological and cultural controls are organically acceptable management tools. The use of 415 oils repeatedly during the spring and summer has shown good results in winegrapes. This also helps manage mildew but the use of sulfur must be avoided. No research studies have yet been done in California on the efficacy of oils or calcium polysulfide in controlling vine mealybug, but they have not proven effective in controlling the grape mealybug.

**Chemical Management-- in Newly Infested Vineyards**

If vine mealybug is discovered in the vineyard in late summer or fall, apply a foliar insecticide immediately after harvest if possible (before the nymphs begin to move to the lower parts of the trunk), to kill mealybugs on the leaves and wood so that the infestation is not spread to other parts of the vineyard when leaves drop or when the vines are pruned and if preharvest interval restrictions permit, apply methomyl or dimethoate to infested vines. Take precautions during harvest operations to prevent movement of insects to non-infested vines.
The following year, apply a delayed dormant treatment of chlorpyrifos or buprofezin and then, in areas with light soils, treat with imidacloprid (soluble formulation) at bloom. Make either a single application through the drip system of imidacloprid or a split one, depending on soil type. During summer, treat with buprofezin. Other materials (methomyl and dimethoate) are available for treating vine mealybug during summer, but they are not as effective and are more disruptive of beneficials. (In the North Coast, the first application of buprofezin is not recommended until late spring or early summer; imidacloprid is not as effective in controlling pests in heavy clay soils dinotefuron.) The University of California recommends following this program for a maximum of 2 years. If vine mealybug is still present in the vineyard after 2 years, switch to a yearly management program.

**Step 2. DEFINE A SOLUTION**

Cultural methods of control can help contain VMB spread but will not eradicate the pest. It is extremely important to promote parasites because they are active late in the growing season and can reduce vine mealybug populations before the pest begins to move to the lower part of the trunk in October.

In this case the use of chemical control is warranted. Since VMB was first discovered in late summer, apply a postharvest treatment of a foliar insecticide (chlorpyrifos, methomyl or dimethoate) to kill mealybugs on the leaves and wood so that the infestation is not spread to other parts of the vineyard when leaves drop or when the vines are pruned. Postharvest treatments are only recommended the first season that vine mealybug is discovered.

Starting the following year, apply a (pre-budbreak) delayed dormant treatment of chlorpyrifos (Lorsban®) or buprofezin (Applaud®) and then treat with imidacloprid (Admire®) or dinotefuron (Venom®) at bloom. Make either a single application of imidacloprid (Admire®) or a split one, depending on soil type. During summer, treat with buprofezin (Applaud®) or acetamiprid Assail® or clothianidin (Clutch®) if insects are active. Other materials (methomyl and dimethoate) are available for treating vine mealybug during summer, but they are not as effective and are more disruptive of beneficials.

**Step 3. OFF-SITE MOVEMENT RISK ANALYSIS**

**Beginning on FC1, Evaluate the Risk for Irrigation Runoff**

Irrigation runoff is not likely due to the use of drip irrigation and the time of the season, post harvest.

**FC1, Evaluate the Risk for Storm Water Runoff**

With soil conditions conducive to forming a surface crust limiting infiltration rates combined with the vineyard’s slope—a risk of runoff from winter rains exists—go to FC4.
FC4, Reducing the Risk of Offsite Movement of Agricultural Chemicals in Storm Water Runoff

**Implement an IPM Program**

The steps to implement an IPM program have been utilized (see above).

- proper pest identification;
- understanding pest life cycles and conditions conducive to infestation;
- monitoring for the presence, locations and abundance of pests and their natural enemies;
- treat when established action thresholds (economic, aesthetic, tolerance) are reached;
- consideration of multiple tactics for pest suppression – biological, cultural, and chemical—and selection of the lowest-risk practical and effective approach.

**Pesticide Selection to Minimize Water Quality Risks**

A post harvest or a delayed dormant application is at risk of causing off-site residue from rains causing runoff. Selection should be based on efficacy, persistence in the environment (half-life), and water toxicity. In this case, all materials recommended for a late season application are organophosphate insecticides. However, there are differences in the potential for the pesticides to runoff. Dimethoate and methomyl have much lower solution aquatic toxicity and less persistence in the environment than chlorpyrifos does. Both have good efficacy however dimethoate has the lowest fish solution risk (Table CS1 and Table 2). The potential pesticide water related risks can be evaluated and materials compared using the UC IPM web site.

To use this feature select the crop, the pest and then the option button “Compare Treatments—Water Quality” http://www.ipm.ucdavis.edu/PMG/r302301911.html) to compare recommended pesticides risks to water quality. If a risk still exists after pesticide selection additional mitigation practices should be employed.
Table CS1. Potential pesticide hazard for pesticides used for vine mealybug control.


<table>
<thead>
<tr>
<th>Ingredient (AI) (Sample trade name)</th>
<th>Fish (Long-term)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leaching</td>
</tr>
<tr>
<td>Acetamiprid (Assail)</td>
<td>no known risk**</td>
</tr>
<tr>
<td>Buprofezin (Applaud)</td>
<td>L</td>
</tr>
<tr>
<td>Chlorpyrifos (Lorsban)</td>
<td>H</td>
</tr>
<tr>
<td>Dimethoate</td>
<td>V</td>
</tr>
<tr>
<td>Imidacloprid (Admire Pro)</td>
<td>V</td>
</tr>
<tr>
<td>Methomyl (Lannate)</td>
<td>I</td>
</tr>
<tr>
<td>Narrow range oil (Superior)</td>
<td>no known risk**</td>
</tr>
</tbody>
</table>

** No known risk: UC IPM knows of no water quality risk associated with this pesticide.

V = Very low  
L = Low  
I = Intermediate  
H = High  
X = Extra high

Methomyl has a shorter residual and may be less disruptive of any beneficial parasites. An additional compound to consider is Movento®, with the active ingredient spirotetramat. Spirotetramat is a lipid biosynthesis inhibitor and has a low aquatic toxicity and a short half-life (Table 2). Movento can be used in April through early June as a sprayable that is absorbed into the leaf and taken through both phloem and xylem. It is quite effective. **NOTE:** Currently (March 2010) a federal court in New York invalidated U.S. EPA’s approval of spirotetramat products. Currently, the sales of spirotetramat have been halted while product on hand can still be used.

**Mixing and Loading**

The mixing and loading site is within 50 feet of the surface water ditch. Mixing and loading practices include not over-filling the tank, triple rinsing containers and adding the rinsate to the tank, and rinsing the tank and applying the rinsate to the field. The use of a concrete pad with catchment sump is also a good solution to reduce risks from mixing and loading near surface water sources.
Avoid Application Risk Prone Times

Management practices to mitigate the offsite movement risk include avoiding application when rain is predicted, especially when soils are saturated by previous rainfall. It is best to apply organophosphate materials immediately after harvest to avoid the heavy rain season.

Protect the Soil Surface

Since the soil is prone to crusting, soil surface protection using cover crops during the previous winter and early spring will protect the soil surface from surface soil dispersion and the creation of water infiltration limiting crusts—reducing runoff potential. Increased organic matter form the cover crop will also promote increased infiltration.

Use Cover Crops and Other Practices to Improve Water Infiltration Rates

These practices would have been implemented in the previous and/or current season. In our case study, the soil tends to crust, and with some slope, high intensity rainfall is likely to cause surface runoff even if the soil was not saturated. Light cultivation to break up any soil surface crust is good management practice to increase infiltration rates.

Tillage

If a crust is likely or has already forms light surface tillage can improve infiltration, and if done after the pesticide application incorporates residues in to the soil reducing runoff potential.

Evaluate and Institute a Chemical Solution to Increase Water Infiltration

A wide variety of chemical solutions to water infiltration problems is available depending on the specific soil and irrigation water constituents. The implementation of a solution is dependent on a diagnosis of the problem. See pg— for more detailed information.

Intercept the Movement of Surface Water

Any reduction in the runoff volume or decrease in the velocity of runoff flow can reduce both soluble and sediment-attached residues. There are several methods of intercepting off-site movement of surface water and sediment. Some are temporary and used with a new vineyard or in emergency situations where the need for runoff control is short lived, and some are permanent. Steep hillside vineyards should have several types of permanent erosion control measures in place, such as permanent cover crops, adequately sized filter strips between the vineyard and any waterways, and permanent sediment basins.

Capture Runoff Water

Sediment basins can prevent runoff from entering surface water sources only if the capacity is great enough to store the runoff waters until they infiltrate. Some growers on higher infiltration soils install a berm around the lower end of the field to trap runoff waters until they infiltrate. On sloping soils, temporary structures including straw wattles can divert and slow runoff
Vegetated filter strips can help infiltrate runoff water containing soluble residues by infiltrating runoff.

*Treat Runoff Waters*

Runoff waters containing organophosphate insecticide residues can be treated with a degradation enzyme, Landguard OP-A to reduce or eliminate residues in runoff water before water exits the farm. This product promotes the breakdown of most organophosphate pesticides into less toxic metabolites. Since no pyrethroid insecticide is recommended for vine mealybug control sediment reduction measures are not considered.

**FC1, Evaluate the Risk of Application near Surface Water Sources**

With a ditch containing water adjacent to the field and draining to other surface waters, a risk exists—go to FC5.

**FC5 Reducing the Risk of Offsite movement of Ag Chemicals Near Water Surfaces in Drift Situations**

*Drift Management*

Drift management practices should be incorporated to prevent off-site movement of any of the materials discussed, especially if surface water drainage ditches are adjacent to the application area. See Pesticide Application Practices to Reduce Off-Site Pesticide Movement section concerning application practices, delivery systems, product choice, and the use of buffer zones. See pg—
MANAGEMENT PRACTICES TO REDUCE SURFACE WATER PESTICIDE CONTAMINATION

INTEGRATED PEST MANAGEMENT

The University of California Integrated Pest Management Programs defines IPM as:

“...an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment.” http://ucipm.ucdavis.edu

IPM is a systematic approach to pest management. The decision process includes:

- proper pest identification;
- understanding pest life cycles and conditions conducive to infestation;
- monitoring for the presence, locations and abundance of pests and their natural enemies;
- treat when established action thresholds (economic, aesthetic, tolerance) are reached;
- consideration of multiple tactics for pest suppression – biological, cultural, and chemical—and selection of the lowest-risk practical and effective approach; and
- evaluate results.

Because many print and on-line publications are available to help winegrape growers use IPM in their vineyards, they are not discussed in detail here. Winegrape pest and disease biology, monitoring, management, as well as water quality considerations in selecting and using winegrape pesticides, may be found in and from:

- The online UC IPM Guidelines for winegrapes, mentioning the pest-specific “Water Quality – Compare Treatments” risk assessment button,
- The UC IPM Year Round Program for grapes, with annual checklist,
- Licensed Pest Control Advisors, and
- UC IPM Advisors and Farm Advisors.

SELECTING PESTICIDES TO REDUCE WATER QUALITY RISKS

Knowledge of how pesticides move and degrade in the environment is useful for product selection. Pesticides and pesticide residues can move along several different pathways, depending on properties of the pesticide, the application method, and conditions at the application site (Fig. 1). This movement is a complex process and, combined with several other factors, influences a pesticide’s fate and potential water quality impacts. From a surface water
management perspective, keeping the pesticide on or in the soil by preventing runoff is the most desirable option.

Figure 1. Pesticide fate processes


Winegrape pesticide active ingredients vary in water solubility, soil adsorption and half-life. Pesticides with high water solubility can move directly in the runoff waters while those adsorbed to soil sediments move with the sediment. Half-life is an indication of the persistence in the environment, usually in the days it takes to degrade one-half of the product. A USDA-NRCS program was carried out to determine a pesticide’s tendency to move in dissolved form with water or adsorbed to the soil particles. The potential to move off-site, either in solution or with the soil, was then categorized as high, intermediate, and low. Table 2 indicates this relationship for commonly used vineyard insecticides, and table can be used to select pesticides based on their risk risks of off-site movement.
Table 2. California-registered insecticides ranked by potential to move in solution or as adsorbed particles and overall pesticide runoff risk.

<table>
<thead>
<tr>
<th>Insecticide active ingredient (common name)</th>
<th>Trade name</th>
<th>Chemical Class</th>
<th>Solution runoff potential(^1)</th>
<th>Adsorption runoff potential(^2)</th>
<th>Overall runoff risk(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>diazinon</td>
<td>Diazinon</td>
<td>organophosphate</td>
<td>high</td>
<td>high</td>
<td>very high</td>
</tr>
<tr>
<td>endosulfan</td>
<td>Thiodan</td>
<td>organochlorine</td>
<td>high</td>
<td>high</td>
<td>very high</td>
</tr>
<tr>
<td>chlorpyrifos</td>
<td>Lorsban</td>
<td>organophosphate</td>
<td>high</td>
<td>intermediate</td>
<td>very high</td>
</tr>
<tr>
<td>abamectin</td>
<td>Agri-Mec, Zephyr</td>
<td>glycoside</td>
<td>high</td>
<td>intermediate</td>
<td>High</td>
</tr>
<tr>
<td>permethrin</td>
<td>Pounce</td>
<td>pyrethroid</td>
<td>low</td>
<td>high</td>
<td>High</td>
</tr>
<tr>
<td>carbaryl</td>
<td>Sevin</td>
<td>carbamate</td>
<td>intermediate</td>
<td>low</td>
<td>Moderate</td>
</tr>
<tr>
<td>malathion</td>
<td>Malathion</td>
<td>organophosphate</td>
<td>intermediate</td>
<td>low</td>
<td>Moderate</td>
</tr>
<tr>
<td>methomyl</td>
<td>Lannate</td>
<td>organophosphate</td>
<td>intermediate</td>
<td>low</td>
<td>Moderate</td>
</tr>
<tr>
<td>phosmet</td>
<td>Imidan</td>
<td>organophosphate</td>
<td>intermediate</td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>fenpropathrin</td>
<td>Danitol</td>
<td>pyrethroid</td>
<td>low</td>
<td>intermediate</td>
<td>moderate</td>
</tr>
<tr>
<td>imidacloprid</td>
<td>Provado</td>
<td>Neonicotinoid</td>
<td>high</td>
<td>intermediate</td>
<td>low</td>
</tr>
<tr>
<td>spinosad</td>
<td>Success, Tracer</td>
<td>Naturalyte</td>
<td>intermediate</td>
<td>intermediate</td>
<td>low</td>
</tr>
<tr>
<td>dimethoate</td>
<td>Cygon</td>
<td>organophosphate</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>naled</td>
<td>Dibrom</td>
<td>organophosphate</td>
<td>low</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>spirotetramat</td>
<td>Movento</td>
<td>Ketenol</td>
<td>intermediate</td>
<td>intermediate</td>
<td>low</td>
</tr>
</tbody>
</table>

1 Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.

2 Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.

3 Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide


The UC IPM site (ucipm.ucdavis.edu) provides guidelines for treatment of pests listing pesticides for use and a comparison among pesticides as to water-related risks of treatment materials. To use this feature select the crop, the pest and then the option button “Compare Treatments—Water Quality” to compare recommended pesticides risks to water quality.

A comparison of pesticides used for vine mealybug is shown in Table 3.
Table 3. Potential pesticide hazard for pesticides used for vine mealybug control.
Source: http://www.ipm.ucdavis.edu/TOX/multitox.php?pmgnum=302301911&x=100&y=24

<table>
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<th>Ingredient (AI) (Sample trade name)</th>
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<tbody>
<tr>
<td></td>
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<td>Acetamiprid (Assail)</td>
<td>no known risk**</td>
</tr>
<tr>
<td>Buprofezin (Applaud)</td>
<td></td>
</tr>
<tr>
<td>Chlorpyrifos (Lorsban)</td>
<td>H</td>
</tr>
<tr>
<td>Dimethoate</td>
<td>V</td>
</tr>
<tr>
<td>Imidacloprid (Admire Pro)</td>
<td>V</td>
</tr>
<tr>
<td>Methomyl (Lannate)</td>
<td>I</td>
</tr>
<tr>
<td>Narrow range oil (Superior)</td>
<td>no known risk**</td>
</tr>
</tbody>
</table>

** No known risk: UC IPM knows of no water quality risk associated with this pesticide.
- V = Very low
- L = Low
- I = Intermediate
- H = High
- X = Extra high

Both of these resources can be used to evaluate the risk of potential applications. A change in pesticide within a same class or to a different class can significantly reduce the environmental risk.

**HANDLING PESTICIDES TO REDUCE WATER QUALITY RISKS**

The risk of off-site pesticide movement is great during mixing and loading due to the possible spillage of full strength pesticides. Care should be taken to ensure all of the material goes in the tank. Partially fill the tank prior to adding the pesticide to prevent high strength materials entering spray lines. Agitation and the use of a bypass can assist good mixing. Avoid over filling the tank, because spillage can move offsite aided by cleanup waters. Mix and load at a distance of greater than 50 feet from sensitive areas (surface water) —more if there is a potential for movement in the direction of the sensitive area. Triple rinse pesticide containers and pour the rinsate into the sprayer tank for use on the field. Also apply tank rinse water to the field. The use of a concrete pad with catchment sump is a good way to reduce risks from mixing and loading near surface water sources.
PESTICIDE APPLICATION PRACTICES TO REDUCE OFF-SITE PESTICIDE MOVEMENT

Minimizing Spray Drift

Drift is the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter, from the target site to any non- or off-target site. All ground and aerial applications produce some drift. How much drift occurs depends on such factors as the formulation of the material applied, how the material is applied, the volume used, and prevailing weather conditions at the time of application, and the size of the application job. Drift can impact surface water quality through direct contact with open ditches or surface water adjacent to the treated field.

Spray drift can be mitigated by management practices to reduce off-target drift. Application practices that take weather and other site conditions into consideration, appropriately equipped delivery systems (low-drift nozzles), appropriate product choice (low vapor pressure, low water solubility), and the use of buffer zones can significantly reduce the risk of off-site movement of pesticides.

Application Conditions

- Don't apply pesticides under dead calm or windy/gusty conditions; don't apply at wind speeds greater than 10 mph, ideally not over 5 mph. Read the label for specific instructions.
- Apply pesticides early in the morning or late in the evening; the air is often more still then during the day.
- Determine wind direction and take it into account when deciding whether or not or how to make an application.
- Calibrate and adjust sprayers to accurately direct the spray into the canopy “target”.
- Delay treatments near ditches and surface water bodies, until wind is blowing away from these and other sensitive areas.
- Don't spray during thermal inversions, when air closest to the ground is warmer than the air above it.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) while still obtaining good coverage and control. Droplet size is one of the most important factors affecting drift
- Use low drift nozzles that produce larger droplet sizes. Fitting an airblast sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.
- Use a directed spray, over the top or wrap around equipment
- Be sure you are getting the spray deposition pattern you expect.
- Service and calibrate your equipment regularly.
- Check your system for leaks. Small leaks under pressure can produce very fine droplets. Large leaks contaminate soil where residues can be moved by water offsite
- Use appropriate (for the time of season, and canopy size) spray volume per acre, and low pressure.
**Product Choice**

- Choose an application method and a formulation that are less likely to cause drift. After considering the drift potential of a product/formulation/application method, it may become necessary to use a different product to reduce the chance of drift.
- Use drift control/drift reduction spray additives agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and aid in deposition.
- Use spray adjuvants, which can greatly reduce application volumes without compromising pesticide efficacy.
- Use maximum spray volume per acre and low pressure.
- Use the least disruptive to aquatic life active ingredient within the buffer zone.

**Buffer Zones**

- Maintain adequate buffer areas or zones between the treated site and sensitive areas to ensure that pesticides don’t drift the target area. Read the label as to the size of buffer zone required as related to the rate of active ingredient.
- Wolf et al. (2003) documented 75 to 95 percent reductions in drift deposits up to 98 feet downwind when setback distances were vegetated with grass or shrubs.

**VINEYARD IRRIGATION MANAGEMENT**

Irrigation management entails assessing the vines’ water need and applying irrigation water to supplement stored winter moisture. Irrigation frequency and duration should ensure that all water infiltrates such that plant water use is met while preventing water loss through runoff and deep percolation. Surface runoff occurs when water is applied faster than it can enter the soil. Runoff water can carry pesticides in the water itself or adsorbed to eroding soil particles. The extent of runoff depends on several factors including: 1) the slope or grade of an area (topography); 2) the texture and moisture content of the soil; 3) how well the soil surface supports water infiltration. Runoff containing pesticides can cause direct injury to non-target species, harm aquatic organisms in streams and ponds, and lead to ground water contamination.

Two basic types of irrigation systems are used in winegrape production: surface gravity systems (furrow, or border-check), and pressurized systems (sprinklers and microirrigation). Each has distinct cultural, cost, and offsite movement advantages and disadvantages. Some disadvantages can be overcome using specific management practices.

In pressurized irrigation systems water should be applied to soils at a rate lower than the intake rate, to prevent runoff. However, as irrigation progresses the infiltration rate declines making runoff more likely. In order to prevent runoff, the system should be turned off before significant runoff occurs. When properly managed, pressurized irrigation systems cause no irrigation water runoff, effectively reducing the risk of pesticide residue moving off-site.
In surface gravity systems soil characteristics control the amount of water infiltrated and its distribution across the field as it travels down slope. Runoff is necessary to maximize of distribution uniformity (DU) within the vineyard. However, limiting runoff after a reasonable DU has been achieved is a good practice to reduce the continued movement of residues off-site. Closed-end furrows used on relatively flat ground can also eliminate runoff. The successful use of this practice relies on a high infiltration rate and precise irrigation cutoff. Lastly, the irrigation system can capture runoff and return it to the irrigation inflow to be applied to adjacent sets or another field. At sites with runoff risks, changing from surface gravity irrigation to pressurized irrigation is recommended.

**Vineyard Irrigation Systems**

Grape growers must determine the amount of irrigation water to apply, when to apply it, and the most efficient method of irrigation for a given set of conditions. That avoids problems associated with over- or under-irrigating. The goal is to maintain root zone moisture content at a level that will balance vine growth and not reduce yield or quality in the current or subsequent years.

**Surface Gravity Irrigation Systems**

Surface gravity irrigation systems, flood, border-check, and furrow irrigation, while the simplest irrigation systems with regard to hardware, are the most difficult ones to manage properly. Control of runoff water is essential for controlling off-site movement of pesticides, sediments, and nutrients.

With surface gravity methods, water is applied to the soil surface and gravity moves the water across the vineyard. Soil characteristics control both the rate at which water enters the soil and its distribution across the irrigated area. As irrigation begins, the rate at which water enters the soil is high, primarily because of soil dryness and easy access to the soil pores. As irrigation proceeds, the infiltration rate declines rapidly to a basic or sustained rate. Figure 2 shows the typical relationship between the amount of water infiltrated into the soil and hours of irrigation.

**Figure 2. Typical water infiltration characteristics.**

A soil’s water intake characteristics depend on both its physical and chemical composition as well as the chemical composition of the water.
**Operation of Surface Gravity Irrigation Systems**

In general, the objective of any irrigation system is to have water infiltrating for the same length of time at in all parts of the field. This is difficult to accomplish with flood and furrow systems because it takes time for water to flow down the row to the fields end (called “advance time”). This shorter time that water is in contact with the soil means less water is infiltrated.

For surface gravity irrigation, the head of the vineyard irrigation run almost always has more water applied to it than the tail of the vineyard run. The exception is if water is allowed to pond at the end of the row. The part of the vineyard which gets the least water applied to it is frequently at approximately 2/3 to 3/4 of the distance down the row. Often, water on-flow rate to the furrow or check is increased to get water down the vineyard more quickly and improve irrigation uniformity. Unfortunately, this practice will increase runoff volume.

In general, it is advantageous to keep borders as short as practical, which keeps irrigation uniformity high. The tradeoffs to short furrows/borders are increased labor and pipeline costs and increased runoff volumes. Tailwater return systems can be used with border-check irrigation systems to increase their efficiency and eliminate discharges.

One difficulty with managing surface gravity irrigation systems is measuring the water going onto the vineyard. If water supplies are from a pump, a flow meter such as a propeller meter can be installed in the outlet pipe. Following the manufacturer's recommended installation criteria is important for accurate measurements. If water supplies are from an open ditch, etc., water measurement is difficult. Consulting the irrigation district may help in getting a good estimate of the flow rate to the vineyard.

The following formula may be used to determine the average amount of water applied to a vineyard.

\[
\text{Flow in cubic feet per second (cfs) } \times \text{ Irrigation Time (hours)} = \text{ Area Irrigated (acres) } \times \text{ Depth of Water (inches)}
\]

Note: If your flow meter reads in gallons per minute (gpm) rather than in cubic feet per second (cfs), the conversion is as follows:

\[
1 \text{ cfs} = 448 \text{ gpm}
\]

Depth of Water applied in the above formula should match the amount of water used by the vineyard since the last irrigation, and is roughly equivalent to the vineyard evapotranspiration (ET) (see Irrigation Scheduling to Meet Vine Requirements section). Remember that some additional water should be applied because no irrigation system is 100 percent efficient. The efficiencies of flood-irrigated vineyards...
are generally lower than those of drip-irrigated vineyards.

Measuring distribution of infiltrated water under surface gravity systems is difficult at best. However, the overall goal is to provide near equal opportunity time along the length of the furrow or check. The photo on the previous page shows a relatively flat vineyard using large furrows fill quickly, providing reasonable distribution.

**Reducing Runoff Surface Gravity Irrigation Systems**

Surface gravity irrigation runoff that enters surface waters can carry both dissolved and sediment adsorbed pesticide residues. The degree to which soils erode during irrigation will depend on a number of factors with soil aggregate stability – the ability of soil particles to cling together and resist the forces of flowing water—being the most important. Aggregate stability can be enhanced by chemical and physical amendments and management practices discussed in the Reducing Runoff by Improving Water Infiltration in Vineyards section. Soil erosion rates will depend on the soil conditions, including the amount, size, and density of loose particles on the soil surface. For example, erosion increases after cultivation. The degree of soil erosion depends on the velocity of the water and the duration of runoff. Therefore, reducing the peak volume and the duration of runoff will reduce sediment loss.

**Cutoff Time**
The cutoff time is the time that an irrigation set is ended and no more water flows down the furrow. Decreasing the cutoff time of the irrigation water (shortening the amount of time a field is irrigated) can reduce the amount of surface runoff from furrow-irrigated fields. The cutoff time for a given field depends on the time needed to infiltrate sufficient water along the lower part of the field. It may need to be determined on a trial-and-error basis. However, in cracked clay soils, infiltration times of only two to three hours may be necessary because water flow into the cracks results in a very high initial infiltration rate. After the cracks close, infiltration rates become very small. Thus, in cracked soils the cutoff time should occur about two to three hours after water reaches the end of the field (Hanson and Schwankl 1995). Figure 3 illustrates inflow and outflow rates in a field using furrow irrigation. Note the 700 minutes of water advancing to field end (before runoff begins) and the nearly equal time the irrigation is allowed to continue in order to have equal intake opportunity time at the tail end of the field. The result is significant – about 2/3 of the inflow water running off for 500 minutes. A shorter cutoff time would have reduced runoff volume but may also slightly reduce the distribution uniformity across the field.
Convert to Pressurized Irrigation
A way to reduce runoff water is to change the irrigation system from a surface to a pressurized system. This option significantly reduces the chance of runoff, but requires a significant investment. See the Pressurized Irrigation Systems section.

Capture and Recycle Runoff
Use of a tailwater collection system can mitigate runoff and therefore off-site residue problems, and make irrigation more efficient. For more information see the Tailwater Runoff Collection and Recycling section.

Pressurized Irrigation Systems
Pressurized vineyard irrigation systems include overhead full coverage sprinklers and micro irrigation systems. Overhead sprinklers are not common in vineyards, due to disease and irrigation water nutrient content concerns. Microirrigation systems, known as drip or micro sprinkler systems, allow small amounts of water to be applied slowly and frequently through emitters spaced along polyethylene tubing. Water is applied to the vineyard frequently at a high degree of uniformity to a relatively small volume of soil.

For the most part, microirrigation systems differ only in emitter spacing, the type of emission device used, and the size of the components. Systems are designed to have just enough emitters per unit area to meet vine water needs.
Operation of Pressurized Systems

Unlike surface gravity irrigation systems where soil water is recharged on an infrequent basis and then drawn down by vine use, microirrigation, by virtue of frequent applications, can be operated to replace water used by the vine. The process occurs on a time scale of days. This feature allows for more consistent results and deficit irrigation strategies – well suited for wine grapes. Pressurized systems are operated to meet the vineyard’s water requirement while eliminating any surface runoff. Unfortunately, most of these highly engineered irrigation systems are not managed to their full potential because they need constant monitoring and maintenance. Problems such as clogged emitters rob growers of the full benefits of the system. One of the great advantages of drip irrigation is the ability to decide exactly how much water to apply and when.

Reducing Runoff in Pressurized Irrigation Systems

Drip systems can apply irrigation water uniformly and efficiently, but only if they are designed, operated, and maintained properly. Irrigation scheduling—determining when to irrigate and how much water to apply—is critical to operating the system efficiently. Effective irrigation scheduling requires knowing how much water the vine is using or has used since the last irrigation (the evapotranspiration or ET of the vine) and how much water the irrigation system applies in a given period of time (the application rate). See the Irrigation Scheduling to Meet Vine Requirements section.

Uniformity is designed into pressurized irrigation systems, with management left to ensure not only efficiency but the elimination of runoff losses by turning off the system before runoff occurs. In hilly terrain, a small amount of runoff tends to accumulate from each emitter, potentially causing off-site movement.

Irrigation Scheduling to Meet Vine Water Requirements

Irrigations should be applied to: (1) meet the variable crop requirements over the season, (2) be distributed evenly to maximize irrigation efficiency and facilitate the uptake of nutrients, and (3) minimize saturated soil conditions that encourage diseases and result in excess runoff. Some water in excess of the crop requirement may be needed to maintain a favorable salt balance in the root zone.

“Appropriate irrigation scheduling” entails scheduling irrigation water to apply an optimum quantity that maximizes productivity. This often results in maintaining soil water content near field capacity. In recent years it became clear that maintenance of a moderate plant water deficit can improve the partitioning of carbohydrate to reproductive structures such as fruit, and also control excessive vegetative growth (Chalmers, et al. 1981), giving rise to the concept termed ‘regulated deficit irrigation’ (RDI) by Chalmers et al. (1986). RDI is the practice of regulating or restricting the application of irrigation water, limiting vine water use to less than that of a fully watered vine. By irrigating at less than the full potential wine grape consumptive use, the chance of offsite water movement from runoff is minimized.
Achievement of successful RDI requires accurate soil moisture or plant ‘stress’ sensing, the ability to estimate crop water demand, and the ability to irrigate frequently. RDI can be a component of a “standard” irrigation strategy or utilized in a “drought strategy” to curtail vine water use during periods of limited water availability.

**Deficit Irrigation Scheduling**

Typical deficit irrigation scheduling relies upon an assessment of vine water stress level to begin irrigation(stress threshold) and an estimate of full vine water use and selecting an appropriate level of deficit irrigation (RDI%). When used together this method is called “Stress Threshold RDI Irrigation”. If irrigation begins too early, water deficits are postponed or eliminated, effectively losing the positive effects of water deficits. For detailed information on when to begin irrigation, and how to measure water deficits, see Prichard et al. 2010. Once the determination is made to begin irrigation, and a specific RDI% is selected, an irrigation schedule can be constructed.

An RDI schedule is established by first estimating the full potential water use of the vineyard combined with a deficit irrigation factor (RDI%). Full potential water use by the vineyard varies as a result of climatic conditions and the size of the canopy. The climate factor can be estimated using the reference evapotranspiration (ETo) values, which indicate variable vine water use over the course of the season. Water use is also influenced by vine canopy growth from bud break to full canopy expansion. Canopy growth is accounted for by a modifying factor of the ETo called the Crop Coefficient (Kc). Kc increases from a small value after bud break as the vine canopy expands to maximum size. Together, these factors (ETo x Kc) define a water use pattern that begins at a low rate in spring, peaks in mid-summer, and then declines as leaf drop approaches.

\[
\text{Vine water use} = \text{ETo} \times \text{Kc} \times \text{RDI}\%
\]

**Evapotranspiration Reference Values (ETo)**

Evapotranspiration Reference Values (ETo) are calculated using measurements of climatic variables including solar radiation, humidity, temperature, and wind speed, and expressed in inches of water. ETo values most closely approximate the water use of a short mowed full coverage grass crop. The California Irrigation Management Information System (CIMIS) uses continuously collected climate data to calculate ETo values and make them available. CIMIS is managed by the State of California Department of Water Resources, which collects, maintains and provides Reference Evapotranspiration (ETo) values from nearly 100 weather stations throughout the state. Both historical (normal) averages and real time (current year) values are available. CIMIS is on the web at: [http://www.cimis.water.ca.gov](http://www.cimis.water.ca.gov)

**Crop Coefficient (Kc)**

The Crop Coefficient (Kc) is a factor that is used with reference evapotranspiration values (ETo) to estimate full grapevine water use (ETc) in a non-water stressed vineyard. Kc values have been experimentally linked to the percent shaded area in the vineyard, measured at midday. They can be measured at any time of the season, but when using the Stress Threshold RDI Method, it is
only necessary to measure at the threshold or beginning of the irrigation season. At that time, canopy expansion is essentially complete. The canopy should be re-measured if growth continues or canopy reductions occur, such as those due to hedging or leaf removal.

Larry Williams, Professor of Viticulture at UC Davis, using a weighing lysimeter, demonstrated that vineyard water use and Kc increase linearly with the percentage of land surface shaded by the crop. He suggests measuring the percent shaded at midday and using the following equation to determine the Kc:

\[
\text{Simplified Equation: } Kc = 1.7 \times \text{percent shaded area (e.g., 0.40 for 40 percent shaded area)}
\]

For example, let’s look at the vineyard illustrated in the figure below, with 11-foot row spacing and 7-foot vine spacing. The average amount of shade between two vines is measured at 31 sq ft. Comparing the 31 sq ft to the single vine area of 77 sq ft (7x11) yields a 40 percent shaded area. The Kc is calculated as follows:

\[
Kc = (1.7 \times 0.40) = 0.68
\]

Example of 40 percent shaded area at noon on a 7 x 11 foot vine spacing

**Calculating Full Potential Water Use with Historical Average ETo**

The best way to illustrate calculation of the amount of water to apply is to select a vineyard with specific site conditions and to perform the calculations using a spreadsheet. Specific vineyard conditions in the above example are:

- **Variety:** Cabernet Sauvignon, mature vines
- **Spacing:** 7 x 11 feet bi-lateral cordon
- Leaf water potential threshold of -13 bars reached July 8
- **Shaded area:** 40 percent or 0.40
- **Kc:** 0.68
- **Area:** Lodi, CA CIMIS station # 166
- **Harvest:** October 1
The spreadsheet below is divided into two parts (Tables 3 and 4) to illustrate each step. The first step is to calculate full potential water use of the vineyard.

Table 2 shows an example calculation of weekly full potential water use for Lodi, California using the 1984 to 2003 historical average ETo for CIMIS stations #42 and #166. After the -13 bar threshold was achieved (July 8 in this example), the net irrigation requirement can be calculated in weekly increments from the threshold date to the end of the season using average historical ETo values. The Kc used is 0.68 for a 40 percent midday shaded area. Calculations are made only after the threshold midday leaf water potential (-13 bars) was measured in the vineyard on July 8. The product of ETo and Kc yields the full potential water use:

\[ \text{ETo} \times \text{Kc} = \text{Full Potential Water Use (ETc)}. \]
Table 3. Irrigation scheduling worksheet - Lodi, California.

Assumptions:
1. Leaf Water Potential threshold was reached July 8th.
2. Harvest Date was October 1.

<table>
<thead>
<tr>
<th>Date (Period)</th>
<th>A = Historical ETo(^1) (inches/period)</th>
<th>B = Crop Coefficient(^2) (Kc)</th>
<th>C = A x B: Full Potential Water Use (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 8-14</td>
<td>1.82</td>
<td>0.68</td>
<td>1.24</td>
</tr>
<tr>
<td>July 15-21</td>
<td>1.72</td>
<td>0.68</td>
<td>1.17</td>
</tr>
<tr>
<td>July 22-28</td>
<td>1.69</td>
<td>0.68</td>
<td>1.15</td>
</tr>
<tr>
<td>July 29 - Aug 4</td>
<td>1.68</td>
<td>0.68</td>
<td>1.14</td>
</tr>
<tr>
<td>Aug 5-11</td>
<td>1.63</td>
<td>0.68</td>
<td>1.11</td>
</tr>
<tr>
<td>Aug 12-18</td>
<td>1.56</td>
<td>0.68</td>
<td>1.06</td>
</tr>
<tr>
<td>Aug 19-25</td>
<td>1.49</td>
<td>0.68</td>
<td>1.02</td>
</tr>
<tr>
<td>Aug 26 - Sept 1</td>
<td>1.45</td>
<td>0.68</td>
<td>0.98</td>
</tr>
<tr>
<td>Sept 2-8</td>
<td>1.37</td>
<td>0.68</td>
<td>0.93</td>
</tr>
<tr>
<td>Sept 9-15</td>
<td>1.23</td>
<td>0.68</td>
<td>0.83</td>
</tr>
<tr>
<td>Sept 16-22</td>
<td>1.17</td>
<td>0.68</td>
<td>0.80</td>
</tr>
<tr>
<td>Sept 23-29</td>
<td>1.05</td>
<td>0.68</td>
<td>0.72</td>
</tr>
<tr>
<td>Sept 30 - Oct 6</td>
<td>0.97</td>
<td>0.68</td>
<td>0.66</td>
</tr>
<tr>
<td>Oct 7-13</td>
<td>0.88</td>
<td>0.68</td>
<td>0.60</td>
</tr>
<tr>
<td>Oct 14-20</td>
<td>0.78</td>
<td>0.68</td>
<td>0.53</td>
</tr>
<tr>
<td>Oct 21-27</td>
<td>0.66</td>
<td>0.68</td>
<td>0.45</td>
</tr>
<tr>
<td>Oct 28 t- Nov 3</td>
<td>0.54</td>
<td>0.68</td>
<td>0.37</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>14.75</strong></td>
</tr>
</tbody>
</table>

\(^1\) [http://www.cimis.water.ca.gov/cimis](http://www.cimis.water.ca.gov/cimis) or [http://ucipm.ucdavis.edu](http://ucipm.ucdavis.edu) ETo are the averages of daily data from 1984 to 2003 from the Lodi (CIMIS #42) and West Lodi (#166) weather stations

\(^2\) Crop Coefficient calculated based on 40 percent midday land surface shaded (0.68)

Calculating the Water Use Using the Regulated Deficit Percent (RDI%)

Once the full potential water requirement for the vineyard is calculated, the Regulated Deficit percent (RDI%) is used to calculate the amount of water the vineyard will use under the RDI% you have selected. In our example, 0.50 or 50 percent of full potential water use was selected. As illustrated in Table 3, full potential water use x RDI% equals the net amount of water use for the selected RDI%. Notice that the RDI% increases to 1.0 or 100 percent after harvest, because full watering is required to encourage root growth, nutrient uptake, and further carbohydrate accumulation. An increase in RDI% to near 100% is common with extended maturity harvests near 19° Brix measured by berry sampling.
Table 4. Irrigation scheduling worksheet, Lodi, California

1. Leaf Water Potential threshold was reached July 8th.
2. Harvest Date was October 1.

<table>
<thead>
<tr>
<th>Date (Period)</th>
<th>C = A x B: Full Potential Water Use (in)</th>
<th>D = RDI coefficient¹ (RDI %)</th>
<th>E = C x D: Net Irrigation Requirement (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 8-14</td>
<td>1.24</td>
<td>0.5</td>
<td>0.62</td>
</tr>
<tr>
<td>July 15-21</td>
<td>1.17</td>
<td>0.5</td>
<td>0.58</td>
</tr>
<tr>
<td>July 22-28</td>
<td>1.15</td>
<td>0.5</td>
<td>0.58</td>
</tr>
<tr>
<td>July 29 - Aug 4</td>
<td>1.14</td>
<td>0.5</td>
<td>0.57</td>
</tr>
<tr>
<td>Aug 5-11</td>
<td>1.11</td>
<td>0.5</td>
<td>0.55</td>
</tr>
<tr>
<td>Aug 12-18</td>
<td>1.06</td>
<td>0.5</td>
<td>0.53</td>
</tr>
<tr>
<td>Aug 19-25</td>
<td>1.02</td>
<td>0.5</td>
<td>0.51</td>
</tr>
<tr>
<td>Aug 26 - Sept</td>
<td>0.98</td>
<td>0.5</td>
<td>0.49</td>
</tr>
<tr>
<td>Sept 2-8</td>
<td>0.93</td>
<td>0.5</td>
<td>0.47</td>
</tr>
<tr>
<td>Sept 9-15</td>
<td>0.83</td>
<td>0.5</td>
<td>0.42</td>
</tr>
<tr>
<td>Sept 16-22</td>
<td>0.80</td>
<td>0.5</td>
<td>0.40</td>
</tr>
<tr>
<td>Sept 23-29</td>
<td>0.72</td>
<td>0.5</td>
<td>0.36</td>
</tr>
<tr>
<td>Sept 30 - Oct 6</td>
<td>0.66</td>
<td>1</td>
<td>0.66</td>
</tr>
<tr>
<td>Oct 7-13</td>
<td>0.60</td>
<td>1</td>
<td>0.60</td>
</tr>
<tr>
<td>Oct 14-20</td>
<td>0.53</td>
<td>1</td>
<td>0.53</td>
</tr>
<tr>
<td>Oct 21-27</td>
<td>0.45</td>
<td>1</td>
<td>0.45</td>
</tr>
<tr>
<td>Oct 28 - Nov 3</td>
<td>0.37</td>
<td>1</td>
<td>0.37</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14.75</strong></td>
<td></td>
<td><strong>8.68</strong></td>
</tr>
</tbody>
</table>

¹ Regulated Deficit is 50% (0.5)

After the net irrigation amount is determined--in this case using historical average ETo data--further adjustments can be made to account for the current season’s climate (ETo), soil water contribution after irrigation begins, effective rainfall, and distribution uniformity of the irrigation system (Prichard et al. 2010).

**REDUCING RUNOFF BY IMPROVING WATER INFILTRATION IN VINEYARDS**

Poor water infiltration can increase runoff from irrigation or winter rains. Irrigation runoff is typically associated with flood-irrigated vineyards and less frequent irrigation, but can occur with drip systems on sloping land as well.

The first step in determining a solution or remedial practice for water infiltration problems is to understand the soil and water that influence it.

At the onset of irrigation, water infiltrates at a high rate. Initially the soil is dry and may have cracks through which water can infiltrate rapidly. After the soil near the surface wets for a few hours, these factors become less important in sustaining infiltration rates. The clay particles swell, closing cracks and limiting access to soil pores and decreasing infiltration rates. As the wetting process continues, the salinity and salt composition of the soil-water (water contained
between soil particles) begins to more closely reflect that of the irrigation water, which is generally less saline. By reducing the soil water salinity water infiltration is retarded.

Water infiltration can only be improved by increasing soil total pore volume and/or individual pore size, and providing easy access to surface pores. Physical soil disruption practices and chemical and organic additions all attempt to influence one or more of these factors.

**Soil Structure and its Impact on Water Infiltration**

Pores are the spaces between mineral and organic particles in soils through which water and air move. Soils with a predominance of sands (spherical particles) tend to have larger pores. With some exceptions, soils with larger pores generally have higher infiltration rates. Clay-dominated soils (clays are plate-like particles) tend to have smaller pores. Water usually moves slowly through these soils because smaller pores provide more surface area for water to adhere to. Soil cracks that form as clay soils shrink upon drying on the other hand can help increase water infiltration in these soils.

Individual soil particles can clump together, forming larger structures called aggregates. The small pores within particles remain, and larger pores formed between the aggregates (Figure 4) significantly enhance water infiltration and gas exchange. Soil water salinity and individual mineral constituents as well as organic matter content plays a significant role in stabilizing soil aggregates and increasing pore size.

Figure 4. Conceptual illustration of soil aggregate stability: forming stable aggregates with plentiful calcium on clay exchange sites (left), compared to weak soil aggregates due to low salinity and/or excessive sodium in the soil pore water.

**Soil Crusting**

Soil crusts or surface seals reduce infiltration by impeding water access to soil pores beneath the crust layer. Crusts form at the soil surface when the soil aggregates become dispersed, causing a loss of porosity at the soil surface. Weak cementation of the crust often follows when the soil dries slowing water penetrating in succeeding irrigations.

Soil surface crusts can be divided into either structural crusts or depositional crusts as defined below.
Structural crusts form when surface soil aggregates are destroyed by the impact of rain or sprinkler droplets. The mechanical breakdown of soil aggregates tends to sort soil particles, leaving a film of finer particles on top (sealing layer) that blocks the entry of water into the larger intact pores beneath. Another type of structural crust forms under furrow and flood irrigation through a process is called “slaking”. As the soil is wetted a combination of mechanical and chemical dispersion of soil aggregates occurs causing the structure to collapse. Upon drying the crust becomes hard.

Depositional crusts form when small (usually clay- and silt-sized) soil particles, suspended and transported in flowing water, settle out of suspension and form a thin low-porosity surface layer. In agricultural settings, this type of soil crust is most often the result of high-velocity water in the head end of the furrow or watershed eroding fine particles that settle out when the water slows.

Both structural and depositional crusts are thin, characterized by higher density, greater strength and smaller pores than the underlying soil. These crusts are usually less than one tenth of an inch thick (Figure 5), but often limit infiltration for the entire root zone. Structural crusts are a far more common cause of poor water infiltration problems in California vineyards than depositional crusts.

Figure 5. Conceptual illustration of structural and depositional crusts.

In fine-textured silty soils, soil crusts are often the result of sodic conditions caused by excess exchangeable sodium in the soil or irrigation water, and/or too little total salinity. In coarse- to medium-textured, nonsaline and nonsodic soils, continued cultivation can reduce pore size and number volume to the point where water infiltration is affected. This problem can be made worse where very low salinity irrigation water is used, such as from irrigation districts on the east side of the San Joaquin Valley. Additionally, wells that contain high bicarbonates and relatively low calcium levels encourage crusting. The increased use of herbicides for no-till management can also decrease soil organic matter and soil microbial activity. This also results in decreased soil aggregation and reduced pore size.

Irrigation Water Quality

Irrigation water quality influences water infiltration or water infiltration. It affects whether soil particles tend to absorb water, stay together, or become separated by swelling. Swelling causes aggregate breakdown, and soil particle dispersion resulting is surface crust formation.
**Salinity**

The higher the salinity of the irrigation water the more likely the aggregates will remain together preserving infiltration rates. Salinity is measured in the laboratory by determining the electrical conductivity (EC) of the irrigation water (ECw) or soil water extracted from a saturated soil paste (ECe).

**Sodicity**

The index for sodicity is the sodium adsorption ratio (SAR) which depends on the relative amounts of sodium, calcium, and magnesium content of the irrigation water. SAR can also be used to estimate exchangeable sodium levels in the soil. With increasing exchangeable sodium, the affinity of soil particles for water increases and aggregate stability decreases.

**Combined Effect of Salinity and Sodicity**

Since both salinity and sodicity of the irrigation water effect aggregate stability and water infiltration rate, both must be assessed in diagnosing a problem. In the top three inches of soil salinity and sodicity of the irrigation water and soil are closely linked. Consequently both surface soil samples and water samples are necessary to diagnose the problem and evaluate the success of mediation practices. In general, aggregate stability increases as EC increases and the SAR decreases (Table 5). As a general guideline, the SAR should be less than 5 times the EC (Figure 6). The exception is low salt waters with EC values of less than 0.5 dS/m. They are corrosive and deplete surface soils of readily soluble minerals and all soluble salts. They often have a strong tendency to dissolve all sources of calcium rapidly from surface soils. The soils then break down, disperse, and seal, resulting in poor water infiltration.

These EC and SAR-based guidelines discussed above may not necessarily work for California soils. Some soils contain a large amount of serpentine clays rich in magnesium (Mg) and low in calcium (Ca). In these soils, Mg may have the same soil-dispersing effect as sodium. Soils with a predominance of montmorillonite and illite clays are also easily dispersed by excess magnesium. Although the diagnostic criteria for such conditions have not been extensively tested, some suggest that when the Mg to Ca ratio of these soils exceeds 1:1, they may be prone to water infiltration problems. Some reports report that high soil potassium levels can also promote aggregate dispersion and soil crusting.

Table 5. Potential for a water infiltration problem.

<table>
<thead>
<tr>
<th>SAR*</th>
<th>Problem Likely ECe¹ or ECw²</th>
<th>Problem Unlikely ECe or ECw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dS/m</td>
<td>dS/m</td>
</tr>
<tr>
<td>0.0 – 3.0</td>
<td>&lt; 0.3</td>
<td>&gt; 0.7</td>
</tr>
<tr>
<td>3.1 – 6.0</td>
<td>&lt; 0.4</td>
<td>&gt; 1.0</td>
</tr>
<tr>
<td>6.1 – 12.0</td>
<td>&lt; 0.5</td>
<td>&gt; 2.0</td>
</tr>
</tbody>
</table>


* Sodium Adsorption Ratio.

¹ Electrical conductivity of extract indicates that soil is saturated paste soil salinity.

² Electrical conductivity of water indicates irrigation water salinity.
High carbonate (CO$_3$) and bicarbonate (HCO$_3$) in water increase the sodium hazard of the water to a level greater than that indicated by the SAR. In alkaline soils, high CO$_3$ and HCO$_3$ tend to precipitate calcium carbonate (CaCO$_3$) and magnesium carbonate (MgCO$_3$) when the soil solution concentrates during soil drying. The concentrations of calcium and magnesium in soil solution are reduced relative to sodium, and the SAR of the soil solution tends to increase.

An adjusted SAR value may be calculated for water high in carbonate and bicarbonate if the soil being irrigated contains free lime (calcareous soil). The adjusted SAR and knowledge of soil properties help determine management practices when using high bicarbonate water.

**Mitigating Water Infiltration Difficulties**

Solving an infiltration problem by modifying irrigation practices – as discussed in other sections of this workbook – should always the starting point and will be generally be less costly than soil- and water modifying treatments discussed below. Water infiltration problems not amenable to improvement by optimizing irrigation system design and operation may be mitigated by tillage, improved soil organic matter management, or use of chemical amendments.

**Tillage**

Shallow tillage can be used to disrupt both structural and depositional crusts. Where crusting problems are moderate, a single tillage per season can restore infiltration rates. However, in soils with severely reduced infiltration, tillage before each irrigation is common. Shallow tillage using shallow disking, a harrow, or even a rolling cultivator can effectively breakup the surface crust. Shallow tillage to incorporate the pesticide after application can effectively reduce the residues available for off-site movement.

Some vineyards have been planted to non-uniform layered soils without any deep tillage prior to planting and examination of backhoe pits reveals significant hardpan and other layers that
limit root development. Tillage of vineyard middles is limited to a single pass with the depth related to the draft force required and traction of the tractor.

**CAUTION:** Ripping will damage existing roots, especially in vineyards where water infiltration has been limiting root zone depth. However, the improved soil characteristics and root pruning will help to encourage new root growth. Roots take time to begin growing and re-growth varies with the season and the carbohydrate status of the tree. In any event, do not till all the middles at once. Modifying alternate middles each year produces the best results. Ripping should be most effective in the fall, after harvest when vine water use is low, soils are dry and easy to shatter and mix.

**Managing Soil Organic Matter to Reduce Runoff**

Soil organic matter helps stabilize soil aggregates by increasing the number of exchange sites in the soil matrix and encouraging microbial activity. Soil microbes that decompose soil organic matter produce polysaccharides and polyuronides, which act as binders to stabilize aggregates, thus improving porosity and water infiltration. Over time, continued cultivation and the use of herbicides reduces the organic matter content and aggregate stability of vineyard soils. These changes can reduce water infiltration and increase run-off potential.

It is difficult to increase and sustain soil organic matter the warm semiarid conditions that prevail in most of California favor rapid organic matter decomposition. As such, organic matter additions aimed at improving or sustaining aggregate stability and water infiltration must be incremental and continual to be effective. There are several ways for winegrape growers to achieve this:

**Crop Residues**

Vine leaves and prunings, shredded or soil incorporated, can be left to decompose adding organic matter (and some nutrients) to the soil.

**Manure and Other Organic Materials**

With proper handing and management to avoid risk of crop contamination by human pathogens, animal manures or compost can help increase soil organic matter content and improve water infiltration. However, the application of manures is currently a less common practice due to the limited nitrogen requirement of the modern vineyards and limited availability of manures. If nitrogen requirements are low grape pomace and composted pomace can provide many of the infiltration benefits without exceeding the nitrogen requirement.

**Cover Crops**

Cover crops can help protect the soil surface from droplet impact under winter rainfall or sprinkler irrigation and provide significant organic matter biomass for decomposition and microbial stabilization of soil aggregates. In addition, cover crop residue can slow the velocity
of surface water; reducing erosion and subsequent depositional crusting. Winter annual cover crops are most often planted in vineyards because they grow during the wet season, reducing the competition for water and nutrients that is a disadvantage of perennial covers. They are sown or allowed to reseed in the fall and mowed or disked in the spring. A winter annual cover crop—planted in fall, grown during the winter and early spring, and mowed or disked to remove it in spring—for example, can produce as much as 3 tons of dry matter (above and below ground) per planted acre. A comprehensive review of this topic is available in: Cover cropping in vineyards—a grower’s handbook. ANR Publication 3338 (Ingels, et al. 1998)

**Chemical Amendments Used to Improve Water Infiltration**

The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Most chemical amendments work by increasing the total salt concentration and/or decreasing the (SAR) of the soil-water. Both of these actions enhance aggregate stability and reduce soil crusting and pore blockage.

Four types of materials are used to ameliorate water infiltration problems: salts, as fertilizers; calcium materials; acids or acid-forming materials; and soil conditioners, including polymers and surfactants.

**Salts**

Any fertilizer salt or amendment that contains salts, when applied to the soil surface or dissolved in irrigation water, increases the salinity of the irrigation water and ultimately influences the soil-water. Whether the increased salinity is advantageous depends on the SAR of the irrigation water. Increasing salinity above an EC of 4 dS/m has little effect on infiltration. The largest effect of a salt addition is with very low (less than 0.5 EC) salinity irrigation water.

**Calcium Materials**

Adding calcium (Ca) salts to soil and water increases both the total salinity and soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum (CaSO₄), calcium chloride (CaCl₂), and calcium nitrate (CaNO₃). These are fairly soluble and can easily be applied through the irrigation water. Care should be taken if waters contain more than 2 meq/L of bicarbonate (HCO₃). Adding gypsum to such waters through a drip system significantly increases the chances of plugging the system with lime precipitate. In these cases, an acid application may provide a better solution. Lime and dolomite are used only for broadcast applications on acid soil, as they are virtually insoluble in alkali conditions.

**Gypsum Injection Rates for Water**

Amendment rates from 1.0 to 3.0 meq/L Ca in the irrigation water are considered low to moderate; rates that supply 3.0 to 6.0 meq/L Ca are considered moderate to high. The following example calculations show the reader how to estimate the quantity of gypsum required to improve infiltration. Table 6 lists the amount of gypsum and other products needed to increase the Calcium content of irrigation water by 1 meq/L per acre foot. Applying 234 pounds of 100 percent pure gypsum per acre-foot of water equals 1 meq/L of Ca.
It is rarely necessary to inject gypsum constantly. Injection every other or every third irrigation may be all that is necessary to end the season with the required amount. The benefits of gypsum injection during the season in drip irrigation systems are usually superior to those of dormant season applications.

Table 6. Amounts of amendments required for calcareous soils to increase the calcium content in the irrigation water by 1 meq/L.

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Trade Name and Composition</th>
<th>Pounds/Ac-ft of Water to Get 1 meq/L Free Ca*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur</td>
<td>100% S</td>
<td>43.6</td>
</tr>
<tr>
<td>Gypsum</td>
<td>CaSO₄·2H₂O</td>
<td>234</td>
</tr>
<tr>
<td>Calcium polysulfide</td>
<td>Lime-sulfur</td>
<td></td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>23.3% S</td>
<td>191</td>
</tr>
<tr>
<td>Calcium thiosulfate</td>
<td>KTS -- 25% K₂O₃, 26% S</td>
<td>256</td>
</tr>
<tr>
<td>Ammonium thiosulfate</td>
<td>Thio-sul</td>
<td>110**</td>
</tr>
<tr>
<td>Ammonium polysulfide</td>
<td>12% N, 26% S</td>
<td>336***</td>
</tr>
<tr>
<td>Ammonium polysulfide</td>
<td>Nitro-sul</td>
<td>69**</td>
</tr>
<tr>
<td>Monocarboxide dihydrogen</td>
<td>N-phuric, US-10</td>
<td>136***</td>
</tr>
<tr>
<td>Sulfate/ sulfuric acid</td>
<td>10% N, 18% S</td>
<td>242***</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>100% H₂SO₄</td>
<td>133</td>
</tr>
</tbody>
</table>

* Salts bound to the soil are replaced on an equal ionic charge basis and not equal weight basis.
** Combined acidification potential from S and oxidation of N source to NO₃ to release free Ca from soil lime. Requires moist, biologically active soil.
*** Acidification potential from oxidation of N source to NO₃ only.

Gypsum Rates Broadcast to Soils

An alternative to water treatment is broadcasting amendments such as gypsum on the soil surface and irrigating the amendment into the soil. The primary advantage of this approach is that it is often less expensive than water treatments. However, for surface application to be nearly as effective as water treatment, it must be properly timed. If infiltration is a problem in the summer months, then apply the amendment at the onset of those months—not in the preceding fall or winter. If the application is made too early, the amendment will percolate with post harvest and winter irrigations and rainfall to depths below that where the crust forms. Surface applications are most effective when applied at rates equivalent to 500 to 1,000 pounds of gypsum per acre, prior to the onset of irrigation. Use finely and consistently ground gypsum products in surface applications. Applications that are limited to the berm have been successful at decreased rates when using drip irrigation. For maximum effect on surface crusting, do not till the soil after the gypsum is applied.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H₂SO₄) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide
exchangeable calcium. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take months or years depending on the material and particle size (in the case of elemental sulfur) not clear whether the phrase in parenthesis refers to both material and particle size, or not. Since these materials form an acid via the soil reaction, they will reduce soil pH if applied at sufficiently high rates.

Acids are applied to water for two different purposes in relation to water infiltration problems. The first is to dissolve soil lime (the soil must contain lime), increasing the free calcium in the soil/water matrix and improving infiltration. The second is to prevent lime clogging in drip systems when adding gypsum to waters containing greater than 2 meq/L bicarbonate.

Table 6 indicates that it takes 133 lbs/ac-ft of 100 percent pure sulfuric acid to release 1 meq/L Ca. This assumes the acid contacts lime (CaCO₃) in the soil, neutralizing the carbonate molecule and releasing Ca. This is the same amount of acid required to neutralize 1 meq/L of HCO₃ in the water. If the water contains bicarbonate the acid will neutralize it, converting it to carbon dioxide which is released to the atmosphere. If acid applications exceed the bicarbonate level, the pH of the water decreases, dissolving lime in the soil.

**Soil Conditioners**

There are two types of amendments in this category; organic polymers and surfactants.

**Organic Polymers**

Organic polymers, mainly water-soluble polyacrylamides (PAM) and polysaccharides, are used to stabilize the aggregates at the soil surface. These extremely long-chain molecules wrap around and through soil particles to bind aggregates together. This action helps resist the disruptive forces of droplet impact and decrease soil erosion and sediment load in furrow irrigation systems. They can improve infiltration on soils with illite and kaolinitic clays common in the northwest United States, but USDA researchers have found that infiltration is not improved in soils with the mostly montmorillonite clays typical in the San Joaquin Valley.

Water-soluble PAM is not to be confused with the crystal-like, cross-linked PAMs that expand when exposed to water and does not influence water infiltration. Cross-linked PAMs enhance the water-holding capacity of soils for small-scale applications, for example in container nurseries.

Organic polymers can have different effects on infiltration. The effect depends on polymer properties—such as molecular weight, structure, and electrical charge—and salinity of the irrigation water. There are charged (ionic) and non-charged (nonionic) polymers that can behave differently depending on whether they are added to very pure water (surface waters where EC is 0.03 to 0.1 dS/m) or higher-salinity well waters (above 0.8 dS/m).

Polymers have been shown to work best when sprayed on the soil surface at a rate of about 4 pounds per acre, followed by an application of gypsum in soil or water.
Other amendments include synthetic and natural soil enzymes, and microbial soups. Although there is a long history of soil conditioner development and testing, not enough data exists on the materials to conclude that they are uniformly effective.

**Surfactants**

Surfactants or “wetting agents” are amendments that reduce the surface tension of water. They are not effective in vineyard soils.

For an in depth analysis of water infiltration problems and solutions see: Water Penetration Problems in California Soils: Diagnosis and Solutions, Singer et al. 1992.

**INTERCEPTING MOVEMENT OF SURFACE WATER AND SEDIMENT**

Any reduction in the runoff volume or decrease in the velocity of runoff flow can reduce both soluble and sediment-attached residues. There are several methods of intercepting off-site movement of surface water and sediment. Some are temporary and used with a new vineyard or in emergency situations where the need for runoff control is short lived, and some are permanent. Steep hillside vineyards should have several types of permanent erosion control measures in place, such as permanent cover crops, adequately sized filter strips between the vineyard and any waterways, and permanent sediment basins.

Storage of runoff waters in impoundments is often suggested as a mitigation practice. The sheer volume of runoff makes this a poor option. For example, a 2-year 24-hour storm in Stockton, CA falling on a 40-acre parcel would produce over 1,700,000 gallons or 5.3 acre feet of water—equivalent to a one acre pond over 5 feet deep. A 2-year 24-hour storm would be the rainfall event one could expect during a 24-hour period on the average of every 2 years. A hundred-year storm would require three times that volume for just a single storm. Of course, some of the water would infiltrate into the field. However, if one storm came on the heels of another, most of the rainfall would run off. For more information on runoff storage and storm precipitation rates, see: Storing Runoff from Winter Rains, Schwankl et al. 20007, ANR Pub 8211.

**Temporary Measures**

**Filter Fabric Fencing**

A barrier of filter cloth with woven wire stretched between temporary fence posts across a slope to reduce soil movement. Make sure the posts are on the downslope side of the fencing.

**Straw Bale Check Dam**

To construct a check dam, place bales of clean straw bound with wire or plastic twine across an area of surface sheet flow or gully erosion, and anchor them into the soil surface with rebar or stakes.
**Straw Bale Water Bars**

Straw bales used to create a temporary water bar across a road or a temporary sediment barrier to protect a drop inlet from siltation. A series of straw bale water bars may be needed for long slopes.

**Straw Wattles**

Straw wattles or fiber rolls are designed to slow down runoff, reducing erosion, filter and trap sediment before the runoff gets into watercourses. Straw wattles are porous and allow water to filter through fibers and trap sediment. Straw wattles must be installed on contour.

![Photo of straw wattles used for erosion control](image1)

**Temporary Drainage Structure**

Constructed at the tail of field temporary drainage structures are designed to slow and trap runoff for short periods of time. The water eventually infiltrated the soil.

![Diagram and photo showing a temporary drainage structure](image2)

**Temporary Sediment Basin**

Used to catch and settle out sediment before it can enter a waterway. They are usually placed at the base of a slope or drainage area. A small basin can be created from compacted soil and rocks or straw bales. The embankment should not exceed 4 feet in height and a drain or outlet should restrict flow from the basin to allow sediment to be trapped.
Permanent Measures

Sediment Basins

A sediment basin or trap is created by constructing an embankment, a basin emergency spillway, and a perforated pipe-riser release structure. The basin may be located at the bottom of a vineyard slope where drainage enters a swale or waterway. These basins can be designed by the Natural Resources Conservation Service (NRCS) or a civil engineer on a site-specific basis, and installed using proper construction and compaction for the berm, and correct sizing and construction for release structures and spillways. When runoff volumes are small, basins can be effective for reducing off-site movement of sediment containing adsorbed pesticide residues. If runoff is sufficient to cause low retention times, sediment removal efficiency declines rapidly.

![Diagram of a sediment basin with spillway and release structure](image)

Effectiveness in Removing Pesticide Residues

Long et al. (2010) found that a 60 to 90 minute retention times effectively removed particles coarser than fine silts. The sediment basin was 1.4 percent of the irrigated area. Finer soil particles, which generally adsorb pyrethroid pesticide residues, were not removed from the runoff. During the first irrigation of the season, soon after cultivation, 39 percent of the sediment load entering the pond was removed. In second measured irrigation sediment removal was insignificant. The effectiveness of sediment traps was found to be limited by the time available for suspended sediments to settle out of the runoff. Sediment basins may be ineffective with finer soils at higher runoff rates.

A study was conducted in the Central Valley of California to measure pyrethroid removal by tail-water recovery pond. The field was a border-check irrigated almond orchard to which a pyrethroid, lambda-cyhalothrin was applied at the rate of 0.04 lb ai/A. Runoff waters were measured for volume, sediment, and pyrethroid residue concentration as inflow to a recycling pond and as outflow. About 15 percent of the irrigation onflow water exited the field as runoff. The pond was 19 feet by 16 feet by 7 feet deep. Sediment in the water was reduced by 80 percent, inflow to outflow. Pyrethroid residues were reduced by 61 percent. The difference in the removal efficiencies for sediment and pyrethroid residues was most probably due to the absorption of lambda-cyhalothrin residues to lighter weight clay particles, which did not have a
chance to settle out in this trial. Removal efficiency may have been further improved with lower flow rates or longer retention times in the ponds (Markle 2009).

Permanent Cover Crops

Cover crops are usually grown in vineyard middles with rows kept free of vegetation and are classified as annual or perennial. Plant species used for cover crops may be annuals (planted, grown and removed each season) or perennials, which generally live three or more years. Annual cover crops can be composed of species (for example, annual clovers and medics) that reseed themselves naturally each year, or others that are generally removed before they form seeds and, as such, must be intentionally replanted each year. Perennials such ryegrass, orchard grass, and fescues are not often used because they will compete with the vines for water and nutrients during the summer.

Cover crops can help reduce offsite movement of water-borne pesticide residues in several ways. By shielding the soil from the impact of rain droplets, a winter-grown cover crop can help reduce the likelihood that soil particles will be eroded from the soil surface. Cover crop vegetation may also help slow increase sedimentation by directly “filtering” soil particles out of moving water and by slowing the speed of water moving over the soil surface. As weather warms in late winter and spring, cover crops can help deplete excessive soil moisture and increase the water storage potential (thus reducing run-off) from storm events at this time of year. Also See: Cover Cropping in Vineyards—a Growers Handbook, Ingels et al. 1998, ANR Publication 3338. For further reading see: Erodibility of Agricultural Soils with Examples in Lake and Mendocino Counties, O’Geen, et al. 2006a, ANR Pub 8194, and Orchard Floor Management Practices to Reduce Erosion and Protect Water Quality, O’Geen, et al. 2006b, ANR Publication 8202.

Vegetative Filter Strips

A vegetative filter strip (VFS) is any area of dense grass or other vegetation—natural or planted—between the vineyard and a nearby waterway to help capture and remove water-borne sediments before they reach the waterway. Tall, sturdy, and hardy perennial grasses are preferred, since once established they withstand the force of runoff waters and summer drought conditions. The width of the VFS required to effectively remove sediments depends upon the slope of the area draining into the strip. For slopes of less than 1 percent, the strip should be at least 25 feet wide increasing proportionally with the increase in slope, up to 50 feet wide for 10 percent slopes. Filter strips can also be used between vineyard blocks to reduce sediment flow between blocks.

Vegetative filter strips function in three distinct layers—surface vegetation, root zone, and subsurface horizon (Grismer et al. 2006). As surface flow enters the VFS, water is infiltrated until the shallow surface and shallow subsurface is saturated. This infiltration phase is most important for reducing offsite movement of residues. The pesticide residues are trapped by soil constituents and organic matter, allowing pesticide degradation to occur. The remaining flow volume and velocity is decreased, reducing the ability to transport sediment. The sediment particles are trapped on the surface litter layer, which is high in organic matter. As the process continues, water continues to move through the subsurface horizon, further
decreasing the volume of runoff.

One common type of VFS is a vegetated ditch, typically a “V”-shaped ditch, 2-3 feet deep, and 4 feet wide at the top. Vegetation can be resident, such as rushes and bermudagrass, or intentionally planted to species such as rushes, pennywort, creeping wild rye and red fescue. Vegetated ditches can help reduce chemical contaminants, as does a VFS by infiltration, direct adsorption of chemicals to plant surfaces and by promoting sedimentation of particle-bound contaminants. Vegetated ditches in contrast to VFS increase the treatment area per unit of surface land area. Residue removal efficiency is strongly influenced by runoff flow rate per unit ditch wetted area. Higher flow rates reduce the removal efficiency.

![Vegetated Ditch](image)

**Effectiveness in Removing Pesticide Residues**

The chemical characteristics of different pesticides determine the type and amount of residue reduction achievable with vegetation systems. Organophosphate pesticides tend to be water-soluble while pyrethroids are virtually non-soluble in water and are adsorbed to sediments. Diazinon, an organophosphate of high solubility in water, can be expected to remain in solution for long periods (Bondarenko and Gan, 2004). Previous evaluations of the effectiveness of vegetation for removing diazinon from water have shown mixed results. Watanabe and Grismer (2001) evaluated diazinon removal by vegetated filter strips under controlled laboratory conditions and found that the majority of diazinon removal occurred via infiltration into the root zone and adsorption to vegetated matter. However, 73 percent of the applied diazinon up to was detected in the runoff water after the VFS. Anderson et al. (2008) found that a vegetated ditch containing aquatic vegetation removed only 4 percent of diazinon in contaminated runoff. Moore et al. (2008) used a simulated runoff event to evaluate removal of diazinon in vegetated ditches in Yolo County, California. They described reductions in diazinon runoff using a V-shaped vegetated ditch, but significant concentrations of diazinon remained in the system outflow after five hours. Essentially, runoff waters containing residues which are not infiltrated is little reduced.

Chlorpyrifos, another organophosphate, is more hydrophobic than diazinon. Gill et al. (2008) applied chlorpyrifos at 1 pt/ac and found a 40 percent reduction in the water column concentration after passage through a vegetated ditch, though the outflow water was still at 33 times the water quality standard of 15 ppt. Anderson et al. (2008) found an average 35 percent reduction of chlorpyrifos concentration in two evaluations after passage through a vegetative ditch containing aquatic vegetation. On the other end of the spectrum, Cole et al. (1997), found
VSF’s effective in reducing 62-99 percent of chlorpyrifos residues in runoff waters. It is suspected that local conditions including runoff flow rates, size of the vegetated area, and the initial residue concentration strongly influence the effectiveness in these studies.

Because of their hydrophobic nature, pyrethroids adsorb readily to plant surfaces and soil particles and, as such, are easier to remove from run-off waters than organophosphates. (Moore et al. 2001; Schulz, 2004). Moore et al. (2008), for example, found that vegetation was much more effective at removing the pyrethroid pesticide permethrin than the organophosphate diazinon. Anderson et al. (2008) found nearly 100 percent reduction of permethrin after treatment in a vegetated ditch. Additionally, Gill et al. (2008) found a 25 percent reduction of pyrethroid (Lambda-cyhalothrin) residues after moving run-off waters through vegetated ditch. Long et al. (2010) found that reduction in sediment load was directly related to pyrethroid residue removal in VFS. In another study, Long et al. (2010) found that sediment run-off was reduced by 62 percent when furrow run-off waters passed through a well-established VFS. The VFS was planted to either tall fescue or a perennial ryegrass and tall fescue mixture that represented 2.8 percent of the field being irrigated.

**Tailwater Runoff Collection and Recycling**

Water running off the tail end of a field, a part of normal irrigation practices, is referred to as tailwater. Tailwater is most often associated with surface gravity irrigation (furrow and border-check irrigation), since well-designed sprinkler and microirrigation systems should not produce tailwater run-off.

Tailwater collection systems have most frequently been used in row and field crops and are not as common in surface gravity irrigated tree and vine crops. There is no reason tailwater collection and recycling systems cannot be used in permanent crops using furrow or border-check irrigation. Their use is an excellent management practice to improve irrigation efficiency and minimize tailwater run-off impacts.

![Tailwater collection system.](image-url)
Methods of Dealing with Tailwater
If a new tailwater return system is being planned, the planned management approach must be a key factor in its design. There are numerous ways of managing tailwater. Tailwater generated by irrigation practices is generally handled in one of the following ways.

1. The ends of the furrows or borders are sealed with soil dams or berms, and water often ponds on the tail end of the field. This practice may lead to crop damage due to standing water or - if irrigations are managed to minimize ponded water - the tail end of the field may be under-irrigated.
2. Tailwater from an irrigation set is allowed to flow into the tail end of adjacent, un-irrigated furrows. This is most frequently done on fields with minimal slope.
3. Tailwater is allowed to run off the field, collected, and discharged to a natural water body, or back to the supply system for use downstream. This practice can only be used when the tailwater is free of pesticide residues and sediments.
4. Tailwater is collected and placed in a pond, with no capability to re-use the collected tailwater. Water in the pond is allowed to infiltrate or evaporate. Usually irrigations are managed to minimize tailwater, since the pond is of finite size.
5. Tailwater is collected and re-used for irrigation. Most often, a pump and a ditch/pipeline conveyance system is used to move the tailwater to where it will be reapplied. Such a system, well operated, maximizes irrigation efficiency and minimizes environmental impacts.

Advantages and Disadvantages of Tailwater Return Systems
Advantages:
- Off-site environmental impacts of tailwater potentially containing pesticide and fertilizer residues or sediment are minimized.
- Irrigation efficiency is improved since tailwater is beneficially re-used as irrigation water.
- Water costs may be reduced by re-using tailwater.
- Irrigation water management for flood systems with no ready outlet for tailwater can be simplified, since irrigations, especially those at night, do not need to be as closely monitored to prevent tailwater runoff.
- Tailwater collection systems remove standing water that can cause crop loss and weed infestations from the tail end of the field.

Disadvantages:
- Cost of installation, maintenance, and operation of the tailwater return system. Land must be taken out of production for the pond and other tailwater recovery system components.
- Good management, requiring timely recycling of tailwater pond contents, is necessary to prevent groundwater pollution by chemicals in the tailwater.

Tailwater Return System Management
There are numerous ways of managing tailwater return systems, and their management is often constrained by the system design. If a new tailwater return system is being planned, the planned management approach must be a key factor in the design. See ANR publication number 8225, “Tailwater Return Systems” for information on design, construction, costs and Operation and
TREATMENT OF RUNOFF WATERS

Runoff water treatment can be chemically treated to reduce pesticide residues. This treatment can be done in the vineyard, in a tailwater ditch or in a holding basin. Two two products are available and have been shown effective for this purpose: Polyacrylamide (PAM), for treatment of pyrethroid laden sediments, and Landguard OP-A Enzyme®, for most soluble organophosphate pesticides.

Polyacrylamide (PAM)

PAM is a solid or liquid water-soluble polymer that flocculates sediments—binding them together and causing them to drop out of the water. When added to runoff waters, PAM can mitigate transport of sediment-sorbed pesticides from surface gravity irrigated fields.

Liquid PAM can be injected into the irrigation water, constantly deposited in granular form into turbulent irrigation ditch water, or applied to the furrow as dry tablets (40 percent PAM) or granules (89 percent PAM), where it is slowly dissolved by irrigation water. The in furrow methods are generally less expensive and easier to apply than liquid or granular PAM applied to the inflow ditch or piped water. However, they do not allow for as precise control of product concentration. Table 7 shows a comparison of costs using the different forms of PAM for an 80-acre furrow-irrigated row crop planted on 5-foot beds using data provided by a grower. The smallest cost occurred for granules placed in the furrow, while the costs were the highest using liquid PAM.

At a furrow length of 600 feet, 60 inch beds would require about one ounce or 2 tablets per furrow. It is applied in a “patch” in a 3-foot section of the furrow, far enough from the furrow head to prevent sediments from covering the PAM patch. In the Northwest, placement 5 feet from the furrow head was successful. In California, the patch was quickly covered and not effective; whereas 100 feet down furrow was successful. Once applied as a “patch,” PAM seems to be effective for a few irrigations. If the soil is disturbed by cultivation, it must be reapplied. PAM is more effective in finer texture soils and in irrigation waters that contain calcium and little sodium.

Season long control costs are difficult to estimate because effectiveness from a single application varies with, the number of irrigations, and the number of field cultivations. Liquid PAM that contains oil-based carrier materials is available but the cost per acre is high and the product can be toxic to some aquatic life at recommended field application rates (Weston et al. 2009).
Table 7. Cost comparisons for different single irrigation PAM formulations for a typical 80-acre furrow irrigated row crop planted on 5-foot beds.

<table>
<thead>
<tr>
<th>Application method</th>
<th>Unit cost of material</th>
<th>Cost per acre</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granules placed in furrow</td>
<td>$2.79 per pound</td>
<td>$1.05</td>
<td>1 oz of granules per furrow</td>
</tr>
<tr>
<td>Tablets placed in furrow</td>
<td>$4.82 per pound</td>
<td>$6.36</td>
<td>Two tablets per furrow</td>
</tr>
<tr>
<td>Granules injected into irrigation water</td>
<td>$2.79 per pound</td>
<td>$5.46</td>
<td>Target concentration = 5 ppm; injection time = 12 hours (time needed for water advance to end of furrows)</td>
</tr>
<tr>
<td>Liquid PAM injected into irrigation water</td>
<td>$34 per gallon</td>
<td>$32.31</td>
<td>Target concentration = 5 ppm; injection time = 12 hours</td>
</tr>
<tr>
<td>Liquid PAM injected into irrigation water</td>
<td>$34 per gallon</td>
<td>$12.93</td>
<td>Target concentration = 2 ppm; injection time = 12 hours</td>
</tr>
</tbody>
</table>

Source: Long et al. (2010)

Costs per acre are based on the gross acreage of the 80-acre field.

**Effectiveness in removing pesticide residues**

Sojka et al. (2007), in their Northwest studies on furrow-irrigated soils over a three-year period, found application rates of 1 pound per acre/irrigation (about 10 ppm) eliminated 94 percent of sediment loss in field runoff. A seasonal rate of 3-7 pounds per acre was used, depending on the crop and number of cultivations. One of the mechanisms of decreased sediment loss is increased infiltration of irrigation water into the field because PAM effectively reduces runoff water volumes (Trout et al. 1995). Sojka, using the recommended 10-ppm PAM rate, found increases in infiltration of 15 to 50 percent compared to untreated controls. In California Long et al. (2010) found no PAM effect on infiltration into loam and clay loam soils at a lesser application rate assumed to be near 2ppm.

In a California study conducted on loam and clay loam soils, Long et al. (2010) found an application rate of 1-2 ounces per 600-foot furrow using the “patch method” reduced sediment loss between 57 and 97 percent in numerous trials. Furrow flow rates averaged 17.5 gallons per minute. They found greater than 80 percent sediment control in 60 percent of the trials. The concentration of a pyrethroid, lambda-cyhalothrin or zeta-cypermethrin, was reduced by the same amount.

**Landguard OP-A Degradation Enzyme**

Runoff waters containing organophosphate insecticide residues can be treated with a degradation enzyme, Landguard OP-A to reduce or eliminate residues in runoff water before water exits the farm. This product promotes the breakdown of most organophosphate pesticides into less toxic metabolites. The powder-like enzyme is mixed with water into a stock solution and applied to runoff water. The enzyme treatment rate, residue concentration, and the time available before runoff discharge are both important to assure degradation at a minimum material cost. The more time available before discharge allows a lower enzyme rate.
The key factor in determining the correct dosing rate is the maximum expected runoff rate. Runoff rate is typically not constant over time. When using a single dosing rate based on the maximum estimated flow rate, over-dosing is likely at the lower flows that typically occur at the beginning and end of a runoff event. Additionally, the practice of irrigating more checks during a nighttime set can lead to different peak flows of different duration.

A comparison was made of the amount of enzyme required for single maximum rate dosing for the entire runoff period and for a variable rate dosed as required by flow rate—essentially keeping the dosing rate constant (Prichard and Antinetti 2009). A single rate setting to dose for the maximum volume the first irrigation set overdosed about resulted in a dosage that was more than double the amount actually needed. Estimating that the next set would be near the same runoff flow rate and using the same dosing rate, the second set required over 6 times that of a correctly dosed variable system do to the lower amount of runoff.

**Effectiveness in removing pesticide residues**

A field trial in California found chlorpyrifos in runoff at a concentration near 10 ppb prior to Landguard OP-A treatment. Twelve minutes after the enzyme was added at a rate of 4.3 oz to one acre foot runoff water, the chlorpyrifos concentration declined to 0.4 ppb. At higher enzyme dosages, chlorpyrifos became undetectable. The effects of the enzyme on chlorpyrifos-related toxicity are equally dramatic. The enzyme reduces chlorpyrifos toxicity to *H. azteca* (a test organism) by at least 70 fold compared with untreated water (Weston and Jackson, in press). Without enzyme the concentration of chlorpyrifos required to kill half the test organisms was 141 ppb. With enzyme, they saw no ill effects to the test organisms.

A team led by Brian Anderson of the UC Davis Marine Pollution Studies Laboratory dosed Landguard OP-A at the rate of 4.3 oz/acre foot runoff water directly into a drainage ditch containing diazinon residues (Anderson et al. 2008). Samples of runoff water were collected from the ditch before dosing and 107 feet downstream from the electronic dosing unit (Figure 7).

*Figure 7. Anderson trial showing vegetated ditch and electronic dosing unit 2008*
Anderson conducted multiple trials finding that samples treated with Landguard OP_A demonstrated no detectable diazinon and all were non-toxic to C. dubia, another aquatic arthropod test organism.
REFERENCES:


