CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

Agricultural Practices and Technologies
DRAFT REPORT

May 2002 DRAFT

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FOREWORD

The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency or the State Water Resources Control Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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Daniel Carlton compiled tables presented in Appendix B of this report and wrote portions of the integrated pest management section. Matthew McCarthy provided input and wrote portions of the soil section. This document also greatly benefited from an existing practices report compiled by the Sacramento River Watershed Program. Sections in this document relating to dormant season practices for orchards, vegetation and soil management practices, and pesticide application methods have borrowed heavily from the aforementioned document.

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1.0 SUMMARY

Organophosphorus pesticides (OPs), such as diazinon and chlorpyrifos, have routinely been detected in the Sacramento-San Joaquin River systems. In the Sacramento watershed, detections have primarily been during the winter rainy season (McClure *et al*, draft). Detections in the San Joaquin watershed have been associated with both the winter rain events and the irrigation season (Leva *et al*., draft). Detections during the winter rainy season generally coincide with dormant season OP applications to orchards. Concentrations observed during the summer growing season generally coincide with irrigation season applications to orchards and to row and field crops. Both summer and winter concentrations are frequently high enough to be toxic to resident aquatic invertebrates, and violate the Basin Plan water quality standard for toxicity, as well as the California Department of Fish and Game and EPA water quality criteria.

Because of these violations, the Sacramento and San Joaquin River systems have been placed on the Clean Water Act 303(d) list of impaired waterways for diazinon and chlorpyrifos. Reductions in concentrations of OP pesticides will depend upon identifying the sources, understanding the mechanisms of offsite movement, and then developing alternative practices to reduce OP runoff to a level that eliminates toxicity in surface waters. Application of OPs during the dormant season, the period in late fall and winter when some vegetation including stone fruit trees enter a period of rest called dormancy, has historically been an important part of pest management programs for almonds and stone fruit and other fruit crops. Numerous advantages are associated with dormant OP pesticide application including reduced worker exposure. In season application to field and row crops is also commonly practiced and in season application to some orchard crops is still conducted. Concern about the toxic effects of OP pesticides on aquatic ecosystems has triggered the search for pest control methods that will reduce concentrations of these pesticides in surface water.

This report examines agricultural management practices and technologies that have the potential to reduce offsite movement of OP pesticides from orchard and field crops in California. Many of the alternatives included here were identified by pest management specialists and toxicologists at the University of California, Davis, and were reviewed through a stakeholder process that included farmers, Pest Control Advisors, County Agricultural Commissioners, and other agricultural professionals. One such process resulted in an agricultural practices document particularly relevant to dormant season applications in the Sacramento and Feather River Basins (SRWP, 2000). Sections in this document relating to dormant season practices for orchards, vegetation and soil management practices, and pesticide application methods have been based upon information compiled in the aforementioned document.

This report is subdivided into two main sections. The first section is a compilation of the various practices. These are grouped into pesticide application practices and technologies, pest management practices, and vegetation, soil and water management. Different portions of this section identify practices that may be more applicable to the dormant season versus the irrigation season and vice-versa. A general overview of the practices is provided in Table 1 below. The final section discusses programs that are involved in the promotion of agricultural management practices. For each, the seasonal and general crop type applicability is included. Applicable National Resource Conservation Service (NRCS) codes[1] and Nonpoint Source (NPS) Program management measures[2] are given in Appendix A.

Many of these practices may be applicable to pesticides in general. The applicability of specific practices would vary according to pesticide chemical properties, method of application, etc. Even with regard to diazinon or chlorpyrifos, some vegetation management practices may have different effects due to differences in chemical properties of the two pesticides. Chlorpyrifos has a high affinity for soil organic matter and sediment while diazinon is more soluble in water. Because diazinon tends to be more mobile while chlorpyrifos tends to sorb to particles, practices involving the use of vegetative strips to reduce the amount of pesticide in runoff may be more applicable to chlorpyrifos.

[1] National Resource Conservation Service (NRCS) Practice Standard code numbers: NRCS Field Office Technical Guide in each state contains Conservations Practice Standards developed for that state. Conservation Practice Standards include a practice definition, purpose of the practice, conditions where practice applies, criteria for applying the practice, special considerations in applying the practice, practice plans and specifications, and practice operation and maintenance requirements.
[2] Nonpoint Source (NPS) program management measures are designed to address specific categories of nonpoint source pollution, including agriculture and urban sources.

Table 1. General overview of practices.

CATEGORY	APPLICABLE FOR TIME PERIOD AND CROP TYPE		
	Dormant Season	In Season	
	Orchard Practices	Orchard Practices	In Season Row and Field Crop Practices
Pesticide Application Methods and Technologies ❑ Spill Prevention/Emergency Response ❑ Mixing and Loading ❑ Disposal ❑ Sprayer Calibration and Nozzle Selection ❑ New Equipment Technologies ❑ Equipment Maintenance ❑ Selection of Ground or Aerial Application ❑ Reduction of Aerial Drift ❑ Setback/Buffer/No Spray Zones ❑ Application Rates and Spray Volume ❑ Spray Adjuvants	YES	YES	YES
Pest Management Practices for Orchards ❑ Conventional Dormant Oil ❑ No Dormant Oil Application or Dormant Oil Only and In-Season Application ❑ Alternate Year Dormant OP with Yearly Oil Application Only ❑ Dormant Oil and Pyrethroids or Carbamates ❑ Dormant Oil and Spinosad ❑ Bt at Bloomtime for PTB ❑ Pheromone Mating Disruption for PTB	YES	YES (to some degree)	
Pest Management Practices for Row and Field Crops ❑ Organophosphorus ❑ Carbamates and Pyrethroids ❑ Bt use ❑ Reduced Risk Alternative Pesticides ❑ Other Row and Field Crop-Specific Practices			YES
Vegetation Management ❑ Cover Crops ❑ Buffers ❑ Reducing Herbicide-treated Berm Areas	YES	YES	YES
Water Management ❑ Water Application ❑ Drainage System Management ❑ Irrigation Systems Selection		YES	YES
Soil Management ❑ Tillage ❑ Soil Structure and Organic Matter	YES	YES	YES

2.0 PESTICIDE APPLICATION PRACTICES AND TECHNOLOGIES

2.1 Introduction

Off-site movement of pesticides is of three main types: sub-surface leaching to groundwater, airborne drift from application sites, and surface runoff. OP pesticides have not been verified in groundwater monitoring studies conducted by the California Department of Pesticide Regulation (C. Nordmark, pers.comm.). This pathway is not believed to be a major source. Aerial drift contributes to off-site movement, but this pathway is not fully understood and is most likely not a primary source. Surface runoff is the main pathway by which OP pesticides are transported to the Sacramento and San Joaquin Rivers.

This section presents a number of general and specific management practices relating to pesticide application that can help reduce OP pesticide movement off-site. Some practices require managerial changes; others require structural changes. As with other practices discussed in this report, site-specific conditions will determine the usefulness of possible management options for each situation.

2.2 Pesticide Application Technologies and Practices

2.2.1 Spill Prevention/Emergency Response

A key practice in the safe and effective use of pesticides is planning for water quality protection. Sensitive runoff areas should be identified before any pesticides are handled. Applicators need to identify the location of rivers, streams, drainage/irrigation canals, wells, and other waterbodies in relation to the area where pesticides will be mixed, loaded, and applied. Slopes, soil types, and areas of potential runoff must be considered to prevent movement of pesticides to waterbodies. Agricultural fields and surrounding lands should be properly graded to retain as much water on site as possible.

Despite all efforts to avoid them, spills may still occur; handlers should, therefore, have a contingency plan for spills or leaks that can occur while mixing or loading. Operators must have access to product labels and material safety data sheet (MSDS)[3] information during all mixing and loading activities and be familiar with cleanup procedures. Label directions must be followed. Spill cleanup material such as clay-based kitty litter should always be available. Spills of any size should be cleaned up immediately (CURES, 2000).

Tank overflows or spray solution spills should be contained by damming, particularly if they are headed for waterways. Absorbent material such as kitty litter can be used to soak up spills on impervious surfaces, and should be disposed of after use according to label directions. Soil on which pesticides have spilled should be removed immediately. This includes all dampened soil plus an additional two inches of dry soil below the spill. The removed soil may, in some cases, be applied to the field with a fertilizer or manure spreader providing the application rate won't exceed label recommendations (CURES, 2000).

Large spills or any spills with the potential to impact human health or the environment may require notifying the local agricultural commissioner. All pesticide labels have emergency telephone numbers to call in case of a spill.

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[3] A material safety data sheet (MSDS) is an information sheet provided by a pesticide manufacturer describing the chemical qualities, hazards, safety precautions as well as emergency procedures to be followed in case of a spill or other emergency.

2.2.2 Mixing and Loading

The location of sensitive areas should be a key factor in selecting mixing and loading sites. Mixing and loading should not occur within 50 feet of wells, streams, canals, irrigation ditches, riparian areas or sinkholes or within 200 feet of drinking water supply wells. State regulations may specify additional or more stringent requirements.

Ideally, mixing, loading and rinsing should be conducted on a containment pad, which includes a cement slab that drains to a central sump. If a containment pad is not available, mixing, loading, and rinsing should be conducted on sites that can be tilled. Hard-packed or paved roadways should not be used because runoff is more likely to occur (CURES, 2000). Mixing and loading sites should be changed periodically to reduce the build-up of contaminates.

Pesticide concentrates pose the greatest hazard to both the handler and the environment; the hazard is reduced after a chemical is mixed into a spray tank of water. Before filling a tank, the hoses and tank should be checked for cracks or leaks and the drain plug must be in place. Tanks should be filled only halfway before chemicals are added, to help prevent overflow. A tank should never be filled to overflowing or left unattended during filling. Drains must never be connected to sewers or open drainage systems but instead to sumps from which rinseates and solids can be easily removed. Tank areas should have proper containment capacity in case of leaks.

The California Code of Regulations Section 6610 requires that each service rig and piece of application equipment that handles pesticides and draws water from an outside source be equipped with an air-gap separation, reduced pressure principle backflow prevention device or double check valve assembly. Backflow protection must be acceptable to both the water purveyor and the local health department. Mechanical devices can fail, however, and an air-gap system is the only system that guarantees that no back-siphoning will occur (CURES, 2000).

Other spill reduction options to consider are water-soluble packaging for OP pesticide wettable powders, and closed mixing and loading systems. Water-soluble bags for wettable powders help reduce risk to handlers and reduce chances of concentrate spills. The bags, which rapidly dissolve in the spray tank, provide pre-measured quantities of chemical. This option also eliminates container disposal problems.

A closed mixing and loading (handling) system can minimize, if not eliminate, accidental spills. It also helps eliminate handler exposure as the operator has no contact with the chemical as it is loaded. Some closed handling systems have hoses equipped with drylock connectors, which virtually eliminate leaks and spills as chemical is pumped directly from a bulk container into the spray tank (University of Illinois, 2000). Closed handling systems can be added to existing orchard airblast sprayers, but this modification is expensive.

2.2.3 Disposal Practices

Proper disposal of leftover spray liquids and spray tank rinseate is another management practice that can help reduce OP pesticide runoff. Steps taken to eliminate the generation of disposal materials will minimize the need for disposal. Operators should measure the treatment area, calibrate the spray rig, calculate the spray volume needed for the treatment area, and calculate the amount of product needed for the treatment area. Additional spray solution remaining at the end of an application should be diluted with water and applied to the field, provided it doesn't exceed label rates. Additional solution may be disposed of per label recommendation. Operators should never just drain out excess material but plan a method of disposal to ensure that excess spray material does not contaminate surface or groundwater (CURES, 2000).

Equipment and containers are best cleaned on a containment pad. If one is not available, rinseate can be poured into the spray tank and reapplied to the field. Disposable containers should be pressure-washed or triple rinsed immediately after emptying and the rinseate added to the spray tank. Empty containers should be punctured and recycled at a pesticide container disposal facility. Pesticides should be purchased in returnable, refillable containers whenever possible (CURES, 2000).

2.2.4 Sprayer Calibration and Nozzle Selection

The goal of calibration is to assure that sprayers deliver a predictable dose of spray mixture and associated pesticide. Improper pesticide concentrations may cause environmental problems. Calibrating equipment to maintain application rates within label requirements helps protect beneficial insects and wildlife. It also reduces the potential for contaminating surface and groundwater. The UC Cooperative Extension publication, *The Safe and Effective Use of Pesticides* (#3324), is an excellent source of information and gives step-by-step instructions for calibrating spray equipment. Equipment should be checked once or twice per season. Equipment can rapidly become worn and out of adjustment; application equipment is usually not calibrated frequently enough.

Spray nozzles control the application rate, drop size and spray pattern. They also contribute to the thoroughness and safety of pesticide applications. Nozzles are one of the most important parts of a sprayer. Studies summarized by the Spray Drift Task Force (1997a,b) confirm that droplet size is the single most important factor in reducing spray drift. The goal of nozzle selection for orchard airblast sprayers should be to select a nozzle and coordinating operating parameters that will produce large droplets and avoid the generation of small droplets, which are most subject to offsite aerial drift. Disc-core nozzles are commonly used in airblast sprayers and are suitable for high pressure and high flow rate applications. Using different kinds of discs and cores provides a wide range of volume output and droplet size (UC IPM, 1999b).

2.2.5 New Equipment Technology

Improved application equipment can reduce pesticide movement. Typical orchard airblast sprayers are high volume, high pressure applicators. Airblast sprayers deliver up to 100 gallons per acre (GPA) for "concentrate sprays" and 300 to 400 or more GPA for "dilute sprays." Application pressure varies from 100 to 200 pounds per square inch (psi). New technologies are being developed that use only 25 to 50 GPA, but these operate at higher pressures and typically produce finer droplet sizes. While decreased spray volumes may decrease amount of spray available for off-site movement, higher pressures and finer particle sizes may increase drift. In one study, however, two to four times less ground deposition occurred at the edge of the orchard from a low volume mist blower than a traditional high volume airblast sprayer (SDTF, 1997a). Additional application technologies are being developed that apply less volume and produce less drift. These new technologies are being tested by university researchers and would require a significant financial investment by growers and applicators.

Electric or sonar sensors mounted on application equipment can detect presence or absence of foliage, such as gaps between trees, missing trees or smaller trees. These sensors, or electronic/sonar "eyes" automatically turn off sprayers when foliage is not present, and turn on sprayers when foliage is present. Equipment costs are $3,000 to 4,000 per unit, with typically three units for each side of the sprayer. Thus, six units per sprayer can cost $18,000 to $24,000. This cost can be offset by up to 25% reduction in spray material costs. An additional benefit is that off-site movement from drift can be reduced up to 20% or 30% (F.R. Hall, pers. comm.).

Several types of new spray applicators have been developed, though not all are commercially available. Air curtain sprayers use a sheet of air to move pesticides onto the target crop. One advantage of this technology is the reduced volume of liquid because air is used as the carrier instead of water. Another advantage claimed by some researchers and the manufacturers of these sprayers is reduced rates of pesticide applications. Steinke *et a*l.(1992) found almost twice as much deposition on twigs with an air curtain sprayer compared to a conventional airblast sprayer. Unfortunately, the air curtain sprayer also resulted in increased airborne and ground level deposits downwind. About twice as much drift deposits were found 250 meters downwind from the air curtain sprayer as the conventional airblast sprayer.

Fox *et al*. (1993) tested a cross-flow sprayer constructed by adding a top fan inclined downward at a 20^{o} angle. At 240 meters downwind, about half as much airborne spray was collected from the cross-flow sprayer as from a conventional axial-fan sprayer. Matthews and Thomas (2000) used a similar concept with a fan-shaped air jet set at a shallow angle to the spray as it exits the nozzle. This resulted in finer spray pattern but the spray remained entrained within the airflow. These technologies have the potential to reduce drift despite the production of smaller droplet size.

2.2.6 Equipment Maintenance

The single most important source of information on the operation and specific maintenance needs of spray equipment is the owner's manual. Pesticide applicators should review operating instructions and follow all equipment maintenance recommendations.

Before using pesticide application equipment the spray tank, pumping system and pressure manifolds should be rinsed and flushed with clean water to remove debris. Filter screens should be inspected and cleaned. All bearings, grease fittings, and other moving parts need to be lubricated. All hoses and manifolds should be checked for leaks, cracks or other damage (CURES, 2000).

Wettable powders are abrasive and accelerate nozzle wear. When used, nozzles need to be inspected frequently and replaced per manufacturer specifications. Pressure gauges and regulators should be in proper working condition.

2.2.7 Selection of Ground or Aerial Application

Most dormant spray applications are performed by private applicators using traditional tractor-pulled airblast sprayers. Some applications are made using aircraft. Licensed pest control applicators are believed to account for a small percent of all dormant spray applications. Aerial applications are more common in years with heavy rainfall during the dormant season when ground access to orchards is restricted.

Aerial applications are considered to be less effective than ground applications and can be more prone to drift. Drift is caused by high travel speed, release height and wing-tip vortices that tend to transport the droplets above the wing (Ozkan, 2000; SDTF, 1997b). Drift can be variable depending on boom and wing length. Various modifications can be implemented to reduce drift potential including booms with nozzles dropped away from wings to prevent spray from getting caught in the vortices and the use of different nozzle sizes.

2.2.8 Reduction of Aerial Drift

Although runoff is the main source of pesticides in surface water, aerial drift (pesticide droplets landing outside the target area) also contributes to the problem. Studies by Dow AgroSciences (1998) demonstrated that aerial drift can be a significant source of pesticides to surface waters. The authors conducted a year-round study on diazinon and chlorpyrifos concentrations in Orestimba Creek in Stanislaus County, focusing on crops other than almonds and stone fruit. The authors found that certain concentration peaks were associated with specific events, and drift was identified as the most probable transport process. For diazinon and chlorpyrifos, five of fourteen peaks and nine of thirteen peaks, respectively, were caused by aerial drift.

Aerial drift is greatest when droplet diameter is less than 150-200 microns. Although larger droplets can decrease aerial drift, they may also increase ground deposition within the field. This fallout can then easily be transported into surface water by rain or irrigation runoff. Thus, efforts to reduce drift may increase surface water runoff (Matthews and Thomas, 2000).

One consideration with airblast sprayers commonly used in orchards is that they are primarily designed for in-season sprays that must penetrate dense foliage, which is a very different mechanical process from that of coating the leafless dormant tree. Studies summarized by the Spray Drift Task Force (1997a) found that dormant season applications by orchard airblast sprayers resulted in 22 times more ground deposition 25 feet from the application site than growing season applications to foliated orchards. Drift is more likely in crops without dense vegetation to intercept the spray.

Weather conditions strongly influence aerial drift. Applications should not be made in high winds, particularly when they are blowing toward waterways or other sensitive areas. Applications in winds greater 10 mph are particularly prone to drift. Drift potential also increases when winds are less than 3 mph due to formation of temperature inversions, which restrict vertical air movement. In an inversion, droplets can remain suspended and move laterally as a concentrated cloud.

High temperature and low humidity contribute to evaporation and result in reduction of droplet size, which increases the potential for drift. This is not typically a problem during cooler, dormant season applications. The foggy conditions common in California's Central Valley during the winter are evidence of stagnant air pockets and/or temperature inversions that can lead to off-site pesticide movement. Applications should not be made within 12 hours of forecasted rain or planned irrigation events.

Aerial drift can be minimized by specific application techniques. Applicators must be particularly careful when spraying near sensitive areas and bodies of water. Studies by the Spray Drift Task Force (1997a) in dormant apples demonstrated that spray deposition on the edge of orchards was decreased by as much as10-fold by treating only the second row of trees versus the outside row of trees. When treating orchards near sensitive areas, spray should be directed from the orchard margin toward the interior of the field, providing a buffer zone for the sensitive area.

Airblast sprayers should be shut off when making row turns. Spraying should begin only when nozzles are adjacent to the first trees. Airflow and nozzle pattern can be adjusted to fit the size and shape of the trees. Deflectors and aiming devices can be adjusted so that spray is directed into the canopy. Upward nozzles should be shut off in areas where there is no foliage overhead, and lower nozzles should be shut off when there is no under foliage. The sprayer should be shut off when there is a gap in a tree row (CURES, 2000; SDTF, 1997 a), however turning off the sprayer when there are gaps between trees or when making turns at the row ends is not always possible for some types of equipment, especially those that are power train operated (PTO).

One new approach is to use different application methods for different parts of an orchard (Matthews and Thomas, 2000). Coarse spray nozzle selection and arrangement could be used along field borders upwind from sensitive areas such as aquatic habitat, residential buildings, sensitive crops, etc. Finer spray nozzles could be reserved for applications in the interior of the orchard, or downwind from sensitive areas.

Aerial applicators have several options for reducing drift. Nozzles should point backwards, toward the tail, to reduce shear and the formation of small droplets. Increasing droplet size for aerial applications can help reduce drift but may result in more orchard floor deposition. Spray offsets should be used with caution and the distance the wind will carry the spray swath should be carefully calculated. At 10 mph wind speed, a full swath adjustment resulted in up to a 3.5 fold decrease in deposition 25 feet downwind from the edge of the field (SDTF, 1997b). The lowest application heights and the shortest boom lengths that are still safe and practical should be used. Applications should not be made in windy conditions (Ozkan, 2000; SDTF, 1997b). Global Positioning System instruments can be used to assure treatment of the correct field and prevent overlap of treatment swaths.

2.2.9 Setback/Buffer/No Spray Zones

Setback, buffer or no spray zones are intended to provide a physical distance between the crop being sprayed and sensitive areas such as surface and groundwater, adjacent properties, and sensitive habitats. Work by the Spray Drift Task Force (1997a,b) demonstrated that spray deposited 25 feet from the edge of a field can be reduced by 50% with a 50-foot setback zone for airblast applications or with a 100-foot setback zone for aerial applications. The relationship between drift fallout and distance from an application site is nonlinear. Generally, there is a logarithmic response and simply doubling a distance will not reduce the fallout by 50%. Some pesticide labels (non-OP pesticide) require buffer zones of 25 feet for ground applications, 150 feet for aerial applications and 450 feet for ultralow volume applications adjacent to waterways.

2.2.10 Application Rates and Spray Volumes

The lower the application rate, the lower the amount of chemical available to move off site. However, if too low a rate is used, target pests may not be controlled and repeat applications may be necessary. Repeat applications increase opportunities for off site drift as well as opportunities for accidents from mixing/loading/transporting. Rate selection is based on the pest species, population level and length of control desired.

Spray volumes are increased or decreased depending on tree size, canopy size and density and needs of the grower. Spray volume does not affect the amount of active ingredient (a.i.) applied per acre. One pound a.i. per acre applied in a 100 gallons per acre (gpa) concentrate spray or in a 400 GPA dilute spray is still 1 pound per acre a.i. Increased spray volumes may offer increased total volumes for off-site movement but the amount of active ingredient is more diluted. Lower spray volumes may minimize off-site movement but those droplets that move off target may have more concentrated amounts of pesticide.

Dibble and Haire (nd) found that low volume (90 gpa) applications resulted in a 3 to 4 fold reduction in surface fallout compared to high volume (400 gpa) applications. Salyani and Cromwell (1992) also found the highest ground level deposits and airborne spray from the high volume (416 gpa) airblast spray compared to the low volume (60 gpa) application.

2.2.11 Spray Adjuvants

Spray adjuvants are added to spray tank mixtures to improve the performance of the active ingredient. Examples of adjuvants include stickers to increase adherence to leaf surfaces, spreaders to provide more uniform distribution over leaf surfaces, penetrants to increase translaminar movement of active ingredients into the leaf, compatibility agents to improve mixing of hydrophobic and hydrophilic tank mixes, and antifoaming agents to prevent foaming during mixing and loading. Some adjuvants are designed specifically to reduce drift and will be referred to here as drift retardants.

Performance of drift retardants is quite variable (Ozkan, 2000), and results often vary between tank mixes. These adjuvants are usually not effective in high pressure airblast sprayers due to pumping action in the tank and increased sheer at the nozzle. Polymer adjuvants often degrade with pumping action of the tank, so are less effective at the end of the field than at the beginning. Short range drift (<50 feet) can be decreased with some adjuvants by increasing droplet size but do not necessarily decrease the number of small droplets, which are responsible for most of the long range drift. Further disadvantages that have been noted with some drift retardants are decreased spray angle, less overlapping coverage from boom swaths and reduced coverage for the target crop.

While drift retardants may effectively reduce the number of small droplets, it is generally more effective to select the proper size and type of nozzles and to use lower spray pressures (Ozkan, 2000). Bouse *et al.* (1988) demonstrated that polyacrylamide and polyvinyl polymers were most effective in increasing droplet size, and decreasing drift potential. Some drift retardants can have significant affects on drift, even under windy conditions, while others have little or no effect. (Ozkan, 2000).

While some drift retardants undoubtedly perform very well, there is little consensus among researchers as to the performance of the group as whole or even how to evaluate performance. The American Society for Testing and Materials (ASTM) Committee E35 is developing standards for drift control agents. Dr. Ken Giles of the UC Davis Department of Biological and Agricultural Engineering has applied for a USDA grant to develop specific aspects of GPS systems used to improve aerial application methods.

3.0 PEST MANAGEMENT PRACTICES

3.1 Introduction

Integrated pest management (IPM) programs rely upon pest identification, field monitoring, control action guidelines, effective management methods, and established monitoring techniques and treatment guidelines in making pest management decisions. IPM programs are information- based and site-specific, and the control measures chosen depend on several factors including location, the crop variety being grown, soil type, climate, and field history. IPM is often misunderstood to mean no use of pesticides. While these programs encourage the use of management methods that are considered less disruptive to the environment, pesticide use is not discouraged when needed. IPM guidelines for specific crops are available from the UC Cooperative Extension County Offices, the world wide web[4], or by subscription.[5] Guidelines for some of the more commonly grown crops for the area are summarized in tabular form in Appendix B.

Pest monitoring is an important component of IPM programs. This is done at various stages including before planting and during the season. Accurate pest identification is necessary since closely related pest species may require a different management method and because beneficial organisms must be correctly identified in order to assess biological control efficacy. Weather is also monitored since the use of degree days[6] can often more accurately predict pest development by measuring the amount of heat the pest is exposed to over time (UCIPM, 1999b). Control action guidelines are generally numeric thresholds such as insect counts gathered during the monitoring period.

Management methods vary, and can be a combination of one or more aspects including biological control, cultural practices, pheromone disruption, pesticide treatment, etc. Biological control includes the use of natural enemies that attack pests; use of such

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[4] http://www.ipm.ucdavis.edu

[5] University of California, DANR/Communication Services, 6701 San Pablo Avenue, Oakland, CA 94608-1239; 510-642-2431; 800-994-8849.

[6] A degree day is defined as the area under the temperature-time curve, between the lower and upper development thresholds, equal to 1 degree x 1 day. Currently, the UCIPM website has degree day calculations for forecasting the development of peach twig borer, oriental fruit moth, codling moth, orange tortrix, and San Jose scale.

biological control agents, however, may not be enough to suppress pest populations to prevent them from reaching damaging levels. Cultural practices include field level practices that can affect the intensity of pest infestation. This includes practices such as orchard sanitation or proper pruning and painting of exposed wood to prevent sunburn as well as reduce tree susceptibility to wood-boring insects. Proper irrigation and fertilization may also help reduce certain pests. Dry conditions, for example, favor mite buildup. Too much fertilizer can increase shoot growth and create more sites for PTB and oriental fruit moth. Pheromone mating disruption can be used to control populations of some pests, including the oriental fruit moth and PTB but success is contingent upon the proper timing and placement of dispensers.

3.2 Major Economic Insect Pests

Listed below are some of the major economic pests for certain crops. A more comprehensive list is provided for various crops in Appendix B.

- *Stone fruits:* The peach twig borer (PTB), and San Jose scale (SJS) are both major economic pests to all stone fruit. The oriental fruit moth is a serious pest of peaches and nectarines, but is less of a problem on other stone fruits. The web spinning spider mite is also a major economic pest to all stone fruits but its numbers will only reach economically damaging levels if trees are water or nutrient-stressed.
- *Almond:* The three key pests of almonds are the SJS, PTB, and navel orangeworm (NOW).
- *Walnut*: Codling moth is the most serious pest of walnuts. Treatment for codling moth may result in an increase of other pest populations due to a loss of natural predators and parasites
- *Apples and Pears*: For both apples and pears, codling moth is the key insect pest. Management decisions for codling moths have a major impact on many other insects and mites in the orchard. The types of materials used to control the codling moth population can affect populations of predators and parasites, and may cause outbreaks of other pest insects.
- *Alfalfa:* The alfalfa weevil is one of the major economic pest for this crop.

3.2.1 Peach Twig Borer (PTB)

PTB is a major pest on most stone fruit and almond, and a minor pest on cherry. It can spread and infest adjacent orchards. This pest has four flights: March-May, late June to early July; August; September or October. Larvae overwinter as first or second instars inside a hibernaculum, a chamber that it bores in the bark in the crotch of 2 to 3 year old wood. Larvae build a pile of frass at its entrance and emerge from the hibernacula in spring. They migrate up branches of new shoots and flower buds, bore into the shoots and feed on shoot tips. This results in "shoot strikes" identified by dead, drooping leaves. Fruit may also be attacked. In general, biological control is not enough to keep populations from reaching damaging level. Yearly treatment with Bt (*Bacillus* *thurigiensis*), a microbial pesticide, at bloomtime or a dormant spray is required. Monitoring should be ongoing to determine if in season spray is required. Pheromone mating disruption may eliminate the need for in season insecticides but should not be used as a substitute for bloomtime sprays or a dormant spray program.

3.2.2 Oriental Fruit Moth (OFM)

OFM is a major pest on peaches and nectarine, and larval damage to young shoots and fruit is similar to that caused by PTB. Usually, this pest has five generations a year in California stone fruits. Pheromone disruption can be used as a management technique to disrupt the mating of OFM adults. Disruption is especially important for the first two generations in the spring. In most cases, pheromone disruptions will eliminate the need for insecticide sprays. Alternatively, a program of pesticide sprays targeting the second and third generation before they bore into the shoots or fruit can be employed, but this program is likely to disrupt biological control of other pests. Additional pesticide applications may be needed for later occurring varieties if monitoring for damage indicates they are necessary.

3.2.3 Codling Moth

Codling moth is a major economic pest of apples, pears, walnuts, and plums. It rarely attacks other stone fruits, even when adjacent to preferred host that are heavily infested. Peach orchards using pheromone mating disruption sometimes sustain codling moth damage in a few rows adjacent to unmanaged walnuts. Three generations of codling moth a year is typical for a Central Valley orchard. Codling moths overwinter as mature larvae in cocoons under loose bark or in other protected areas on trees. In the Central Valley, adults emerge in late March.

3.2.4 San Jose Scale (SJS)

SJS attacks a wide variety of woody plants and is a serious pest of all stone fruits, It damages developing twigs, older wood and fruits. SJS attack twigs, leaves, bark, and fruit, feeding on plant juice and weakening trees when infestations are heavy. Severe infestations on twigs can cause gumming and kill twigs, branches, or entire trees if left uncontrolled. Dormant oil sprays and natural enemies may keep the SJS from reaching damaging levels, but regular monitoring is necessary to determine the need for additional treatments. Scales overwinter predominantly in the black cap stage on infested twigs and branches. The overwintering generation matures in March and first generation crawlers begin emerging in late April or early May. There are four or five generations a year.

A number of natural enemies can help keep SJS populations suppressed. Broad spectrum pesticides applied during the summer may destroy natural enemy populations and result in increased scale infestations. Dormant sprays are recommended to keep populations suppressed followed by regular monitoring to see if populations are increasing and to assess the presence of biological control. Good spray coverage and sufficiently high applications rates are essential for effective control. It is not recommended that dormant oil rates be reduced if scale is present.

3.2.5 Webspinning Spider Mites

Webspinning Spider Mites are a major pest on apples and pears. They overwinter as red or orange females, mostly under rough bark scales at the base of apple and pear trees, on ground cover plants, and in ground litter and trash. As trees leaf out in the spring, mites move up from lower parts of the trees to feed and lay eggs. Spider mites are favored by hot dry conditions, and they build up as the weather becomes more favorable in late spring or summer. Spider mites withdraw nutrients from leaf cells, destroying chlorophyll and causing pale strippling of leaves. When mite populations reach high levels, they spin webbing on leaves, hence the name webspinning spider mites. High populations reduce tree vigor. If defoliation occurs early in the season, fruit size and quality are reduced and the limbs and fruit are exposed to sunburn. Defoliation in mid-to late season may reduce the following years crop. Successful mite management requires regular monitoring both for pest mites and predators, and good cultural practices to maintain healthy trees. Because dry, dusty conditions favor spider mites, regular irrigation and watering or oiling of orchard roads to minimize dust will help prevent mite buildups. In some orchards, the mite may be considered a beneficial predator instead of a pest. Because of the webspinning mites' role as a predator, disruptive pesticides should be avoided when possible.

3.2.6 Egyptian Alfalfa Weevil

Depending on region, the alfalfa weevil or the Egyptian alfalfa weevil are consistent major economic insect pests to alfalfa. In the San Joaquin Valley, it is the Egyptian alfalfa weevil. Early spring sprays, usually applied in February, March or sometimes early April, are conducted to control this pest. A resistant cultivar has yet to be developed. Retaining beneficials in a field can be successful at controlling aphids and summer worms, but are generally not as helpful in controlling Egyptian alfalfa weevil.

3.3 Pest Management Practices for Orchards

3.3.1 Introduction

PTB, SJS, and some mites and aphids are typically controlled by applications of oil and OP pesticides during the dormant season, usually January through March (UC IPM, 1999a). Dormant applications were originally recommended, in part, to help reduce environmental impacts. However, because dormant sprays can wash off trees and the orchard floor during the winter rainy season, they can enter surface water and pose a threat to aquatic organisms. OP pesticides are routinely detected in the Sacramento and San Joaquin Rivers after dormant spray applications during the mid-winter storm season, and studies indicate that a major source of OP pesticides in rivers and tributaries is rain runoff from orchards following dormant spray applications (Domagalski, 1997).

Concern about the toxic effects of OP pesticides on aquatic ecosystems has generated interest in viable pest management practices that can reduce concentrations of OP pesticides in surface water. To be viable, a practice must be likely to reduce pesticide movement offsite, provide an acceptable level of pest control, and be comparable in cost to conventional dormant oil and OP pesticide applications.

Pest management practices that reduce or even eliminate OP pesticide use are already being used by growers. Programs such as Biologically Integrated Orchard Systems (BIOS), Biologically Integrated Farming Systems (BIFS), and the Pest Management Alliance (PMA), discussed in Section 7 have incorporated these practices in their pest management approaches.
These practices are generally more complicated than conventional OP pesticide dormant sprays, although they are not necessarily more expensive, considering the cost of materials applied, pesticide application(s), and monitoring by a pest control advisor (PCA) (Zalom *et al*., 1999).

The use of OP pesticides for dormant applications in stone fruit and almonds declined sharply between 1992 and 1998. In almonds, the reduction was as high as 70% in some counties, due in part to adoption of alternative pest management practices, particularly the use of dormant oil without pesticides, dormant oil with pyrethroids instead of OPs, and bloomtime applications of the bacterium *Bacillus thuringiensis* (Bt). The decline in OP pesticide use in stone fruit orchards was less than in almonds and was accompanied by increased use of pyrethroids (Epstein *et al*., 2000).

3.3.2 Pest Management Options for Orchard Crops

Researchers at the University of California, Davis (Zalom *et a*l., 1999) have identified a number of viable pest management options for orchard crops, which will be discussed in detail below. These pest management practices can be variously combined to fit the needs of individual growers and specific pest management needs.

Conventional Dormant Oil and OP Pesticide

As discussed above, conventional control of PTB, SJS, and aphids on almonds and stone fruits focuses on an application of oil and OP pesticide during the winter dormant period. Other insecticides or miticides may also be applied as needed during the growing season to control specific pest outbreaks.

The dormant oil and OP is generally applied between January and March, after trees are fully dormant but before blooms begin to emerge. As discussed above, this is also the time of year with the most rainfall, and when soils are saturated, which maximizes orchard runoff.

The advantages of winter applications of dormant oil and OP pesticides are that there are no leaves or fruit on the tree, so the oil/OP mixture can thoroughly coat the branches and twigs, where overwintering insects reside. Workers, wildlife, and beneficial insects are less likely to be present in the orchard during the winter, and the absence of fruit means that no residue will be deposited on it. OP insecticides are broad spectrum and control many key pests with only one application, and dormant sprays can be applied over several months, making timing less critical. (Univ. of Calif., 2000).

One option for dormant oil and OP pesticide applications that could reduce the risk of offsite runoff would be to change the timing of the application. Preliminary data indicate that applications made in October or November are as effective in controlling orchard pests as those made later in the winter, during the rainy season (Oliver, pers. comm). Earlier applications are likely to remain on the tree or the ground for a longer time in dry weather, optimizing their breakdown from photolysis and microbial action. Also, when rainfall does occur in October and November it is more likely to soak into the dry ground rather than running off, as happens later in the winter when soils are saturated.

Some of the disadvantages of using dormant oil and OP pesticides, in addition to their tendency to move offsite, are that OPs must be remain on the tree 24 to 48 hours before any rain, and they can be hazardous to the workers applying them and to raptors that often hunt or roost in orchards during the winter.

Fall or early winter applications of dormant oil and OP pesticides should be investigated to determine pest management efficacy and runoff reductions. Studies on the efficacy of reduced rates of OP pesticides in dormant oil would help determine if lower rates could be used, particularly if aphid densities are low. A mass balance study of OP pesticides in treated orchards would further understanding of how pesticides are transported to surface waterways, and could help identify practices that reduce transport in the most important pathways.

No Dormant Application or Dormant Oil Only and In-season Applications as Needed

Reducing the amount of OP pesticide applied is one approach to reducing offsite movement. It may be possible to skip OP pesticide and dormant oil sprays in some years if the orchard is closely monitoring for PTB and SJS, especially if the orchard has no recent history of problems with these pests. Research by the Integrated Prune Farming Practices Program (IPFP) indicates that intensive pest monitoring can substantially reduce dormant season applications. In a two-year field study, 50% to 64% of study orchards did not need dormant applications (IPFP, 2000).

If no dormant spray is applied, monitoring is critical for PTB larvae associated with blooms or emerging shoots as well as twig strikes resulting from feeding by the emerging larvae. If larvae are present at bloom or on emerging shoots, *Bacillus thuringiensis* (Bt) can be applied during bloom, as discussed below. Once strikes are observed, it is likely too late for bloomtime Bt sprays to be effective. If several twig strikes are seen on each tree by mid-April, in-season sprays should be applied for PTB control timed to pheromone monitoring trap catches and the phenology model for PTB.

Often, the application of oil alone can adequately control scale insects and mites in orchards, although the higher rates of oil necessary may be phytotoxic to dormant buds in dry winters when trees are moisture stressed. If OP pesticides are not used, there is a potential cost saving. However, if in-season sprays then become necessary to control aphids or other pests that would have been controlled by a dormant season OP application, then the overall cost is greater than for dormant oil and OPs.

Overwintering aphids are a particular concern in plums and prunes. Usually controlled by dormant oil and OPs, aphid populations would have to be monitored closely; and, if needed, insecticides would have to be applied in-season. These in-season applications can pose greater risks to workers, wildlife, and beneficial insects, and cannot be used too close to harvest. Aphids are not as much of a problem in almonds, and the option of oil only, or no dormant application at all is more feasible.

One option to reduce the impacts of in-season aphid control on beneficial insects is to make augmentative releases to help restore naturally occurring populations after a broad-spectrum pesticide application (UC IPM, 1999a). Predators and parasites of some pest species are available for purchase from commercial insectaries, however natural enemies of the PTB and SJS are not commercially available (UC IPM, 1999a, Hunter, 1997). Research to identify, import, and test natural enemies for SJS is currently underway. Work is also underway on parasitoids for aphid pests of prunes. While natural enemies contribute to the control of insect pests of stone fruit and can keep pest mite populations from causing serious damage, typically they are not able to reliably control pests when used alone (UCIPM, 1999a).

Almonds and peaches are the best candidates for skipping a dormant OP pesticide spray. Oil treatments alone can be effective for scale and mite control, but may not be effective for aphids in plums and prunes.

The California Dried Plum Board is sponsoring a program to acquire, release, and evaluate parasitoids attacking prune aphids. The program monitors both parasitoid establishment and impact on pest aphids in California prune orchards (Mills *et al*., 2002). The California Dried Plum Board is also conducting pheromone trials for mealy plum aphid and leaf curl aphid. (Wilks *et al*., 2000).

Under a Pest Management Alliance grant from the Department of Pesticide Regulation (see discussion of the Pest Management Alliance program in Section 7), the California Tree Fruit Agreement is developing an integrated system for controlling SJS, PTB, oriental fruit moth, and thrips in clingstone canning and fresh shipping peaches and nectarines. The project is designed to examine the efficacy of oil only treatments to control SJS, to describe the natural enemy complex attacking SJS in stone fruits, and to investigate the potential to manipulate one or more of these natural enemy species (Field, 2002).

Research needs include efficacy studies with imidacloprid and other compounds not currently registered for use, biological control agents for aphids, new pesticides or biological control agents for SJS.

Alternate Year Dormant OP with Yearly Oil Only Application

Using OPs only every other year should reduce potential runoff by one-half, assuming all else remained equal and that applications in a specific watershed were restricted to half of the orchards on which a dormant spray might be applied. In years when dormant OP pesticides are not applied, monitoring and in-season sprays could be used as described above, or by other pest management practices described below. A good monitoring program is necessary to determine both the need for treatment and the most effective control measure to use. This practice could save growers money, and is more likely to be accepted than no dormant applications.

The pest management efficacy of alternate-year OP pesticide applications are being examined by the California Dried Plum Board in a six-year study of a prune orchard. Alternate-year dormant OP applications appear to control SJS and PTB for more than one year, but aphids are not present. The effects of alternate-year applications on OP concentrations in surface water have not been studied (Zalom *et al.*, 1999). Alternate year studies for almonds, peaches, and other tree crops have not been conducted.

Dormant Oil and Pyrethroids or Carbamates

Pyrethroids (permethrin and esfenvalerate) and carbamates (carbaryl), can be used to control PTB in the dormant or delayed-dormant season. Pyrethroid use has increased throughout the 1990s, with a corresponding decrease in the amount of OP pesticides applied. Pyrethroids may be less likely to move offsite than OPs because they generally have a higher soil adsorption capacity (Koc). However, pyrethroids are highly toxic to aquatic organisms, and are more persistent in soil and water than are OPs. Pyrethroids are also more likely to be stored in sediments, and to bioaccumulate than are OPs. A particular concern with pyrethroids is that they are toxic to organisms at concentrations below those able to be detected by laboratory analysis, which makes their environmental impacts difficult to assess or monitor.

Residues of the pyrethroid insecticides permethrin and esfenvalerate persist on bark and may impact naturally occurring predator mites for an extended period after dormant season and in-season applications. Mite outbreaks caused by use of pyrethroids may require additional miticide treatments. Insects generally become resistant to pyrethroids more rapidly than other classes of pesticides. While pyrethroids remain effective for controlling PTBs in most areas, greatly increased tolerance by PTB to pyrethroids has been identified in the Sacramento Valley, raising the possibility of resistance. Pyrethroids are also not as effective as OP pesticides and oil spray for controlling SJS during the dormant season.

Carbaryl may sometimes be used as a delayed-dormant application, but cannot be used in orchards where honeybees are present. Other pesticides are not widely used in the dormant season because of possible effects on non-target organisms or because of label restrictions.

Monitoring and treatment costs are the same in almonds, nectarines, peaches, plums and prunes.
Specific label restrictions preclude the use of certain products on some crops and sites so it is necessary to examine the label carefully to ensure a given product can be legally applied to a specific crop. For example, the pyrethroid permethrin is not registered for use on nectarines, no pyrethroids are registered for use on plums, and the pyrethroid miticides.

The effects of pyrethroids on aquatic organisms needs to be examined and applied to field situations. Laboratory exposures indicate that fish and aquatic invertebrates are particularly sensitive to pyrethroids, and the physicochemical properties of pyrethroids indicated that they are likely to be carried off site and persist in water and sediments. Pyrethroids are also likely to bioaccumulate (Zalom *et al*, 1999).

Dormant Oil and Spinosad

Spinosad (Success Naturalyte) is a newly registered “reduced risk” biological pesticide that has been shown to control PTB as effectively as OP pesticides when used with oil (Bret *et al*., 1997; Sanders and Bret, 1997). However, like Bt, Spinosad is specific to PTB, and does not control SJS or aphids, so additional in-season pesticide applications may be necessary.

Bt at Bloomtime for PTB

Overwintering PTB larvae can be controlled during bloom with well-timed treatments of Bt, a microbial pesticide. Bt affects larval stages of lepidoptera (butterflies and moths) and therefore is not harmful to most parasites or predators of pest species. However, because of its selectivity, Bt will not control other pests like aphids or SJS, which are normally controlled by dormant OP pesticide sprays. Dormant oil sprays alone will provide control of European red mite, brown mite and low populations of SJS. Dormant prunings should be examined to determine if SJS populations can be controlled by dormant oil alone. PTB shoot strikes should also be monitored in each generation, as well as the presence of larvae as fruit start to ripen.

Bt is currently used on thousands of acres of California orchards. In many almond and prune orchards, bloomtime Bt sprays may provide satisfactory PTB control without other in-season treatments. However, additional treatments are often necessary in peach and nectarine orchards. Additional treatments, of Bt or other pesticides, add to the costs of using this option. Weather conditions and application timing complicate the use of Bt.

A dormant oil and Bt program may not control PTB below economic levels on peaches and nectarines, and additional in-season treatments may be needed. Oil applied alone to plums and prunes during the dormant or delayed dormant season, as part of a Bt program, provides only partial control of leaf curl plum aphid and mealy plum aphid, and additional in-season treatments may be needed. Monitoring and treatment costs for the basic Bt program are the same in almonds, nectarines, peaches, plums and prunes.

More information is needed on potential PTB resistance and Bt's effects on aquatic and other non-target organisms.

Pheromone Mating Disruption for PTB

Mating disruption with sex pheromones is a relatively new method for control of PTB. It has been shown to be effective against PTB in almond, peach and nectarine orchards although some of the details of application and effective rates of specific products have not been completely established. Pheromone mating disruption is most effective in orchards with lower endemic moth populations and orchards that are not close to other untreated PTB hosts, which can be sources of mated females. It is also most effective when used on an area-wide basis where all growers in an area adopt the practice. Other factors that reduce efficacy of pheromone mating disruption include small orchard size, uneven terrain, reduced pheromone application rates and improper treatment timing.

The cost of the pheromone and its application are higher than pesticide treatments. This, in addition to the factors identified above, has limited its use. The cost of mating disruption for PTB can be reduced in peaches and nectarines if pheromone dispensers are applied at the same time as mating disruption for the oriental fruit moth.

Pheromone mating disruption is specific for each pest, so control of other orchard pests is also necessary. Pheromone mating disruption is most effective when PTB densities are low to moderate so it might be necessary to apply additional control measures prior to its use. Pheromone mating disruption in combination with Bt bloom sprays can provide excellent control of PTB. The difference between pheromone mating disruption and the use of mating disruption in combination with a non-OP pesticide/oil dormant spray is the timing of the application that targets overwintering PTB and the product being applied.

The California Tree Fruit Agreement is developing an integrated system for controlling SJS, PTB, oriental fruit moth, and thrips in clingstone canning and fresh shipping peaches and nectarines. A portion of the project is comparing PTB pheromone formulations and dispensers and developing use recommendations (Field, 2002).

Additional research is needed to reduce the costs of production and application as well as to improve the consistency of results. More information on application/effective rates of various products is also needed, as well as information on the effects on non-target organisms.

3.4 Pest Management Options for Row Crops

3.4.1 Introduction

The section on orchard crops summarizes practices that have been evaluated by Zalom *et al*. (1999) to be viable. Viability was based on likelihood to reduce pesticide movement offsite, provide an acceptable level of pest control and comparability in cost to conventional treatments. To our knowledge, no similar in-depth study has been conducted specifically addressing alternative practices for field and row crops. However, IPM guidelines are available for many of the crops grown in the region. The guidelines for the more common crops grown in the region have been summarized in Appendix B. However, the original documents should be referred to for a more complete details. Practices presented here for row crops have not been analyzed for cost comparability nor for their efficacy in reducing offsite pesticide movement.

3.4.2 Pest Management Options for Row and Field Crops

Organophosphorus

OPs are usually applied during the spring and in the summer months from June through August. Applications on crops such as alfalfa, corn, cotton, cucurbits, sugarbeets, and tomato are conducted to control such pests including but not limited to armyworms, cutworms, and various aphids ands mites. In the past, these compounds tended to be applied indiscriminately once crop damage was observed. However, with the increasing awareness of the effects on beneficials as well as on water quality, other aspects of pest management have been incorporated that may be resulting in reduced pesticide runoff from fields. It is estimated that implementing an IPM program has the potential to reduce pesticide applications by up to 60%.

Carbamates and Pyrethroids

Carbamates and pyrethroids are used on virtually all row crops including alfalfa, corn, cotton, cucurbits, sugarbeets, and tomato for the treatement of alfalfa weevils, cucumber beetle, cutworms, fleabeetle, and grasshoppers. For more information on specific properties of carbamates and pyrethroids, refer to Section 3.3.

Bt use on row crops during growing season

Traditionally, Bt was used as a reduced risk alternative to more conventional pesticides used for treating certain orchard pests. It has now been shown to be extremely effective in controlling pests on certain row crops including cotton, corn, cucurbits, sugarbeets, tomatoes, and alfalfa. Pests controlled include the beet armyworm, cotton bollworm, tobacco budworm, webworms, saltmarsh caterpillar, cutworms, yellowstriped armyworm, cabbage looper, tomato fruitworm, hornworms, corn earworms, and alfalfa caterpillar. Bt can be used right up until harvest, which allows for longer-term control compared to other insecticides requiring a waiting period from time of application to time of harvest. The different strains of Bt are class specific, and beneficial or non-target insects are not harmed. Additionally, the insects that ingest the Bt and later die from it, are not considered dangerous to birds or other animals that may feed on the dead insect. Bt is not known to cause injury to plants on which it has been applied and is not considered harmful to the environment. Little or no resistance has been reported to date, but one should still be cautioned against the overuse of Bt. Relying on any one pesticide can lead to the build up of resistance in the pest population.

Cotton plant varieties are now being genetically engineered with a gene taken from a bacterium *(Bt)* that produces a protein which is toxic to a variety of pests. There is still much debate about genetically engineered crops and only time will tell if crops genetically engineered with a pesticide will be accepted by the consumer.

More information is needed on potential effects on aquatic and other non-target organisms.

Reduced Risk Alternative Pesticides For Row Crops

Reduced risk alternatives for row crops include narrow range oils, insecticidal soaps and Bt. Bt use on row crops is discussed in the previous section. Although reduced risk alternative pesticides are less damaging on the environment they may not always be viable alternatives to traditional pesticides. Some alternatives, such as narrow range oil and Bt were traditionally more commonly used for dormant applications on orchards. These alternatives are presented here as potential options for row crops.

Narrow range oils (NRO) were originally only used in the dormant season due to their detrimental effect on leaves, buds, and sprouts. As a result, they were only initially used on orchard crops. However, the new narrow range oils (a combination of petroleum oil, emulsifying agent, and plant oils) are much more refined and can be used on row crops with little to no damage to the plant. The UCIPM manual recommends the use of narrow range oils on cotton, cucurbits, and sugarbeets. NRO attacks the insects spiracles which makes it a virtually resistance-free pesticide. The flip side to this is it only works on insects which use spiracles to breath.

Compared with more conventional pesticides, insecticidal soaps control many targeted pests with fewer potential adverse effects to the user, beneficial insects and the environment. The UCIPM manual recommends the use of insecticidal soap on cotton, cucurbits, sugarbeets, and tomatoes. Insecticidal soaps work only on direct contact with the pests. Insecticidal soaps are most effective on soft-bodied pests such as aphids, adelgids, lace bugs, leafhoppers, mealybugs, thrips, spider mites and whiteflies. The most common soaps are made of the potassium salts of fatty acids. The fatty acids disrupt the structure and permeability of the insects' cell membranes. There is no residual insecticidal activity once the spray application has dried. It is less likely that resistance to insecticidal soaps will develop as quickly as to the more traditional pesticides. Resistance within the insect tends to develop more quickly with materials that have a very specific mode of action. A material that affects the nervous system in a very specific way has a greater chance of developing resistance in a shorter period of time. Insecticidal soaps can be used in rotation with other pesticides with more specific modes of action to help slow the development of resistance.

More information is needed on potential effects on aquatic and other non-target organisms.

Other Row Crop Considerations: Cultural Practices

Cultural practices for row crops vary from that of orchards. Certain practices can affect the amount of pesticides used for controlling pests. Unlike orchard crops, row crops are usually seasonal. The unharvested part of the plant is left in the field to be burned, rototilled, disked, plowed, or flooded to break down the remainder of the plant. It is this leftover part of the plant that often harbors insect pests over the winter. In the past, burning was one of the most prevalent methods used to control pests and fungus that may have formed over the growing season and that can overwinter and affect the following years crop. Air quality regulations and concerns make this type of control rarely feasible. The most common practice is disking which breaks up plant matter and mixes it into the ground. This is also effective in killing most overwintering pests if done properly and in recommended time increments.

Fields surrounding crops must also be watched for pests during the growing period and in the dormant season. During the growing season, populations can build up in host weeds in surrounding fields and migrate in crops. Weeds are often controlled with an herbicide or monitored throughout the growing season to eliminate or reduce this problem. In the dormant season, these weeds can serve as overwintering grounds for pest insects. If there were any extreme outbreaks of pest insects during the previous growing season, treatment of host weeds should be considered to reduce the chance of an outbreak the following year. Row crops are extremely susceptible to damage from certain pest insects immediately after sprouting. To avoid these pests, crops should be planted according to times recommended by local farm bureau.

There are also certain crop-specific considerations. For example, sugarbeet fields are extremely vulnerable to overwintering pest insects due to underdeveloped sugarbeets being left in the ground. This can be reduced either by removing all sugarbeets from the field or periodically plowing the field in the off season to break up any material that might support the insects.

3.5 Alfalfa-specific Field Crop Practices

3.5.1 Introduction

Unlike other row and field crops, alfalfa is a perennial crop. It is usually replanted every one to two years during which time it is harvested from four to six times. Alfalfa fields are often infested by secondary pests after surrounding fields are harvested. These pests usually move in to the crop in the late fall, and dormant applications may be done during this time. Alfalfa is one of the leading commodities in the region. In 1998, it was grown on one million acres of land in California (CDFA, 2001). In the Central Valley, it is harvested about seven to eight times a year, and stands generally last from four to five years (Long *et al.*, draft).

The consistent major economic insect pest to alfalfa, depending on region, are the alfalfa weevil and the Egyptian alfalfa weevil. In the San Joaquin Valley, it is the Egyptian alfalfa weevil. A resistant cultivar has yet to be developed. Retaining beneficials in a field can be successful at controlling aphids and summer worms, but are generally not as helpful in controlling Egyptian alfalfa weevil.

3.5.2 Pest Management Options for Alfalfa

Conventional Pesticide Treatment

The organophosphorus compounds, chlorpyrifos, phosmet, malathion and dimethoate can be applied to control alfalfa pests such as the Egyptian alfalfa weevil. Carbofuran and pyrethroids can also be applied. Early spring sprays, usually applied in February, March or sometimes early April, are conducted to control this pest. UCIPM guidelines provide thresholds and additional guidelines if application is necessary. Chlorpyrifos is rated as having a relatively high toxicity to general predators and parasites of alfalfa pests and larval and adult honeybees. If chlorpyrifos is to be used, care should be taken to avoid spraying of weak areas of alfalfa fields since this would result in more material being deposited on the ground, thereby increasing the potential for movement offsite. While pyrethroids are another alternative for some pests and may potentially have less impact on water quality due to their low water solubility, they may cause aphid outbreaks resulting from a reduction in beneficial insect populations. It is also highly toxic to fish so that extreme caution should be used when spraying near waterways.

A study by Long *et al*. (draft) suggests pyrethroid may be a viable option since field level studies showed that no toxicity was associated with tailwater samples collected from alfalfa fields. Additionally, no pyrethroid residues were detected in the samples at a detection limit of 50 ng/L. Alfalfa's deep root system helps reduce offsite movement of soil and its vigorous canopy prevents soil from being blown off. The Long *et al.* (draft) data on total suspended solids showed higher particulate levels in some source water samples compared to tailwater samples, suggesting that alfalfa may trap sediments. While this may be a viable alternative for alfalfa, the same advantages may not necessarily be applicable to other crops, particularly if much sediment is transported in the tailwater (R. Long, pers. comm.).

Bt

Some alfalfa pests can be controlled using Bt. Bt has relatively low toxicity to general predators and parasites and honeybees. It can be used to control certain pests without affecting beneficial insects and does not leave undesirable residue in hay. For some pests, this can be used as an alternative pesticide with less potential impact on water quality.

Cutting practices

The timing of cuttings may have an effect on the level of damage, and the necessity for chemical treatment. Certain cutting practices have also been identified as having the potential for maintaining populations of beneficials. Natural enemies, such as parasites, predators, and disease-causing microorganisms, can have an impact in controlling crop pests and in preventing pests from increasing to levels resulting in economic damage. Alfalfa fields can serve as reservoirs for natural enemies of crop pests. In the case of the Egyptian alfalfa weevil, beneficials alone may not be effective in controlling the pest.

- Strip cutting: in addition to maintaining populations of predators and parasites of alfalfa pests within the fields, this method of harvesting alfalfa by cutting alternate strips can also reduce the migration of lygus bug into cotton and other crops.
- Staggering the cutting of adjacent hay fields: Encourages migration of lygus bugs and other natural enemies from cut to uncut fields.
- Alternating irrigation and cutting cycles for large fields
- Border cutting: leaving 10 foot uncut hay strips on alternate irrigation levees/borders so that uncut strips are cut at the next harvest, and previously cut strips are left; can be done when strip cutting is impractical

Overseeding in weak stands

Overseeding in the fall with berseem clover (annual clover), oats, or grass in weak stands with exposed bare soil will help prevent soil from being blown away by wind and will increase infiltration. The overseeded crop fills in and make up for a loss in alfalfa production due to feeding damage by weevils, negating the need for a weevil spray. While this practice will not necessarily prevent damage from pests, it can help in maintaining yield. Weevils will not feed on interseeded crops. The key limitation is that this tends only to be appropriate during the last period (e.g. the last year of production). Another consideration is that this crop competes with the alfalfa crop. Overseeding and companion cropping is discussed in more detail in Canevari *et al*. (2000).

4.0 VEGETATION MANAGEMENT

4.1 Introduction

Various vegetation management practices have the potential to reduce pesticide runoff by increasing soil infiltration, accelerating pesticide degradation at the soil surface and preventing the offsite movement of soil, nutrient, and pesticides during winter storm events. The management practices discussed in this section include the use of different types of cover crops and buffers, as well as the practice of reducing herbicide-treated berm areas.

4.2 Types of Vegetation Management Practices

4.2.1 Cover Crops

Description

Cover crops are forbs and grasses planted in a field or orchard to cover the soil. Cover crops are not usually harvested for sale, but can provide several important functions:

- anchor the soil during winter rains to prevent soil, nutrient, and pesticide runoff,
- accelerate biodegradation of pesticides at the soil surface,
- improve water infiltration and soil structure,
- provide nitrogen (legumes),
- add organic material to the soil,
- help control weeds,
- improve field access during wet weather, and
- provide nectar and habitat for beneficial insects.

Cover crops can reduce pesticide runoff because pesticide fallout is adsorbed to plant surfaces more strongly than to bare soil, pesticide persistence on plant surfaces is shorter than on or in soil, and because cover crops slow or prevent the off-site movement of water and sediment carrying pesticides. (Ross *et al*., 1997).

Disadvantages of cover crops include:

- vegetation and debris interfere with sweep nut harvesting methods,
- increased habitat and reduced predation for gophers, ground squirrels and mice,
- potential for increased fungal diseases due to increased humidity and decreased air circulation,
- increase nematode populations with summer-grown cover crop;
- increased water use, sprinklers blocked by climbing vines, and
- competition with crops for visits by pollinators.

Tall, dense cover crops can reduce nighttime temperatures by as much as 5 or 6 degrees F, increasing the potential for frost damage. However, orchards with closely mowed cover crops and moist soil may be only about 1 degree F colder than bare soil. Alternate row cover cropping can reduce the difference even more. If mowing is performed before bloom, the risk of frost damage can be reduced (Thomas, 2000). Mowing cover crops to a 3 to 4-inch height at the beginning of the frost season can reduce cold temperature damage to orchards. Mowing at appropriate intervals can allow adequate seed production by annual species.

There are many types of cover crops, but they can be considered in two main groups: resident vegetation and seeded cover crops.

Resident Vegetation

Resident vegetation is vegetation already existing in the field, or vegetation that is allowed to invade the field without planting or seeding. It is comprised of both native and non-native plants. Native vegetation often encountered in Central Valley orchards are miners' lettuce and redmaids. Introduced naturalized species include annual sowthistle, burr medic, cheeseweed, common chickweed, common knotweed, filaree, foxtail fescue, henbit, Italian (or annual) ryegrass, mayweed, pineapple weed, prostrate spurge, wild barley and wild oat. Perennial resident vegetation includes field bindweed, Bermuda grass, nutsedge, water grass, and Johnsongrass (Bugg *et al*., 1994).

Resident vegetation does not have to be planted, is adapted to site conditions, tends to have high diversity and harborage for beneficial insects, and can be managed for desirable species by proper mowing, cultivation, fertilization, herbicide use, and other cultural practices. Disadvantages of resident vegetation include: low biomass and nitrogen production, unpredictable seasonal water and nutrient demand, unpredictable response to management such as mowing and cultivation, and harborage of pest insects.

Seeded Cover Crops

Seeded cover crops may include legumes (cowpeas, clover, medics, and vetches), as well as grasses such as cereal grains, turf grasses, and Sudan grass. Planted cover crops offer predictable performance under a given environment and management regime. A seeded cover crop can be specifically selected for the crop and the site. However, cover crops cost money to establish and may need more management than resident vegetation. Seeded cover crops may also suppress resident vegetation and lead to decreased biodiversity. Seeded cover crops may either be annual or perennial, and may or may not be disked in as green manure. These types are described below.

<u>Annuals</u>

Large-seeded winter-annual cover crops include monocultures or mixtures of cereal grains (oat, barley, cereal rye) and legumes (vetches, bell bean, field pea). Small-seeded winter-annual cover crops include monocultures or mixtures of forage grasses (soft chess, foxtail fescue), medics, and clovers (crimson clover, Persian clover, rose clover, subterranean clover). Large-seeded winter-annual cover crops are not usually managed for self-reseeding, while small-seeded winter-annual cover crops are. Large-seeded mixtures permit more rapid stand establishment in the face of low temperatures and deep shade (e.g. in walnut orchards, where late harvest necessitates late seeding), larger-seeded species typically have greater seedling vigor to overcome soil crusting, herbivory by slugs, and competition by weedy winter-annual grasses, all of which are greater obstacles to legume establishment once the weather turns cold. Plants in small-seeded mixtures are typically lower growing and are more easily manageable by mowing. Small-seeded mixtures also interfere less with vehicular and foot traffic. Clover-dominated small-seeded mixtures support higher densities of pocket gopher than vetch-dominated stands. Some winter-annual cover crops include both small- and large-seeded, and are typically chosen for cool season activity to avoid competition.

Perennials

Most perennials are not suited for almond or walnut orchards because they interfere with the shake-and-sweep harvesting technique used by producers in California. In peach or prune orchards, cover crop options include small-seeded, low-stature, non-native grasses and legumes (creeping red fescue, tall fescue, chewing's fescue, perennial ryegrass, sheep fescue and white clover); and small-seeded, low-statured native grasses (creeping red fescue, Idaho fescue, pine bluegrass, California barley). The native grass option costs about five times more than non-native grass, making it unfeasible in low profit margin crops such as prunes. Perennial grass stands require supplemental nitrogen, as much as 25-50 lbs. of nitrogen per acre more than in conventional orchard management.

Green Manure Crops

Green manure crops are a type of cover crop usually grown in the interval between main crops. Green manure crops are disked under to add organic material and improve soil fertility and tilth. The crop is usually disked in when the plants are in full-bloom to post-bloom stage, depending on condition of the target crop, weather and soil moisture conditions. The species used should decompose rapidly and not interfere with the next crop.

Crop-Specific Considerations

In orchard crops, tree rows are generally kept weed free with herbicides or other means to minimize competition and allow soil warming. Almonds and walnuts require a bare orchard floor at harvest, which may prevent growers from using cover crops. However, growing a legume cover crop mix that can be mowed then allowed to decompose during the summer will prevent plant residues from causing problems during harvest. The debris at harvest is most often from summer grasses.

By comparison, most stone fruit orchards (apricots, cherries, peaches, plums, etc.) can support a perennial crop of grasses or even legumes. Cover crops must complement the IPM program used for the crop.

Pending Research

CALFED is funding research by the University of California Integrated Pest Management/Water Quality Team to monitor runoff and develop a hydrologic model for orchards with a variety of orchard floor and pest management practices. The orchard floor practices include bare ground, perennial grass, annual clover, resident vegetation, and ripped resident vegetation (pulling vertical shanks through the soil to open up crevices that allow water infiltration). The pest management treatments include diazinon and pyrethroid (Asana) applications.

The Glenn County Surface Water Stewardship Program (GCSWS), in conjunction with California State University, Chico, the NRCS, and the California Dried Plum Board is studying pesticide runoff in farm cover crop and filter strip trials with ten cover crops at an orchard in Artois.

The Colusa County Resource Conservation District, funded by a Clean Water Act (CWA) §319(h) grant, studied diazinon runoff for three years (1996 through 1999) after the establishment of cover crops. The study was funded from 1996 through 1999. The "Conservation Buffers Section" (below) describes this project and other work being conducted with CALFED funding.

California State University, Chico (CSUC) is conducting several studies on cover crops and filter strips using a range of replicated and demonstration plots. Cover crops and their associated economic crops include annual clovers in almonds, perennial sods in prunes, insectary shrubs in orchards, and studies on nutrients and soil amendments.

Specific studies and their current status are as follows:

-Forty acres of almonds planted in Chico in 1992 with five replications of resident vegetation, including annual bluegrass, Malva, filaree, and annual clovers (planted by Dick Jacobs, CSU, Chico; supervised by Joe Connell, UCCE Farm Advisor for Almonds). The plots exist but is currently not maintained.
-A demonstration planting of 100 cover crops was established in 2000 to provide landowners and researchers with basic information about cover crops and filter strips. Dr. Rich Rosecrance, CSU Chico Agriculture, maintains this plot which was established again 2001 and has been used for training at meetings.
-A couple of studies were discontinued after orchard sale or removal. An evaluation of the effects of potassium, compost, and vetch cover crop on potassium uptake in an orchard in Chico, a study sponsored by the California Department of Food and Agriculture's Fertilizer Research and Education Program (FREP), was conducted by Pat Delwiche and Rich Rosecrance, CSU, Chico Agriculture. The study ended when the orchard was sold. A comparison of resident vegetation (burclover, annual ryegrass, filaree, morning glory), perennial ryegrass, and drought-hardy hard fescue, was conducted in 1999 by the California Dried Plum Board and the USDA NRCS. This replicated plot was removed in its second year when the orchard was removed. No data was taken.

Most of these studies are designed to evaluate the agronomic qualities of the cover crops, rather than their ability to reduce offsite movement of pesticides. However, as these cover crops and filter strips become established, sites that are retained can provide opportunities for future studies of pesticide fate and transport.

Data Gaps

More cover crop research is needed to evaluate:

-Cover crop species that maximize infiltration and minimize runoff in specific soil types,
-The potential for cover crops to vector or exacerbate plant diseases,
-The effect of the phenolyic compounds that sequester chemicals on the plant surfaces, and
-The effectiveness of soils high in organic matter or with a top layer of organic litter in degrading pesticides.

4.2.2 Buffers

Description

Buffers are areas of land located along field edges that are maintained in permanent vegetation. The vegetation and soil buildup in buffers slow water movement and increase infiltration. By slowing its movement, field runoff is more likely to infiltrate into soil, carrying with it dissolved pesticides and nutrients. Properly designed buffers also trap sediment, thereby reducing the offsite movement of pesticides adsorbed to soil particles. Pesticides that infiltrate into the upper soil layer or are trapped by vegetation and plant debris can then be degraded by microbes residing in soil and organic matter.

Many buffer studies have demonstrated pesticide trapping efficacy of 50% or more, provided that runoff flows evenly, as sheet flow. If runoff is channeled by furrows, gaps, or sediment buildup in buffers, it forms a faster-moving concentrated flow, and pesticides don’t have sufficient contact with microbes to degrade before being carried into surface water. Over time, trapped sediment can change buffer profiles, increasing concentrated flow. Buffers require maintenance, such as periodic leveling or reshaping, to maintain their function (NRCS, 2000).

Buffers can also produce additional environmental benefits such as habitat and food for beneficial insects and wildlife, windbreaks, pesticide drift barriers, and stream bank protection. Types of buffers include filter strips, hedgerows, riparian strips, vegetated waterways, and constructed wetlands,. Many of these types of buffer strips can be used in combination to provide a full range of benefits. Many of these buffer strips can also include cover crops, and the cover crop information provided above would apply to these buffer strips, as well.

The types of vegetation used for buffer strips must be considered carefully. Certain species can harbor pest insects. Some also may attract endangered species, especially when native vegetation is used. Safe Harbor Agreements are available to protect growers if the farming practices they use attract endangered species, but growers should inform themselves about these agreements before choosing vegetation to use in buffer areas.

Filter Strips

Filter strips are sections of low growing, permanent vegetation, such as grass or clover sod, used to slow field runoff. Slowing runoff increases water infiltration and causes sediments to drop out of suspension. Filter strip vegetation also traps sediment and its associated pesticide residues.

Runoff does not usually enter waterbodies in uniform sheet flow along the bank, but in small areas of concentrated flow. If runoff is channelized into concentrated flow by topography or vegetation in the field, a narrow grass or sod strip may not be able to trap the pesticides effectively. Other management practices, such as those described below (BMPs for Water Quality, Conservation Technology Information Center (CTIC)),would be needed further up the watershed to reduce pesticide load before it reaches surface water,.

Although filter strips are most often located between crop fields and waterbodies, many areas of bare ground in and around crop fields can be planted with grass or clover sod. Grassed roadways can serve as vegetative filter strips, as can sod around and on mixing pads. The area around wellheads can be planted with grass or clover to eliminate spraying for weed control, and to trap spilled pesticides before they reach the wellhead.

Hedgerows

Hedgerows are living fences of shrubs or trees in, across, or around a field. One of the benefits of hedgerows is that they slow or prevent field runoff, thereby increasing infiltration and trapping sediment. Hedgerows are also used to delineate field boundaries, serve as fences or windbreaks, establish contour guidelines, provide wildlife habitat, and improve the landscape. Hedgerows are comprised of an herbaceous understory of grasses and forbs, a shrub midstory of upland or riparian species, and sometimes a discontinuous overstory of trees. This discontinuity reduces shading of adjoining farmlands and crops, but provides habitat and aesthetic benefits.

Hedgerows have much in common with filter strips, described above, and riparian buffers, discussed below. However, hedgerows are not used only as buffers for waterbodies but also between fields and bordering roads, buildings, etc. Hedgerows can be used as part of the landscaping to screen rural homes from agricultural activities, and are particularly useful in blocking pesticide drift and providing food and habitat for wildlife and beneficial insects.
Hedgerows have significant potential to reduce off-site movement of pesticides. Downwind deposition of pesticides can be decreased 60% to 80%, with evergreen species two to four times more effective than broadleaf species (Hall *et al*., 1999).

Hedgerows are also often comprised of a mixture of native plants, such as those that may have grown on the site before it was farmed. For California agricultural areas, the USDA's Resource Conservationists recommend a variety of native grasses, perennial forbs, shrubs, and trees that attract different types of beneficial insects, mammals, reptiles and birds (Yolo County Resource Conservation District, 1999). Native plants work well in hedgerows because they require little care after an establishment period of about three years. Many native species have deep roots that hold soil and increase water permeability.

Because many native species are sensitive to over watering, irrigation methods and site selection must be considered. Another consideration is distance from roads and highly traveled areas. Many of the recommended species can grow 10-15 feet wide, so space must be allowed for equipment to pass. If a goal of the hedgerow is to attract beneficial insects, select plant species with plentiful nectar and pollen. By considering a species' flowering timing, appropriate varieties can be combined in a hedgerow to stagger flowering times, ensuring flowering during key times when beneficial insects are looking for pollen and nectar, typically in late spring and early fall when crops are being planted or harvested.

Riparian Buffers

Riparian buffers are areas of trees and shrubs located adjacent to streams, lakes, ponds and wetlands. The tall, woody vegetation provides food and cover for wildlife, helps lower water temperatures by shading the waterbody, protects stream banks, and slows flood flows. Deep tree roots take up nitrate entering streams, and provide surface area and a carbon source for microbes that degrade pesticides. Riparian buffers frequently include perennial grasses and forbs as an understory that helps stabilize surface soil and provides the benefits described above for filter strips.

Vegetated Waterways

Vegetated waterways are natural or constructed channels located in areas of concentrated runoff and planted in low-growing, permanent vegetation, such as grass sod. These channels are graded to carry runoff slowly enough to prevent erosion, and deposit it where the concentrated flow can spread over and infiltrate a vegetated area. This combination prevents gully erosion and traps sediment, nutrients, and pesticides. Properly designed, vegetated waterways can also provide wildlife habitat and food, particularly where flows are intermittent.

Constructed Wetlands

Constructed wetlands are useful in areas where field drainage tiles deliver subsurface drainage directly to surface water. Wetlands constructed at tile outlets or as part of riparian buffer systems can effectively degrade pesticides and denitrify nitrate.

Pending Research

In 2000, the Glenn County Surface Water Stewardship Program, in conjunction with the CSUC Agriculture and Geosciences Department, began a filter/buffer strip study at an Orland almond ranch to determine the surface and subsurface movement of diazinon. Another site was also established to determine the persistence and efficacy of seven species for orchard filter strips. (Glenn Co. Surface Water Stewardship Site Tour, May 24, 2001).

The Colusa County Resource Conservation District, with funding from CALFED, is conducting a study of buffer strips vegetated with native grasses, shrubs, and trees buffer strips planted between an almond orchard and a creek. Sediment and diazinon runoff are being monitored.

Data Gaps

Research is needed to evaluate buffers and optimize buffer design for pesticide runoff under California conditions. Research needs include, but are not limited to:

- Most effective buffer dimensions to use for specific runoff range,
- Most appropriate plant species and plant density for soil type and rainfall,
- Most effective buffer location,
- Most effective slope and channel dimensions for vegetated waterways, and
- Most effective size, shape, and placement for constructed wetlands.

4.2.3 Reducing Herbicide-treated Berm Areas

Description

The raised, bare berm areas under tree rows in stone fruit orchards are typically sprayed with herbicides at least annually, and sometimes as many as three times per year. Water from rainfall or sprinkler irrigation can run off these areas very quickly, carrying with it dissolved pesticides and pesticides adsorbed to sediment. Bare berm areas often occupy as much as 30% of orchard floors, and keeping this area vegetated could help reduce orchard runoff.

In some crops, harvest is difficult unless the orchard floor is bare, and in these cases an alternative would be to allow resident vegetation to grow during the winter dormant spray season, and then till it in and keep the floor bare until after harvest in the fall.

Other options for managing bare berms:

- Reduce all strip spray widths by 25%,
- Eliminate pre-emergent herbicides,
- Apply dormant sprays after vegetation covers the berm in January/February,
- Leave outside tree rows unsprayed to maintain a vegetated barrier around the orchard, and
- Apply herbicides to a five-foot block around trees; leave vegetation on remainder of berm.

Crop-Specific Considerations

Producing almonds in some areas would be difficult without an herbicide strip since almonds limbs (and the harvestable crop) can become tangled in vegetation on the berm.

5.0 WATER MANAGEMENT

5.1 Introduction

Water management practices can help reduce the amount of pesticide in surface runoff through the reduction and management of runoff, reduction of erosion, and trapping of sediment to which pesticides may be adsorbed. The aspects of water management discussed are water application, drainage system management and irrigation system selection. Most of the discussion that follows applies to irrigation season pesticide use but may be useful for dormant season applications, as indicated.

5.2 Water Application (Irrigation Efficiency)

In addition to irrigation efficiency, water application can have the potential to reduce the amount of runoff from a field, and possibly, by extension the amount OP that moves offsite with irrigation or stormwater. The following discussion includes improved water application, including controlled irrigation during the dormant season, irrigation water additives, and irrigation water storage. The CALFED Program's Water Use Efficiency is also discussed.

5.2.1 Improved Water Application

Improved water application has the potential to reduce pesticide runoff by reducing or eliminating the amount of water that runs off a field. Several systems can be put in place for water control and efficient water application. This could include measuring devices, division boxes, checks, turnouts, valves and gates for control, regulation and measurement of water.

Water application can include changes in volume of water applied for increased irrigation efficiency. Such changes can include :

- reduction in volume of water applied to refill the crop root zone
- change in the amount, rate or timing of water being applied to the crop that leads to improved efficiency and no loss of crop production
- reduction of erosion caused by irrigation
- increased distribution uniformity of applied water
- changes in stream size to compensate for changes in intake rates
- installation of one or more structural components that improve irrigation efficiency

During the dormant season, applying a controlled amount of irrigation water to an orchard could carry pesticide that has been deposited on the orchard floor into the soil profile, where it can decompose before a heavier rainfall washes it off the orchard floor and into surface water.

CALFED

The CALFED Program's Water Use Efficiency component attempts to increase agricultural water use efficiency through on-farm improvements. The major focus of the CALFED program is an increase in the Distribution Uniformity (DU) of irrigation. The DU is the uniformity of irrigation water distribution to a field. Irrigation experts maintain that current practices limit the DU to 0.8, which means that 80% of the field irrigated to desired depth while 20% is not. Because of the relationship between irrigation efficiency and DU, an increase in efficiency is unlikely without a corresponding increase in DU.

An increase of the DU to a range of 0.8 to 0.9 will result in a marked improvement of water use efficiency. Data analysis indicates that a DU increase to this level will result in a reduction of applied water by 8 to12%. Despite the reduction in water applied, crop water requirements are still met and beneficial uses such as leaching are maintained. This reduction will not result in a reduction in crop water requirement or beneficial uses. This increase in DU can be achieved through advances in design and manufacturing of irrigation equipment along with increased awareness and implementation of irrigation system maintenance.

A reduction of applied water can reduce the potential for runoff and the corresponding movement of pesticides from agricultural fields to natural waterways. Under the CALFED program, advances in DU and water use efficiency can be achieved while still maintaining optimum crop production.

5.2.2 Irrigation Erosion Control/Irrigation Water Additives

Addition of irrigation water additives such as polyacrylamide (PAM), gypsum, and humic acid may have the potential for reducing pesticides in the tailwater by increasing infiltration during irrigation events, and reducing the amount of pesticides that may be associated with particulates by reducing erosion and promoting the aggregation of dispersed soil colloids. These water additives are primarily added to irrigation water for erosion control and/or improved water infiltration.

Based on a study by Havens *et al*. (1999), only PAM is discussed below as this was the additive that showed the most promise in reducing the amount of chlorpyrifos in tailwater. Other additives examined in the study included humic acid, gypsum and an enzyme additive treatment were also considered. PAM and careful water management was shown to have the most promise for reducing chlorpyrifos residues in the tailwater.

Polyacrylamide (PAM)

The addition of polyacrylamide (PAM) to irrigation water may reduce pesticide runoff by controlling irrigation-induced erosion and increasing soil infiltration. PAM is a polymer composed of many subunits of acrylamide molecules, which are linked to identical copies of itself to form long chain-like molecules. PAM is synthesized from natural gas and was originally developed in the 1940s and 1950s for use as a soil conditioner. PAM is a generic term. There are actually many different types of PAM, varying in length and iconicity of the polymer chain.

PAM is added to irrigation water during the advance phase of the first irrigation and each irrigation following a soil disturbance. Turbulent mixing is required to achieve uniform distribution. Tailwater containing PAM should be used on other fields or stored for future irrigation. There are several considerations that should be taken into account when using this substance. PAM is a flocculating agent that can cause deposition in canals, laterals, head ditches, pipelines, furrows or other locations where it comes in contact with sediment-laden water. Downstream deposition from the use of PAM may require frequent cleaning to maintain normal functions. PAM affects advance rates and would vary rates greatly between hard row (wheel-packed rows) and soft rows. Since generally, infiltration increases when used, stream size may need to be increased. The concentration may also have to be reduced based on soils, slope and stream size. PAM should not be applied to peat soil or where irrigation waters exceed a sodium adsorption ration (SAR) of 15. PAM must be anionic and meet EPA and FDA acrylamide monomer limits and applied according to labeling.

Bahr and Stieber (1996) examined the effects of PAM on nutrients, sediments, and pesticides in irrigation water. They found that application reduced sediment loss, increased infiltration, reduced the concentrations of N and P leaving the furrows, and reduced pesticide concentration in tailwater; pesticide analyses included chlorpyrifos. Additional research work relating to PAM can be found on the USDA/ARS website[7]. Note that there is limited toxicological data on effects of PAM on aquatic organisms.

5.2.3 Irrigation Water Storage/Regulating Reservoirs

Water application irrigation efficiency can also be affected by the type of structures used to control the application of water either via storage reservoirs or control structures to regulate water flow. Proper use of combinations of these structures as part of irrigation management can have the potential to reduce runoff from the field. Two examples of irrigation water storage, irrigation pits and irrigation regulating reservoirs, are discussed below. Both provide for improved management of irrigation water and can provide storage for reuse irrigation systems.

Irrigation Pit

An irrigation pit is a small storage reservoir constructed to regulate or store a supply of water for irrigation. Its purpose is to collect and store water until it can be used beneficially to satisfy crop irrigation requirements. Open pits excavated below ground surface intercept or store surface water or unconfined groundwater for irrigation. The usable capacity of the pit must be sufficient to satisfy irrigation requirements throughout the growing season of the crop or crops being irrigated.

Irrigation Regulating Reservoir

An irrigation regulating reservoir is a small storage reservoir constructed to regulate or store a supply of water for irrigation. Reservoirs are created by impounding structures and pits excavated below the ground surface for short-period storage of either diverted surface water, water from pumped or flowing wells, or water from an irrigation delivery system. Regulating reservoirs can also be created by earth embankments or steel and concrete regulating reservoirs used for collecting water from irrigation wells for application with sprinkler or drip systems.

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[7]More information relating to PAM and PAM research can be found at http://nps.ars.usda.gov.

5.3 Drainage System Management

Some drainage management practices may have the potential to trap sediment and adsorbed pesticides and may have the potential to reduce and manage runoff. The practices discussed below are primarily applicable to the irrigation season but may have some applicability to the dormant season. Seasonal applicability is noted within the discussion.

5.3.1 Berms

Raised berms at low ends of fields could trap sediment and adsorbed pesticides, and reduce runoff of dissolved substances in fields with low slopes and sandy soil types by holding water, increasing runoff retention and allowing for infiltration. This is potentially applicable for both dormant and irrigation seasons. During the dormant season, berms also may be useful in areas with lower rainfall by reducing the amount discharged into surface water or providing for an increased time during which water is held, which may result in increased infiltration and/or increased time for pesticide breakdown prior to release into surface water.

5.3.2 Water and Sediment Control Basins

Water and sediment control basins can be used to form a sediment trap and water detention basin. Their purpose is to reduce erosion, trap sediment and pesticides adsorbed to soil particles, reduce and manage runoff, change the flow of nutrients and pesticides, and improve water quality. The control basin can be an earth embankment or a combination ridge and channel. It is generally constructed across the slope and the minor watercourses to form a sediment trap and water detention basin. The basins serve to increase residence time by temporarily storing runoff on-site. The basin releases water slowly, through infiltration or a pipe outlet and tile line. The increased residence time allows suspended particles to settle out, resulting in better water quality. Water and sediment control basins are applicable to both dormant and irrigation seasons.

The SRWP (2000) practices document notes that for many orchards in California, given the rainfall patterns, basins would not be viable for individual growers to implement because of the basin size that would be required to manage the volumes of water typically observed. It was suggested that this practice may be appropriate for community level implementation, where a given basin could serve a given area and multiple farms. It should be noted that the precipitation levels in the San Joaquin watershed are significantly less relative to the Sacramento. Further evaluation would be needed to determine this practice' applicability for use in the San Joaquin watershed.

5.3.3 Tailwater Recovery Systems

Tailwater recovery refers to the practice of collecting, storing and transporting irrigation tailwater for reuse in an irrigation distribution system. These systems are suitable for use on sloping lands with surface irrigation systems or for use in areas where there is recoverable irrigation runoff flow or where such flows can be expected under the management practices used.

Tailwater recovery systems require a sump or pit to store the collected tailwater and return facilities such as pipelines or lined and unlined ditches. Sump sizes vary depending on the amount of water control desired. Small sumps with frequently cycling pumping plants may be sufficient if tailwater discharges into an irrigation regulation reservoir or into a pipeline where flow is controlled by a valve. Tailwater sumps large enough to provide the regulation needed to permit efficient water use are necessary for systems without facilities for regulating fluctuating flow. Sumps must be equipped with inlets designed to protect the side slopes and the collection facilities from erosion. A dike or ditch may be necessary to limit the entrance of surface water to the inlet, and the use of sediment traps also may be necessary.

Return facilities are necessary for the conveyance of tailwater from the storage sump to the point of re-entry into the irrigation system. These facilities may consist of a pump and pipeline to return the water to the upper end of the field, or they may consist of a gravity outlet having a ditch or pipeline to convey the water to a lower section of the farm irrigation system.

The Yolo County Resource Conservation District is currently conducting a monitoring study to measure the effects of tailwater return systems on constituents such as sediment and nutrients (P. Robins, pers. comm.). Samples are currently not being monitored for pesticides. The effects of tailwater return systems on pesticides levels in select fields in the San Joaquin watershed was to be monitored as part of a CALFED grant proposal submitted by CURES in 2001. Unfortunately, funding was not received for this project.

Examples of types of some types of tailwater systems are discussed below.

Quick cycling tailwater systems

Quick cycling tailwater systems or "sump/pump" are small tailwater systems that are more common in orchards where, due to high land and crop value, a grower may be reluctant to take land out of production to build a large storage reservoir. These systems eliminate farm runoff but may compromise distribution uniformity due to lower than optimum initial furrow onflow rate. Water may also be lost to deep percolation at the upper end of the field.

Dedicated tailwater system with reservoir on each field

In this type of system, the reservoir is located at the lowest part of the field, and gravity is used to facilitate the movement of tailwater from the collection ditch to the reservoir. A return pipeline is used to convey the water back into the irrigation supply where it drops into a stand pipe. Runoff from the previous irrigation set is used to augment the principal water supply during the furrow advance phase. After the water reaches the end of the furrows, the tailwater reservoir pump is shut off providing for an irrigation cut-back flow into the furrow set.

Sequencing

This system consists of a series of fields with a collector ditch and reservoir located at the lower end of each. The reservoir must be large enough to meet the varying demands of the crops and soils downslope.

Common Reservoir

In a common reservoir system, a number of fields drain into a common and very large reservoir. An extensive collection ditch and return pipeline network supplies the reservoir and returns the water to the irrigation supplies.

Tailwater system in conjunction with a regulating reservoir

A large earthen tailwater irrigating reservoir is located at the highest corner of the field and is built above field level to facilitate gravity flow to the head ditch.

5.3.4 Vegetated Drainage Ditches

Drainage system management is an approach which seeks to increase the filtration effects of the drainage system. Increased filtration removes sediments, nutrients, and pesticides from the water, resulting in increased water quality downstream. One method of increasing filtration is through the use of vegetated drainage ditches.

Vegetated drainage ditches can be incorporated into a management program to help mitigate offsite movement of pesticides with storm runoff. This involves using drainage systems that are a part of existing agricultural landscape features. The USDA Agricultural Research Service National Sedimentation Laboratory has initiated study in this area (Moore *et al*., 2000). Interest arose from edge-of-field constructed wetland studies at the Laboratory for the mitigation of atrazine, metolachlor and chlorpyrifos storm runoff and the recognition that many in-place agricultural drainage ditches are similar in length and design to suggested constructed wetland buffers.

While no reference was found suggesting how drainage ditches affect OP runoff, a study by Moore *et al.* (2000) evaluated the effect of drainage ditches on runoff of an herbicide, atrazine and a pyrethroid pesticide, lambda cyhalothrin, after a simulated storm.   For both types of pesticides studied, use of a drainage ditch reduced the amount of pesticides to levels that produced no noticeable toxicological effects. Over the course of the study, the pesticides were found to be associated with plant material and sediment in the drainage ditch, and aqueous concentrations of both pesticides was mitigated using a 50 meter length of agricultural drainage ditch.

5.3.5 Grassed Waterways and Constructed Wetlands

These also are a means of managing water, but following the NRCS approach in categorizing practices, they are addressed as part of the discussion on buffers in Section 4.

5.4 Irrigation Systems Selections

The type of irrigation system chosen is the result of many factors including crop type, topography, water supply, soil type, system capabilities and cost. The irrigation system used can determine the potential for surface runoff and by inference, the amount of pesticide running off a field. The main types of irrigation systems to be discussed are subdivided into three categories: surface, sprinkler and microirrigation. In general, surface irrigation has the most potential for runoff, and in fact, some forms of surface irrigation require runoff to achieve uniform distribution. Structures (such as tailwater recovery systems discussed above) can be put in place to increase efficiency and reduce runoff. Usually little to no runoff is associated with sprinkler and microirrigation systems. This section defines the most common irrigation systems. The advantages, disadvantages and additional considerations for each category are included. Irrigation scheduling for each system is briefly discussed in the final portion of this section. Most of the information summarized below comes from Burt *et al.* (1999).

5.4.1 Surface Irrigation

Description

A large group of irrigation methods falls under the classification of surface irrigation. This method relies on soil as the transportation medium while water is distributed over the surface of the field by gravity. The two basic categories of surface irrigation are "ponded" and "moving water." Some runoff is required in "moving water" methods in order to ensure adequate infiltration at the lower end of the field. Tailwater return flow systems can be used in conjunction with surface irrigation to prevent runoff from farms (tailwater recovery is discussed in Section 5).

Typically, water enters the field at a high point or at the edge of a field and covers the field through overland flow. Soil type is important for this method since the depth infiltrated over time is determined by soil type. For sprinkler and microirrigation systems, on the other hand, the depth infiltrated is controlled by the application rate. The infiltration and advance characteristics of fields irrigated through surface irrigation changes over time. Because of this, pre-determining management recommendations is difficult or impossible to do. Irrigation control through field management is more important in surface irrigation compared to other mechanized systems where the need for intensive management is replaced by design and equipment (Burt *et al.*, 1999).

The main advantages associated with this type of irrigation are:

- Relatively simple equipment requirements
- Capital Cost: lowest initial capital investment.
- Labor Cost: low labor requirement if systems are flexible, have large flow rate supplies and tailwater return systems for sloping methods.
- Water Source: silty and dirty water can be used.
- Irrigation Efficiency and Uniformity: with the right combination of soil, land grading, management, variable flow rate supply and tailwater return systems, high efficiencies and uniformity can be achieved.

The main disadvantages associated with this type of irrigation are:

- Management Limitations: requires the most “art” in order to attain high application efficiencies and distribution uniformities.
- Soil Differences: within-field soil differences will greatly affect the distribution uniformity.
- Irrigation Scheduling: requires excellent historical records on each field.
- Land Grading Limitations: excellent land grading is required for some of the methods. This is difficult to achieve in small fields.

Basin Irrigation

Basin irrigation is defined as the application of water to a completely level area that is enclosed by borders or dikes. It is also known as check flooding, level borders, check irrigation, check-basin irrigation, dead-level irrigation or level-basin irrigation. Variations of this method include flat-planted basins that can be ridged, channeled or furrowed, bedded or furrowed basins, and fill and drain. The advantages associated with this method are the ease of operation, simple equipment requirements, low labor requirements, and the use of large fixed rate streams. The basin length is limited by soil type. In soils with very coarse textures, the basin length limit is 330 feet. The length limit for other types of soil is 1320 feet. Because the soil surface is flooded in this method, crusting of the soil surface may occur. This method is ideal for salt leaching.

Crop limitations associated with basin irrigation often result from soil limitations. In general, basin irrigation can be used for both field and row crops and is also used on trees and vines. The method variations are flat planted or bedded (i.e. ridged, channeled, furrowed) basins. Trees and vines can either be flat-planted or bedded. Bedded basins are usually used with row crops requiring light applications of water, where inundation should be avoided, and where control of moisture within the bed is needed. Vegetables such as melons, cotton, potatoes, corn, sugar beets and other row crops are often planted using narrow ridges to wide beds. Uniform wetting or germination, which may be difficult to achieve in furrows, can be achieved with level beds and small basins. Flat-planting is suited for field and row crops, such as alfalfa, wheat, sorghum, barley, cotton, that are not sensitive to inundation for short periods of time. This method helps eliminate salinity problems and helps with heavy water applications. If managed correctly, these methods result in no runoff. However, care should be taken so no crop damage occurs from excessive overapplication or excess rainfall.

Border Strip Irrigation

Border strip irrigation is considered to be the most complicated of irrigation methods, having a high potential for application efficiency that is rarely attained. In this type of irrigation, a sloping strip of land that is level across the strip is bounded by borders, such as dikes, levees or ridges that prevent the lateral spread of water. Water is started at the upper end of the strip and allowed to advance down the strip before being turned off. The recession front is the area where standing water has soaked into the soil, moving down the strip with time.

Border strips can be contoured, graded or guided. Contour strips go across the slope with a slight downslope longitudinal gradient and are usually narrow and form small benches at each border. Graded border strips are the most common form of border strips. These strips are graded, usually using laser guided equipment, to a uniform slope lengthwise and are usually level at right angles to the flow direction. Guided border strips are narrow strips that run downslope and are generally used on shallow soils and non-uniform topography. These are managed more like furrows than border strips since their recession curves are unique.

While it is, in theory, possible to attain high irrigation efficiency with this method, it is hard to achieve in practice. A runoff return flow system may need to be included in order for higher efficiency to be attained. In general, the upper and lower ends of the strip tend to be under-irrigated relative to the middle part. It is possible to have only a small amount of runoff, approximately 10%. This method is not suitable for salt leaching.

Although this method can be used on a variety of crops, it is most suited for pasture alfalfa, orchards, vineyards and other crops with constant soil moisture deficit (MAD)[8] requirements. Annual crops, which have changing root zones and allowable soil moisture deficiencies, can be irrigated with this method but the application method is compromised or supplemental supply lines should be used to account for changes in soil moisture deficit (SMD)[9] and duration of irrigation during the season. Considerations that

[8] MAD (Management Allowed Deficit): defined as the desired soil moisture deficit at the time of irrigation; this value relates to the optimum allowable soil moisture stress for the crop-soil-water-weather system (Merriam, 1966)

[9] SMD (Soil Moisture Deficit): defined as the difference in the depth of water actually stored in the crop root zone at any given time and the depth of water stored in that crop root zone at field capacity (Burt, 1999).

should be noted when determining use for specific crops are flooding of the soil surface and crusting, which may inhibit the sprouting of seeds. Additionally, particularly for finer texture soils that remain moist for long periods, wetting of the plant may make plants susceptible to fungi and diseases. Field crops planted in rows such as grain, hay, pasture, flat-planted crops as well as orchards and vineyards can all be irrigated with this method. Note that ponding at the lower end of the blocked-end border strip, which may last for longer than a few hours on fine textured soils, may be detrimental to plants.

Continuous Flood (Basin Paddy)

The continuous flood or basin paddy method is used for level or near-level fields bounded by dikes that retain ponded water continuously, even though water supply may be intermittent or continuous. Continuous flood irrigation works best in soils with low intake rates. Typically for continuously flooded fields, water is applied at a slow continuous rate.

This type of irrigation is used specifically for rice requiring or having the ability to adapt to the saturated soils. The crop is usually flat-planted.

Ponding (Fill and Drain)

Ponding is a continuous flood irrigation method variation, but with the soil surface exposed intermittently. The diked area is filled with water, and water is held until the desired infiltration depth is reached. This method is adapted to slow intake rate soils and poorly graded fields. Runoff is required to drain ponded water from the field. The duration of irrigation is critical for high application efficiency. This type of method is adapted to heavy irrigations. This method may be used for any crop capable of being temporarily inundated for the duration of the irrigation.

Furrow Irrigation

Furrows are defined as sloping channels formed in the soil. Furrow shapes range from the typical "V" to trapezoidal, parabolic, or broad-flat shapes with wetted widths from 0.5 to 2.5 feet or more. Furrow lengths range from 200 to 2000 feet. In furrow irrigation, water infiltrates through the wetted perimeter of the furrow laterally and vertically. Infiltration time is longer at the upper end than at the lower end. The optimal length is determined by intake rates and stream size. Cultural practices result in variable intake rates in furrows. Furrows that are new still have open soil conditions and high intake rates. After the soil settles, the intake rate decreases, resulting in increased advance rates. Intake rates are also lower in wheel rows versus non-wheel rows. In V-furrows, the intake rate at the upper end tends to be greater relative to the lower end. In broad furrows, there is not much difference between the ends since the furrows are level across.

The uniformity and efficiency of this type of irrigation method is very much dependent upon the management. A runoff return flow system may need to be included in order for higher efficiency to be attained. If soil is uniform and well-graded, efficient furrow irrigation can be achieved by (a) tailwater return slow system with a reservoir, (b) short furrows for acceptable advance ratio, and (c) large variable water supply streams. Spills, gate pipes, siphon tubes or cuts in the ditch bank are used to apply water to individual furrows. If a large number of furrows are irrigated simultaneously and the flow rate is fixed and small, it is difficult to achieve desirable advance ratios for uniformity and application efficiency. The use of tailwater runoff systems with furrow management can help increase efficiency.

Tailwater that flows into a collection system reduces the need for irrigation management because irrigators can spend less time ensuring similar advance rates down the furrows. Tailwater return systems designed to provide about 12 hours of buffer storage are easiest to manage. Runoff can be reduced by cutting back the inflow to the furrow (reducing the furrow onflow rate) once water has advanced to the end of the furrow and has run-off for a short time. This can reduce the amount of storage needed for tailwater. When supply water can not be controlled through cutback flows, the mechanical methods of cablegation or surge flow valves can be used. These methods are discussed below.

Cablegation

Cablegation is a mechanized method that can be used in association with furrow irrigation that can, in theory, improve the advance ratios while limiting runoff. It is not often used due to more complex hardware and management requirements. In cablegation, a "plug restrained by a cable released at a constant rate from the upper end, is pushed through a sloping gated pipe by the water pressure behind the plug" (Burt *et al.*, 1999). When water first starts to flow to a furrow, the flow and advance rates are high. New outlets for additional furrows are opened as the plug advances, and the head on the first outlet reduces and the flow rate decreases. A gradually decreasing cutback stream results until the flow stops.

Surge Flow

In surge irrigation, water is turned on and off as it flows down the furrow. Water is allowed to flow down the field a given distance before flow is stopped. Flow is not restarted until the water in the furrow recedes. Flow can be diverted to other parts of the field during the off-times; a second water surge wets both the previously wetted part of the furrow and an additional section of dry soil; flow is stopped again, the water recedes, and restarted. This continues until the water reaches the end of the field. This method allows for a slower infiltration of the water compared to conventional continuous flow irrigation methods.

The advantages of this method over conventional continuous flow methods is a reduction in surface runoff, deep percolation and energy costs. The disadvantages are that close management is required, underirrigation may result due to slowed water infiltration rate, and it is necessary to maintain surge equipment including a gated pipe. Additionally increased runoff may result if not managed properly. The acceptance of this method has been variable across the United States. In California, extensive field trial research was conducted but growers have not widely adapted the method. This is partly due to difficulties in implementing the system. The same benefits can be achieved by using shorter furrows and higher flow rates while using simpler management and hardware relative to surge flow system requirements. This method has been widely applied in areas such as Texas that have high summer rainfall and where farmers have minimal tailwater runoff.

Furrow irrigation may not be suitable for some field crops with cultural practices requiring going through the furrows e.g. field or other crops requiring tractor travel transverse to the furrows. They are well adapted to row crops, orchards and vineyards. Furrows have also been adapted for wide-spaced vine crops like melons or for crops that should not lie on wet soil. The application of water in alternated furrows on either side of a crop row at each irrigation can be used for row crops requiring more frequent but smaller applications. This is not a good option if soils crack since water will move laterally into adjacent dry furrows.

Corrugations

Corrugations are really just a furrow variation that are most adaptable to irregular and/or steeper topography where land grading is not economical or practical. The corrugations are generally more closely spaced, smaller, run straight downhill, and are generally used on smaller fields. Corrugations can be constructed before or after crop establishment. Smaller flow rates are usually used. Modern irrigation practices are more difficult to implement with corrugations.

Contour Ditches (Wild Flood)

Contour ditches are built on the ridges or the contour of the field. Irrigation is done by flooding the field downslope from the ditch. The ditches are generally earthen, and have portable dams and cutouts through the ditch bank through which the water is distributed on to the field. This method is usually used in areas where water is inexpensive or could be unreliable. It has low capital costs, and labor requirements range from high to negligible. A minimal amount to no land grading may be necessary. However, little uniformity of coverage is achieved through this method.

This method is usually used on low value, erosion resistant crop such as grass raised for hay or pasture. The crop goes dormant when water is unavailable. Unless a cover crop is already present, crop establishment may be difficult, requiring high labor and high level of control of the water.

5.4.2 Sprinkler Irrigation

Description

Water delivery in sprinkler irrigation systems is through a pressurized pipe with nozzles, jets or perforated pipes. Sprinkler systems can apply water evenly and can result in better uniformity than surface irrigation. Sprinklers can be used to irrigate most crops, and can generally be used on any topography and most soil types. Soils with very low intake rates (less than 3 mm/hr) will require additional measures either to increase intake or to control runoff by providing uniform surface ponding. Crop height and susceptibility of crops to rot or discoloration are important considerations. Sprinklers keep foliage and branches wet for prolonged periods and may make orchards more susceptible to diseases such as shot hole, powdery mildew and aerial *Phytophthora* (UCIPM, 199b,1985). These systems can also be used for frost protection and fertilizer and herbicide application. Greater energy requirements are necessary compared to surface irrigation, but labor costs are less.

Efficiency varies depending on the system selected, the design and its operation. A sprinkler irrigation system that is well-designed and properly operated will have little to no runoff.
Less water is required to leach salt from the soil using sprinklers than with flooding methods since water will be moving through smaller soil pores in unsaturated conditions. Some filtration of surface water supplies will be necessary to remove debris that could plug orifices.

Some of the main advantages associated with this type of system are:

- Irrigation Scheduling: since application rate is dictated by the system in place, irrigation scheduling is not complicated
- Management: unlike surface irrigation, management will not be dependent on strategies for obtaining good distribution uniformity. Because components such as nozzle size, pressure and spacing are all fixed by design, what can be managed are maintenance and scheduling.
- Land grading requirements: minimal
- Labor costs: generally low although some systems, such as the hand move system, may be labor intensive.

Some of the main disadvantages associated with this type of system are:

- Energy requirement: more pumping energy may be required compared to either surface or microirrigation.
- Filtration requirement: better source water filtration than surface but less than microirrigation.
- High capital costs.
- Other: If saline water, systems that apply water to leaves may not be suitable.

Hand Move Portable or Lateral Move Portable

This method of irrigation uses sprinklers, nozzles or jets to spray the water delivered through a pressurized pipe into the air. Hand move portable systems have one or more laterals or lateral sections of pipeline with sprinkler heads installed on pipe risers at regular intervals along the pipe. The sprinkler lateral line is portable and can be moved from one locations to another. Pipe lengths generally range from 6, 9 or 12 meters. "The sprinkler lateral is "set" in one location until the desired amount of water has been applied-the lateral line is then disassembled and carried to the next "set." Usually, water is applied at a rate below the soil infiltration rates. The low application rates results in less runoff of standing water. The following are variations of the portable sprinkler irrigation system.

End-tow Lateral

Operation and design of the end-tow lateral is similar to the hand-move system, but the lateral line is moved after a set by towing pipe joints. This system is most suited to square or rectangular fields with more or less uniform topography with close-growing as opposed to row crops.

Side Roll/Wheel Line Systems

The side roll system is a variation of the hand-moved lateral sprinkler line. In this case, the lateral pipeline is mounted on wheels. The wheel height is chosen so that the line clears the crop as the system moves from location to location. A drive unit is used to move the system from one irrigation position to another. This system is best suited to fields having a regular shape and more or less uniform topography and to close-growing crops and low-growing row crops.

Side Move Lateral

The movement of the side move lateral across the field is similar to the side roll system. The wheels are mounted to a structural frame which supports the pipe lateral. The supply pipe does not rotate. This may no longer be in much use. This system is best suited to fields having a regular shape and more or less uniform topography and to close-growing crops and low-growing row crops.

Traveling Gun System and Rotating Boom System

Both the traveling gun system and the rotating boom system are high volume and high pressure, with application rates determined by design, water pressure and rate of advance. The "gun" is a high pressure and high volume sprinkler head that is mounted on a trailer. The water supply is through a flexible hose or an open ditch. The boom sprinkler are pipe arms rotating about a center support system mounted on a trailer. Due to the large droplets and high application rates produced, this system is more suited to coarse soils with high intake rates. Both systems can be used on most crops but are most suited to crops with good ground cover due to the large droplets produced and the high rates of application.

Center Pivot System

A center pivot system uses a sprinkler lateral that rotates around a pivot point located in the center of the irrigated area. A complete revolution of the sprinkler lateral can range from less than a day to several days. A linear move system is similar to a center pivot, but in this case, the ends of the lateral pipeline are not fixed. Movement of the lateral is perpendicular to the field. The disadvantage of a center pivot is since it irrigates in a circle, there are areas in the corners that remain unirrigated. Options for irrigating the corners include using a solid set sprinkler system, drip irrigation or special cornering equipment. The rate of application is dependent upon the length of the lateral. The end of the lateral travels faster and irrigates a larger area the longer the lateral. For longer laterals, a higher water application rate is required at the end to cover the area during one rotation. This may result in runoff, particularly in cases where the system is not designed or operated properly. These systems can irrigate most field crops and are occasionally used to irrigate tree (dwarf orchards) and vine crops.

Linear Move (Lateral Move) System

The linear move system is similar to a center pivot sprinkler system except it uses a self-propelled lateral line. One of its main advantages is that it can cover an entire field in a highly uniform manner and at a lower application rate than the outer ends of center pivots. The types of sprinklers, common on both linear move and center pivot systems are the Low Energy Precision Application (LEPA) and the Low Elevation Spray Application (LESA) sprinklers. These are described briefly below.

LEPA sprinkler (Low Energy Precision Application)

The LEPA system uses drop tubes as low pressure orifice emission devices that discharge water just above the ground surface into a furrow. This reduces losses due to evaporation that is common to sprinkler systems. High efficiency is possible if soil intake rates are high or if furrow microbasins have adequate storage to prevent runoff and non-uniformity. It can be combined with micro-basin land preparation for improved runoff control.

LESA (Low Elevation Spray Application)

LESA systems also employ drop tubes, but have sprayers near the ground. Unlike the LEPA systems which apply water directly to the ground, LESA systems spray water onto the plant canopy. These systems have been used successfully with crops such as onions and potatoes but may not be suitable for taller, closely spaced crops because sprayers may become tangled in the canopy.

Solid Set and Permanent System

A solid set system consists of main lines and laterals that cover an entire irrigated area and stay in place for all or part of the crop's growing season. A "permanent solid set" system is one where the main line and laterals are buried and left in place from season to season. A portable solid set is a system installed on the surface, usually after the crop is planted, and is removed before harvest. Sprinkler risers can be obstacles to farming operations when solid set systems are used on field crops.

Undertree Orchard Sprinkler System

Undertree orchard sprinkler systems are either portable or permanent and can irrigate one to four trees with or without overlap. Some fruits or tree trunks may be more prone to damage or increased disease problems due to wetting. Leaves may also absorb salty water and leaf drop may result. Reduced wetting of foliage and reduced canopy interference can be achieved by using low trajectory angle sprinklers.

5.4.3 Microirrigation

Description

Microirrigation systems allow for the distribution of water directly to plant root zones. It is used for efficient and uniform application of irrigation water and maintenance of soil moisture, and can also be used for the application of chemicals, i.e. chemigation. In this type of irrigation system, runoff is either reduced or eliminated and deep percolation is reduced. The need to over-irrigate to compensate for uneven application of water is eliminated.

The main classifications of microirrigation systems are surface or subsurface drip irrigation and microspray or microsprinkler systems. The surface and subsurface applicators range from drip tapes, trickle emitters, bubblers, sprays or spinners. The rates for each is generally less than 60 gal/hr for bubblers, less than 2 gal/hr for drip or trickle emitters and tapes and less than 45 gal/hr for spray or spinners. The water supply requires almost continuous flow rates during peak ET periods; which means implementation would be almost impossible unless ground water is used, and reservoirs can be used to buffer the supply. Drip can use saltier water than other irrigation methods because it can keep the soil moisture at high optimum water content, thereby reducing osmotic stress. Emitters, however, are very susceptible to clogging if water contains high solids. Dirty source waters have to be filtered extensively. Reservoirs serving as pre-filtration prior to regular filtration may be necessary to settle out sand and silt, or oxidize iron in well water.

This irrigation system can be used on row and orchard crops on almost all soils and topography. The soil type affects the number of emitters used per plant and affects the decision on whether to use microsprays/sprinklers versus drip. The net depth of application must be enough to replace the water used by the plant during the plant peak use period or critical growth stage without depleting the soil moisture in the root zone of the plant below the management allowed depletion (MAD). Because microirrigation raises the soil moisture level and decreases soil water storage capacity, the probability of runoff or deep percolation during storm events increases. This would not be a problem in areas with low to no rainfall during the irrigation season. In order to maintain a steady state salt balance, an adequate amount of water should be applied for leaching.

In general, distribution uniformity is dependent upon proper design, installation and maintenance. Distribution uniformity can be maintained with frequent irrigations (unlike surface irrigation) and without excessive non-beneficial evaporation losses (unlike sprinkler methods). In practice, however, it has been found that distribution uniformity tends to be low. Distribution uniformity may degrade quickly with time as a result of lateral flushing, insufficient filtration and/or chemical injection. Runoff is either reduced or eliminated and deep percolation is reduced. The need to over-irrigate to compensate for uneven application of water is eliminated.

Some of the advantages associated with this type of irrigation system are:

- Enhanced nutrient uptake: since upper portion of the root zone can be maintained moist, there is enhanced uptake of nutrients such as phosphorus and ammonium that are usually concentrated near the soil surface.
- Improved plant response: Because the manner of water application is frequent, the water manager can maintain the soil moisture at an optimum level. A well-designed and maintained system can provide a more even application than other forms of irrigation methods.
- Automation resulting in reduced labor costs.
- Reduced salinity hazard: Salts are moved out to edges of wetted soil area, leaving the zone of wetted soil with a lowered salt content for root activity.

Some of the disadvantages associated with this type of irrigation system are:

- Equipment Costs: hardware required includes underground PVC pipe, polyethylene tubing, filters, other hardware required.
- Management: requires excellent design and excellent management.
- Water Supply: requires water supply to be frequent and dependable; this system can not be used if water is delivered on a rotation schedule unless fields are supplied groundwater.
- Energy Costs: high energy costs of installing and operating system; however, total energy use efficiency may actually be higher if fertilizer use is reduced and if yield improvement results; energy requirement may be less if less land grading is required.
- Maintenance: emitters susceptible to clogging.
- Restricted Root Zone: root activity is limited to a small wetted soil zone.
- Drip tape disposal

Crop-Specific Considerations

Whereas irrigation scheduling under furrow and sprinkler irrigation is a soil-based approach, irrigation scheduling under drip irrigation is a crop-evapotranspiration-based approach. In order to apply the proper volume of water, crop evapotranspiration must be estimated. The resulting irrigation frequencies are higher compared to furrow or sprinkler irrigation. Microirrigation has been adapted for use on row crops and orchard crops. Trees irrigated by this system have a relatively reduced root zone compared to trees irrigated using other methods. Because water volume in the soil surrounding the roots is lower compared to other methods, a more frequent refilling of the soil water reservoir is needed. In addition, microsprayer spray patterns should be oriented away from tree trunks to reduce trunk and root rot potential, particularly on heavy soils where it is difficult to maintain adequate aeration. For crops with *Phytophthora* problems on heavy soils (e.g. tomato, peppers), drip has been used more successfully than sprinklers and furrow to reduce risk. Particularly for some fruit crops, it is important to watch for overirrigation as some crops, such as melons, become vegetative.

Above Ground Orchard/Vineyard Drip

Above ground drip irrigation has been successfully used in orchards and vineyards. The equipment required are emitters and hoses. Emitters are available in varying designs and configurations. Most of what's used now are either the "tortuous path" design or the pressure compensating design. Tortuous path emitters have relatively large passageways and are less susceptible to plugging problems compared to vortex or laminar flow designs. They also provide a degree of pressure compensation. Pressure compensating emitters have moving parts that progressively restrict the passageway size as pressure increases.

Generally, one hose per plant is used for closely spaced rows (spacing less than 4m) and one or more hoses are used on wider row spacings. Emitter spacing in arid regions are done such that 60% of the potential root zone volume is wet to provide enough of a moisture reservoir for periods of high evapotranspiration. In orchards, one hose is installed down the tree row on the soil surface adjacent to tree trunks. It is not unusual practice to install two hoses, one on each side of the tree row, in cases where a single line of emitters will not provide adequate soil wetted area. In vineyards, one hose per row, with about two emitters per vine, is usually used since rows are generally tightly spaced.

Subsurface Orchard/Vineyard Drip

The theoretical advantages associated with subsurface drip compared to surface microirrigation include less soil evaporation, fewer weeds, less orchard humidity and a reduction in associated diseases, and no restrictions to tillage. In practice, however, these advantages are not always achieved. This is because water, instead of spreading slowly through the soil around the emitter by capillary action, may rise directly to the soil surface. This may occur as a result of flow rates per emitter that are too high or soil with low hydraulic conductivities. Low hydraulic conductivity is often affected by the irrigation water quality. These problems may be addressed by using emitters with very low flow rates, pulsing irrigation systems automatically in durations of 30 minutes or less, or treating water quality problems with polymers such as polyacrylamides or gypsum injection.

There is also uncertainty as to the correct depth and location of hoses. Catastrophic failure has been known to occur as a result of root intrusion into the emitters and roots pinching the hose. Hoses are generally buried at depths from 0.45-0.75 m, with the shallower depths more common. Hoses must be located so that soil over the hoses are not compacted due to wheels. Some growers locate hoses midway between rows on established vines. Hoses are located midway between rows in orchards. Some orchard growers are also experimenting with combinations such as buried hose midway between tree row and an above-ground hose for the tree. Caution must be taken when installing buried systems on established crops, as extensive root damage may occur.

Orchard and Vineyard Microspray (and Microsprinkler)

Microspray and microsprinkler use on orchards and vineyards became popular in the early 1980s when many drip systems were converted to microspray or microsprinkler systems. These systems tend to have larger hose diameters than drip hoses, and the flow rates of the emitters are much higher than flow rates of drip emitters. Microspray or microsprinkler requires less stringent filtration than drip because there is less potential for plugging. However, silt particles, which are usually not removed by filtration, when combined with the high nozzle velocities, can result in abrasions and wear of the nozzles and spray plates. This will result in an increase in flow rate and a distorted spray pattern. Microsprays/sprinklers produce a larger soil wetted volume than a single hose drip system, and can also provide some frost protection. In some areas, frost protection is achieved by actually placing the microsprayer in the citrus canopies during periods of frosts. This is done only with extreme caution since severe frost can turn the microsprayer discharge from a protective device to an evaporative cooling device.

Row Crop Drip (Above Ground)

The major categories for above ground drip used for row crops are disposable drip tape products used for one or two seasons, retrievable tape or other drip hoses with internal emitters, removable drip tape used for short crops and drip tape used under plastic. Each are described briefly below:

Disposable drip tape products used for one or two seasons

- short-lived systems so filtration systems and usually under-designed and minimal maintenance is required.
- typically uses thin-walled tape (4 to 8 mm).
- used on high value crops such as pole tomatoes, sugar peas and similar crops.
- often used on small fields that are difficult to irrigate by other means because of small flow rates and uneven field sizes.
- eliminates the problems of wetting the foliage and fruit as would occur with sprinklers.

Retrievable tape or other drip hose with internal emitters

- tape can be rolled up from the end of the field.
- used for crops whose yields would be improved by constant high moisture content provided by drip but that may not be well-suited for buried drip due to harvesting or rooting system constraints; e.g. celery harvest is characterized by heavy equipment criss-crossing moist soils, this would compact or destroy any buried tape; sweet potato has an aggressive root systems that tend to give more root intrusion problems with buried drip than do other truck crops.

Removable tape used for short crops

- this system has been used successfully on short crops that are not adversely affected by being exposed to a wet surface. e.g. broccoli, lettuce, peppers, onion, etc.
- Some of this tape is used for three to ten seasons before disposal.
- Removable tape also allows for the different crop row spacings during crop rotations. It is common to place the tape about 1 to 5 cm below the ground surface, just enough to protect from the wind, then retrieve it immediately before or after harvest.

Drip tape under plastic

- The drip tape is placed under plastic as it is installed for vegetables. The surface location is important because there is very little capillary action in the soil to provide upward movement of water from buried emitters. The emitter flow rates of these above ground systems installed under plastic sheets are relatively high.

Row Crop Drip (Subsurface)

There are two categories of row crop subsurface drip systems: one crop and permanent. One crop buried drip systems typically have mainline and submain systems that are permanent and buried. These systems also have a permanent filtration system. Before, during and immediately after the crop is planted or transplanted, the tape is buried approximately 10 to 25 cm below ground. One of the advantages of this method is reduced problems associated with tillage or wind. Strawberry and sugar cane are two examples of crops on which subsurface row crop drip has been used successfully. Strawberries are typically grown on raised beds covered with plastic to prevent mold by preventing berry contact with soil. The drip system allows frequent irrigation of the shallow, sensitive root system and keeps the fruit dry. Generally, the tape and plastic mulches are picked up and disposed of after harvest and before the plants are disked into the soil. A long-term crop that may fall into this category is asparagus. However, there is concern about root intrusion with this crop.

"Permanent" subsurface drip systems have been used successfully on high value crops such as tomatoes, peppers, lettuce, cauliflower and broccoli. For these crops, the drip tape or hose is buried from 20 to 40 cm below the ground surface. It is designed to remain in place for around 6 to 10 years. Special tillage equipment is necessary in order to remove old crops and incorporate crop residue into the soil without causing damage or moving the tape. These systems require a very high level of management skill and attention. During the first year or two or operation, a high percentage of total management time is devoted to management of one field of this type.

Additional considerations must be taken into account when using buried drip systems for germination and transplanting. Special design features, such as emitters with high flow rate, relatively thick tape walls, adjustable pressure regulators at the entrances of the blocks, must be incorporated in order for the system to provide adequate irrigation during these periods. During germination or transplanting, pressures are increased. This may result in soil surface saturation and result in runoff. Lower emitter pressures are used during the remainder of the season so that soil surface remains relatively dry. The use of temporary portable sprinkler systems may be necessary if systems are incapable of providing germination and transplant irrigations. This may result in additional costs as well as delays in establishing row crops.

5.4.4 Irrigation Scheduling

Irrigation scheduling or determining the proper time and amount to apply is an integral part of irrigation management and can have an effect on resulting runoff. Several constraints such as unknown uniformity and lack of system capacity to apply desired amount limit the ability to correctly determine irrigation scheduling. However, various techniques are used to determine the proper time to apply and the amount to apply. These include indicator-threshold, crop stress indicators, soil moisture stress indicators, published ET data, evaporation pans, atmometers and computerized ET prediction programs.

Some irrigators use a water budget to determine when to irrigate and how much to apply. To successfully do this, several variables needs to be identified. This includes the depth of root zone, soil water holding capacity in the root zone, crop's rate of water consumption, and irrigation efficiency of irrigation system. Water budgets are easier to use with localized irrigation because soil water holding capacity and rooting zone depth are not as important, and irrigation efficiency is easier to estimate. Water budgets are not recommended if locations do not have reliable evapotranspiration data or if soils have a high water table.

Irrigation scheduling is often the most complex for surface irrigation. Bali *et al.* (draft) suggests a method to reduce or eliminate surface runoff from irrigation of heavy clay soils by basing irrigation scheduling on a technique that predicts the cut-off time necessary to minimize runoff and improve water use efficiency. Sprinkler and microirrigation systems are relatively simple to schedule since the amount infiltrated depends on the hours of application, not the soil intake characteristics. Runoff is usually not a problem, but may be a problem in areas with water penetration problems.

5.4.5 Pending Research

There is currently ongoing research in the Salton Sea watershed to demonstrate the use of irrigation strategies to reduce soil erosion and minimize runoff of constituents including sediments, fertilizers and pesticides for irrigated fields in the Imperial and Coachella Valleys (Bali and Guerrero, 2001).

6.0 SOIL MANAGEMENT

6.1 Introduction

The fate and transport of pesticides in the environment is directly affected by soil conditions. The most important effect of soil conditions is the movement of water through the soil. Water can either be stored on the field or leave the field through runoff or infiltration. Pesticide degradation is enhanced if water is allowed to infiltrate the soil rather than move as runoff. Management of these conditions is an important part of controlling pesticides. This section describes some soil management options through mechanical and biological means.

6.2 Soil Management Options

6.2.1 Tillage

Description

Tillage is the term used for soil mechanical cultivation activities such as plowing, ripping, disking, aerating, and harrowing. These tillage practices are specifically designed to loosen soil, direct water flow, and encourage vegetation growth. If properly conducted, tillage can dramatically reduce runoff and increase infiltration. The effects of tillage on offsite pesticide movement depend greatly upon the specific tillage technique used, soil type, slope, soil organic matter, and a number of other site specific factors. Improper tillage can also compact soil, reduce soil organic matter, damage soil structure, or have other effects that would greatly increase runoff and reduce infiltration. The following sections discuss individual tillage practices and their potential impacts on offsite pesticide movement.

Water penetration can be increased with appropriate tillage practices in compacted soils or where an impermeable soil layer exists. Increased water penetration can reduce runoff but no studies have been conducted relative to reducing OP pesticide runoff with these approaches. Two drawbacks of tillage are that it can increase erosion under some conditions and necessitate additional orchard floor finishing work, such as scraping. Results vary with soil type and under some conditions compaction could increase. Also, improved soil permeability may increase movement of nitrate and other chemicals into groundwater. The balance of benefits versus disadvantages is not always clear, and more research is needed in this area.

Contour Planting and Cultivation

Planting and cultivating crops along the contour of a sloped field can slow runoff and increase infiltration. While effective when used, this practice is very site-specific and would be applicable to annual or short-lived perennial field crops and new orchards only.

Ripping

Ripping is commonly used on fields to increase water infiltration. For orchards, shank depth must be shallow enough to avoid damage to tree roots. Ripping significantly increases the water storage capacity of soils and can render fields impassable to heavy equipment such as sprayers used during dormant treatments. See the discussion of cover crops, above, for more information on ripping and pesticide runoff.

Aeration

Aerating orchard soils with specialized tillage equipment increases water infiltration. Aeration improves the soil profile with minimal disruption to the orchard floor. A finishing process may be required, however, for almond orchards where shake and sweep harvest methods are used. Aeration may reduce pesticide runoff although no studies have been conducted.

Pending Research

The UC IPM/Water Quality team has suggested future areas of study with ripped resident vegetation and other orchard floor treatments. Another area for future work is determining the vertical movement of OP pesticides when water penetration in soil is improved through ripping.

Data Gaps

Studies are needed to quantitatively evaluate the efficacy of specific tillage practices in reducing pesticide runoff under California conditions.

6.2.2 Soil Structure and Organic Matter

Description

Soil structure strongly influences the offsite movement of water and pesticides. Structure is determined by soil texture and soil organic matter. Soil texture is the proportion of sand, silt, and clay present in a soil. Soils are usually a mixture of all three of these components, although one often dominates. Sand particles have the largest diameter and sandy soils have the largest pore spaces between grains. Sandy soils tend to be loose, do not compact easily, drain rapidly, and can be low in fertility. Pesticides move rapidly through sandy soils and do not adsorb well, although because of the porosity of sand, runoff is less than with silt or clay. Silt soils are medium in grain size, porosity, fertility, and capacity to adsorb pesticides. Clay is comprised of very small particles, compacts easily, and drains poorly. Clay soils have high adsorption capacity for pesticides. If clay soils can be managed to increase their porosity through proper tillage practices, runoff and offsite movement of pesticides can be minimized.

Organic matter is the living, or formerly living, soil component. It's comprised of leaf litter, dead insects, bacteria, fungus, and other life forms in all stages of growth and decay. Soils typically range from 1 to 5% organic matter, by weight, and most organic matter is located within the top 10 inches of the soil. Although organic matter makes up only a small part of the soil profile, it is the most important component because it provides soil fertility and improves soil structure and porosity. Organic matter is very important for pesticide runoff reduction, not only because of its contribution to soil structure, but because it strongly adsorbs pesticides and provides habitat and nutrients for the microbes that degrade them. Increasing soil organic matter can therefore be a very effective approach to reducing offsite pesticide movement.

Macropores and Earthworms

Water and pesticides do not flow evenly through soil, regardless of soil structure or organic content. Soils are highly heterogeneous, and flow follows natural soil channels, such as macropores and earthworm burrows. Macropores are large channels or spaces in the soil that provide a path for water to flow down and through soil. These spaces make a soil more porous, which increases water infiltration as well as reducing the soil's ability to retain water. Macropores are generally advantageous for reducing offsite movement of water and pesticides, however, in areas of shallow depth to groundwater macropores can provide a pathway into groundwater for pesticides and nitrogen.

Water flow also follows earthworm burrows, which are a type of macropore. Earthworms live mostly within the root zone and prefer warm, moist, loose soils high in organic matter and undisturbed by tillage or compacted by heavy machinery. Earthworms are generally beneficial for reducing offsite movement of water and pesticides because of the macropores they create with their burrowing and also because of the organic matter they produce.

7.0 PROGRAMS: COST-SHARING, INCENTIVE, PEST MANAGEMENT

7.1 Introduction

This final section provides brief summaries of programs that promote management practices either by providing technical assistance, grants or cost-sharing programs.

7.2 Programs

7.2.1 Pest Management Alliance (PMA) Program

In 1998 the California Department of Pesticide Regulation (CDPR) introduced the Pest Management Alliance (PMA) program to provide aid for agricultural, nonagricultural and urban groups to develop and demonstrate pest management systems that reduce risks associated with pesticide use. The new program provides funding support up to $100,000 per project year to encourage increase implementation of biologically intensive reduced-risk pest management. The alliance promotes a concept of voluntary cooperative problem solving, which creates a climate where growers and urban residents are better informed and more willing to try to implement the reduced risk practices that work.

PMA grants are administered by CDPR. The PMA program differs from the Biologically Integrated Farming Systems (BIFS) program (described below) in that it is both urban and agricultural, it focuses more on commodity groups than on individual farmers, and it is based more on conventional agricultural systems than on ecologically-based systems

7.2.2 Biologically Integrated Farming Systems (BIFS)

Biologically Integrated Farming Systems (BIFS) began in agricultural areas throughout the US in the 1980s as a response to concerns over the increasing cost of inputs such as fertilizer and pesticides, the environmental impacts from the use of these chemicals, and the decline of farm profits (Lighthall *et al*., 2001) The BIFS approach exemplifies a biological or "whole-farming-system" approach to agricultural extension and non-point source pollution prevention. In contrast to a traditional regulatory approach that prescribes single-purpose “best management practices,” the farming-systems approach addresses multiple environmental impacts by managing the farm as an interactive biological system. (Swezey and Broome, 2000) The BIFS approach substitutes cultural practices, such as cover crops that produce nitrogen or attract beneficial insects, for chemical inputs such as fertilizer or pesticides.

BIFS is a voluntary program, with projects aimed at reducing use of pesticides and fertilizers while maintaining economic viability. A BIFS program was begun in California in 1995 in response to Assembly Bills 3383 and 1998, which requested the UC system to establish and support a program to provide extension services, training, and financial incentives for farmers who voluntarily participate in pilot projects to reduce their use of agricultural chemicals. BIFS is implemented by University of California Sustainable Agriculture Research and Education Program (UC SAREP) as a competitive grants program, and funded by the California State Legislature, the US. Environmental Protection Agency, and the University of California. (UCSAREP, 1999) All funds are administered by the CDPR, which provides financial oversight.

BIFS is helping growers develop lower-input farming methods for several major commodities, including walnuts, prunes, apples, citrus, strawberries, rice, and dairy. The California BIFS program is based on the Biologically Integrated Orchard System program, described below. (Byron and Halprin, 2001)

7.2.3 Biologically Integrated Orchard Systems (BIOS) Program

Biologically Integrated Orchard Systems (BIOS) is a technical assistance program based on reduced chemical inputs and field-specific agronomic practices. The BIOS mission is to bring together farmers, other agricultural professionals, and public institutions to encourage the voluntary adoption of whole-systems approaches to farm management. BIOS encourages practices that are flexible, maintain long term profitability, and reduce reliance on chemical inputs. BIOS program goals are:

- to facilitate the exchange of information based on the knowledge and experiences of farmers, pest control advisors (PCA), and researchers who have developed biologically integrated orchard systems,
- to create and coordinate locally-based teams that provide leadership, program guidance, and technical assistance,
- to monitor and document the effectiveness of BIOS farm management practices, and
- to foster collaboration among farmers, agricultural professionals, researchers, and public and private institutions.

Farmers participating in BIOS work with other farmers, their PCA, and agricultural professionals who specialize in cover crops and biological control to develop a customized plan for each BIOS field. Under this program, farmers and PCAs monitor their field for pests, diseases, and earthworms. At least twice per year BIOS professionals visit the farm to help solve problems and make adjustments to the customized management plan. The BIOS program organizes periodic field days and meetings to educate farmers about pests and diseases, orchard floor and cover crop management, biological control, and other topics. The BIOS approach does not preclude the use of pesticides or fertilizers, but it seeks to minimize their use through farming practices that reduce pest problems and increase soil organic matter and fertility.

Since its founding in 1993, BIOS projects for almonds and walnuts have been established in Merced, Stanislaus, Madera, San Joaquin, Colusa, Yolo, and Solano Counties. BIOS initiatives have also begun in grapes, cotton, row crops, prunes, citrus. BIOS program cooperators include the University of California (UC) Sustainable Research and Agricultural Program (SAREP), the UC Statewide Integrated Pest Management Program, UC Cooperative Extension, the USDA Farm Service Agency, and the USDA Natural Resource Conservation Service.

Recent BIFS, PMA, and BIOS Projects

The following BIFS, PMA and BIOS projects are currently underway or recently completed. Information can be obtained from the UC SAREP web site (www.sarep.ucdavis.edu/BIFS/bifs01/project highlights.htm):

- Prunes: use of diazinon in dormant applications eliminated on 33 farms due to plant-based monitoring,
- Walnuts: use of OP insecticides in dormant applications eliminated in 83% of enrolled orchards due to pheromone mating disruption,
- Apples: use of OPs reduced by 59% and carbamates by 92% , overall traditional pesticide use reduced by 72% by increasing use of "reduced-risk" pesticides, IGRS??
- Rice: 14,000 acres managed with focus on non-chemical weed control and reduced fertilizer, amount of herbicides applied per acre reduced by more than half.

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7.2.4 United States Department of Agriculture Programs

Following are pesticides related programs administered by the USDA Natural Resources Conservation Service (NRCS). NRCS programs are also summarized in a USDA NRCS publication (1998).

Environmental Quality Incentive Program

The Environmental Quality Incentives Program (EQIP) works primarily in areas where there are significant natural resource concerns, such as soil erosion, water quality and quantity, wildlife habitat, wetlands, and forest and grazing lands. EQIP is one of several Federal, State, and local conservation programs that farmers and ranchers can use to solve their natural resource problems. Cost sharing may pay up to 75 percent of the cost of certain conservation practices. Nationally, half of the funding for EQIP is targeted to live stock related natural resource concerns and the remainder to other significant conservation priorities like terraces, filter strips, tree planting, and pest management.

Conservation Reserve Program

The Conservation Reserve Program (CRP) reduces soil erosion, protects the nations ability to produce food and fiber, reduces sedimentation, and improve water quality. It encourages farmers to convert highly erodable cropland or other environmentally sensitive acreage to vegetative cover, such as tame or native grasses, wildlife plantings, trees , filter strips, or riparian buffers. Farmers receive annual rental payments for the term of the multi year contract. Cost sharing is also provided to establish the vegetative cover practices

Conservation Reserve Enhancement Program

The Conservation Reserve Enhancement Program (CREP) is a refinement of the Conservation Reserve Program. The program uses financial incentives to encourage farmers and ranchers to voluntarily enroll in contracts of 10 to 15 years in duration to remove lands from agricultural production. This program is community-based, and a flexible design of conservation practices and financial incentives to address environmental issues is provided.

Small Watershed Program

The USDA designed the Small Watershed Program to work through local government sponsors and helps participants solve natural resource and related economic problems on a specific watershed. The purpose of this project is to protect watersheds, flood prevention, erosion and sediment control, water supply, water quality, fish and wild life habitat enhancement, wetlands creation and restoration, and publish recreation in watersheds of 250,000 or fewer acres.

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APPENDIX A: NPS Measures and NRCS Standards

For each management practice described in the text the applicable Nonpoint Source (NPS) Program Management Measures are identified in Table A1. NPS program management measures are designed to address specific categories of nonpoint source pollution, such as agriculture.

Management Measures are key to California's NPS pollution control. Section 319 of the Federal Water Pollution Control Act requires states to have approved management programs for nonpoint source pollution. The *Plan for California's Nonpoint Source Pollution Control Program* is the first significant upgrade to California's NPS Program. It was required to conform to CWA § 319 requirements and the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA). The plan was adopted by the State Board on December 14, 1999 and approved by the US Environmental Protection Agency (US EPA) on July 17, 2000.

The State is committed to implementing, over a 15-year period, the 61 NPS Management Measures identified in the program. The goal is to have the measures implemented by 2013. There are three 5-year implementation plans for the 15-year period. Implementation of the Management Measures for agriculture is a priority for the first 5-year plan.

Table A1 also identifies the applicable National Resource Conservation Service (NRCS) Practice Standard code numbers for each practice. The NRCS Field Office Technical Guide in each state contains Conservation Practice Standards developed for that state. These state standards are based on national standards in the NRCS National Handbook of Conservation Practices. National standards establish minimum requirements for state standards, which are specifically tailored to each state's local conditions. Conservation Practice Standards include a practice definition, purposes of the practice, conditions where the practice applies, criteria for applying the practice, special considerations in applying the practice, practice plans and specifications, and practice operation and maintenance requirements.

Table A 1. List of Nonpoint Source Program Management Measures and National Resource Conservation Service Practice Standards.

Agricultural Practice	NPS Management Measure	NRCS Practice Standard[1]
Pesticide Application Practices	Agriculture: 1D – Pesticide Management	
Pest Management Practices	Agriculture: 1D – Pesticide Management	
Cover Crops	Agriculture: 1A – Erosion and Sediment Control 1C – Nutrient Management 1D – Pesticide Management	Cover and Green Manure Crops 340A and 340B
Buffers	Agriculture: 1A – Erosion and Sediment Control 1C – Nutrient Management 1D – Pesticide Management.	Filter Strip – 393 Vegetative Buffer Strip – 741 Grassed Waterway – 412 Riparian Forest Buffer – 391A Riparian Herbaceous Cover –390 Wetland Creation – 658 Wetland Enhancement – 659 Wetland Restoration - 657
Reducing Bare Herbicide Zone	Agriculture: 1A –Erosion and Sediment Control 1C – Nutrient Management 1D – Pesticide Management.	
Water Management		Improved Water Application-743 PAM-716 Irrigation Water Storage-552A Regulating Reservoirs-552B Irrigation Storage Reservoir-436 Irrigation System, Micro-irrigation-441 Irrigation System, Sprinkler-442 Irrigation System, Sprinkler (A), Hand-move aluminum Tubing-442A Irrigation System, Surface and Subsurace-443 Irrigation System, Tailwater Recovery-447 Water and Sediment Control Basin-638 Wetland Creation-658
Soil Improvement	Agriculture: 1A – Erosion and Sediment Control 1D – Pesticide Management.	

APPENDIX B: IPM Summary Tables per Crop

Table B 1. List of major pests (insects and mites) on almond (Zalom et al., 2001)

Common Name	Control Methods	Pesticide formulation if treatment is necessary (SP-Spring, DD-Delayed dormant, DS-Dormant season, BL-Bloom, PH-Post harvest, PB-Post bloom, SU-Summer, PF-Petal fall, PR-Preharvest)
Navel Orangeworm (NOW moth larvae)	**Cultural Control**: Remove mummy nuts from trees by February. After blowing or sweeping nuts to row center, destroy nuts by discing or flail mowing. Moist conditions resulting from winter cover crops will enhance mortality of navel orangewoms in mummy nuts that have fallen from trees. Winter sanitation and early harvest are the most important NOW management tools. **Biological Control**: Several parasitic wasps are known to parasitize the NOW. These wasps can be purchased from commercial insectaries. Release must be supplemented with cultural and management practices for good control of NOW. **Organically Acceptable Methods**: Spraying with Bt at hull split. **Pesticides:** listed in the next column in order of their effectiveness.	Azinphosmethyl 50WP, Chlorpyrifos 4E, Phosmet 70WP, Bt, Esfenvalerate, Narrow Range Oil (4%), Soybean Oil, Aluminum Phosphide (PH)
Peach Twig Borer (PTB moth Larvae)	**Biological Control:** PTB has about 30 species of natural enemies. Although in some years and orchards, these natural enemies destroy a significant amount of PTB larvae, they may not reduce twig borer populations below economically damaging levels. **Organically acceptable methods**:The use of Bt sprays at bloom preceeded by a delayed dormant oil treatment for the control of scale mite eggs. Also the use of mating disruptants **Pesticides** listed in the next column in order of their effectiveness	Narrow Range Oil (DS), plus Diazinon 50WP (DS) , Methidathion 25W (DS), Naled 8E (DS), Chlorpyrifos 4E (DS), Phosmet 70WP(DS), Spinosad, Bt (BL), Spinosad (SP), Chlorpyrifos 4E (SP), Azinphosmethyl (SP), Methidathion 25W (SP), Mating Disruptants (SP).
Oriental Fruit Moth	**Pesticides:** listed in the next column in order of their effectiveness	Chlorpyrifos 4E, Azinphosmethyl 50WP, Phosmet 70WP, Carbaryl 80S
Obliquebanded Leafroller	**Organically acceptable methods**: Bloom sprays of Bt **Pesticides:** listed in the next column in order of their effectiveness	Bt (BL),
Fruittree Leafroller	No control recommended	
Western Tent Caterpillar	**Organically acceptable methods**: Sprays of Bt **Pesticides:** listed in the next column in order of their effectiveness	Bt
Ants	**Cultural control**: Remove nuts from orchard floor as rapidly as possible following shaking. **Pesticides:** listed in the next column in order of their effectiveness	Pyriproxyfen Bait, Abamectin Bait, Chlorpyrifos 4E,
Webspinning Spider Mites	**Cultural control**: Reduce dusty conditions in orchards but oiling or watering roadways and maintaining a groundcover. Prevent water stress on trees. **Biological control**: There are several species of parasitic mites that can play a large roll in keeping webspinning spider in check. **Organically acceptable methods**: Oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Propargite 6EC (SP) , Fenbutatin-Oxide 50 WP (SP), Narrow Range Oil (SP), Abamectin .15EC (SP), Galendromus Occidentalis (SP), Pyridaben (SP), Clofentezine (SP), Cinnamaldehyde (SP)
European Red Mite	**Biological control** : The western predatory mite feeds on the immature and adult stages of the European red mite **Organically acceptable methods**: Oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Propargite (SP), Fenbutatin oxide 50WP (SP), Clofentezine (SP), Narrow range oil (DD)
Brown Mite	**Biological control**: The western predatory mite and brown lacewing are both effective predators, but alone may not control brown mite populations. **Organically acceptable methods**: The use of oil sprays. **Pesticides:** listed in the next columnn in order of their effectiveness.	Narrow range oil (DD or SP)
San Jose Scale	**Biological control**: Predators and parasites are helpful in reducing scale populations, but pesticides used during the growing season can disrupt this natural control. Low winter mortality due to mild temperatures will also permit a build up of scale populations. **Organically acceptable methods**: Oil sprays during the delayed dormant period. **Pesticides:** listed in the next columnn in order of their effectiveness.	Narrow range oil (DS), Diazinon 50wp (DS), Methidathion 25W (DS or SP), Chlorpyrifos 4E (DS or SP), Carbaryl 80S (DS), Pyripoxyfen .86EC (DS or SP),
European lecanium (brown apricot scale)	**Biological control:** Many natural enemies help to control populations of European fruit lecanium. **Organically acceptable methods**: Oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Dormant flowable emulsion (DS or DD), Narrow range oil (DS or DD), Diazinon 50WP (DS or DD), Chlorpyrifos 4EC (DS or DD)
Tree Borers (prune limb borer, American plum borer)	**Pesticides:** listed in the next column in order of their effectiveness.	Carbaryl 80S, Chlorpyrifos 4EC
Leaffooted Bug	**Biological control**: Egg parasites can keep bug below economically damaging levels; treat when high populations present. **Pesticides:** listed in the next column in order of their effectiveness.	Carbaryl 80S, Chlorpyrifos 4EC
Tenlined June Beetle	*No chemicals registered for control of this pest after trees planted; control requires removal of infested trees and soil fumigation before replanting.	Methyl bromide, Chloropicrin

Table B 2. List of major pests (insects and mites) on walnuts (Bentley et al., 2000)

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Frosted Scale	**Biological control**: Parasitic wasps play an important role in controlling these soft scales. **Organically acceptable methods:** Sprays of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Methidathion 25WP, Chlorpyrifos 4EC, Narrow range oil
European Fruit Lecanium	**Biological control**: Parasitic wasps play an important role in controlling these soft scales. **Organically acceptable methods:** Sprays of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Methidathion 25WP, Chlorpyrifos 4EC, Narrow range oil
Walnut Scale	**Biological Control:** Several natural enemies of the walnut scale tend to hold it in check. However, if populations are high, the time for predators to bring the population numbers down may be excessive. **Organically acceptable methods**: Sprays of narrow range oil. **Pesticides:** listed in the next column in order of their effectiveness.	Methidathion 25WP, Chlorpyrifos 4EC, Narrow range oil
San Jose Scale (SJS)	**Biological control:** Many predators and parasites have been observed feeding on SJS. In undisturbed situations, these parasites can play a major role in controlling SJS populations. In situations of heavy infestation, response by predators and parasites may not be enough to control damage. Sprays may be needed in such cases. **Pesticides:** listed in the next column in order of their effectiveness.	Methidathion 25WP, Chlorpyrifos 4EC, Narrow range oil
Aphids: walnut aphid and dusky-veined aphid	**Biological control:** An introduced parasitic wasp has reduced the need for chemical control of walnut aphids. **Pesticides:** listed in the next column in order of their effectiveness.	Chlopyrifos 4EC, Endosulfan 50WP, Diazinon 50WP
Webspinning Spider Mites: Two Spotted Spider Mite, Pacific Spider Mite	**Cultural control:** Minimize dust by oiling orchard roads/maintaining ground cover; well-irrigated, vigorous trees are less troubled by mite infestation; avoid pyrethroids, OPs and carbamate. **Biological control:** Predators can keep mites below economically damaging levels. **Pesticides:** listed in the next column in order of their effectiveness.	Supreme oil, Fenbutatin-oxide 50WP, Propargite 30W, Dicofol MF, Clofentezine, Abamectin
European Red Mite	**Biological control:** In low numbers European red mites can be beneficial by providing a food source for the western predatory mite. **Organically acceptable methods:** Narrow range oil. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow range oil, Propargite 30W, Fenbutatin-oxide 50WP, Dicofol MF, Abamectin, Clofentezine
Redhumped Caterpillar	**Biological control:** Among the parasites that help prevent redhumped caterpillars from becoming destructive pests are two parasitic wasps, *Hyposoter fugitivus* and a species of *Apantales*. **Pesticides:** listed in the next column in order of their effectiveness.	Bacillus Thuringienis, Diazinon 50WP and 4EC
Fall Webworm	**Pesticides:** listed in the next column in order of their effectiveness.	Bacillus Thuringienis, Diazinon 50WP and 4EC
Coddling Moth	**Biological Control:** Alone, natural enemies are not able to keep codling moth populations below economic levels. However the release of parasitic wasps when combined with mating disruptants can be helpful in keeping populations in check. **Organically acceptable methods**:The use of mating disruptants, and release of parasitic wasps. **Pesticides:** listed in the next column in order of their effectiveness.	Phosmet 70wp, Chlorpyrifos 4ec, Tebufenozide 2f, Methidathion 25wp, Azinphosmethyl 50wp, Mating disruptants, Trichogramma Planeri,Diflubenzuron 2l, Esfenvalerate, Permethrin, Carbaryl, Methyl Parathion
Navel Orangeworm	**Cultural Control:** Reduce overwintering populations by flailing all crop waste containing sound nuts. Harvest when first possible. **Biological Control:** The release of parasitic wasps can assist in keeping populations in check. A ground cover maintained over winter aids in decomposing trash nuts by molds and other microorganisms. **Pesticides:** listed in the next column in order of their effectiveness.	Phosmet 70wp, Azinphosmethyl 50wp, Methidathion 25wp, Esfenvalerate, Carbaryl
Walnut Husk Fly	**Pesticides:** listed in the next column in order of theit effectiveness.	Nu-lure bait,Malathion 8EC, Esfenvalerate, Chlorpyrifos 4EC
Pacific Flatheaded Borer	**Pesticides:** listed in the next column in order of their effectiveness	Spraying for this insect is not recomended

Note on Narrow range oil: short-term control; apply only when soil moisture is adequate and trees have not been waterstressed at anytime during the year; do not apply when T expected to be >90 at time of app.

Table B 3. List of major pests (insects and mites) on peach (Pickel et al., 2000a).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Peach Twig Borer (PTB)	**Biological Control:** PTB has about 30 species of natural enemies. In some years and orchards, these natural enemies destroy a significant amount of larvae, but they may not reduce twig borer populations below economically damaging levels. **Organically acceptable methods:** The use of Bt sprays at bloom preceded by a delayed dormant oil treatment for the control of scale mite eggs. Also the use of mating disruptants. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow range oils (DS), Diazinon 50WP (DS), Methidation25W (DS), Chlorpyrifos 4EC (DS), Esfenvalerate (DS), Permethrin (DS), Spinsodad (DS), Bacillus thuringiensis (BL), Mating disruptants (BL), Diazinon 50WP (PB), Phosmet 70WP (PB), Spinosad (PB), Permethrin (PB), Esfenvalerate (PB),
Oriental Fruit Moth	**Organically acceptable methods:** The use of mating disruptants. **Pesticides:** listed in the next column in order of their effectiveness.	Diazinon, Phosmet, Permethrin.
Fruittree Leafroller	**Organically acceptable methods:** Oil sprays during the dormant season followed by bloom treatments of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow range oil with Diazinon or Chlorpyrifos, Bt (BL), Spinosad (BL)
Omnivorous Leafroller	**Cultural control:** Remove and destroy fruit mummies; also destroy potential weed host, such as horseweed, common lambs quarters, little mallow, curly dock, and legumes, by clean cultivation. **Biological control:** A number of parasites attack omnivorous leaf roller larvae. Preservation of natural enemies is an important part of keeping leafroller numbers low. Use selective pesticides that are least disruptive of biological control. **Organically acceptable method:** applications of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Spinosad, Bt
Stink Bugs	**Pesticides:** listed in the next column in order of their effectiveness.	Formetanate Hydrochloride 92SP, Endosulfan 50WP
Lygus Bugs	**Cultural control:** Cover crop manipulation is important in lygus management. In orchards located away from an outside lygus bug source, clean cultivation or a weed free orchard floor will aid in suppressing lygus bug populations. **Pesticides:** listed in the next column in order of their effectiveness.	Formetanate Hydrochloride 92SP, Methomyl LV
San Jose Scale (SJS)	**Biological control:** Many predators and parasites have been observed feeding on SJS. However in situations where heavy populations exist , these parasites and predators can not exert sufficient controlling pressure to prevent severe damage, so annual sprays are usually needed for mid and late season varieties. **Organically acceptable methods**: the use of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Diazinon (DS or PB), Methidathion 25WP (DS),Chlorpyrifos 4EC (DS), Carbaryl (DS or PB)
Webspinning Spider Mites	**Cultural control:** Mite build ups are encouraged by hot dry dusty conditions, so keep orchards well irrigated , and treat orchard roads if necessary. Proper pruning and adequate amounts of fertilizer to maintain tree vigor will also discourage two spotted and pacific mites. **Biological control;** The most dependable predator is the western predatory mite. Under optimum conditions, this predator can produce a generation in seven days, which allows it to build up rapidly and in many cases control plant-feeding mites. **Organically acceptable methods**:The use of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Fenbutatin Oxide, Narrow Range Oil, Clofentezine
Peach Silver Mite	**Organically acceptable methods:** Sulfur sprays.	Wettabble sulfur
Brown Mite	**Biological control;** several predaceous species feed on brown mites. **Organically acceptable methods:** Oil sprays and naturally occurring predators **Pesticides:** listed in the next column in order of their effectiveness.	Fenbutatin Oxide (SP or SU)
European Red Mite	**Organically acceptable methods**: sprays of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Fenbutatin Oxide (PB), Clofentezine(PB)
Pacific Flatheaded Borer	**Cultural control:** Maintaining healthy trees and preventing sunburn are the keys to preventing damage. Painting tree with white wash will prevent sunburn and reduce egg laying.	
Prune Limb Borer and American Plum Borer	**Pesticides:** listed in the next column in order of their effectiveness.	Carbaryl Diazinon
Katydids	Currently no recommendations.	

Table B 4. List of major pests (insects and mites) on apricot (Van Steenwyk et al., 2000b).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Peach Twig Borer (PTB)	**Biological control:** The PTB has about thirty species of natural enemies. Although in some years these natural enemies destroy a significant portion of larvae, on their own, they are not able to keep populations below economically damaging levels **Organically acceptable methods**: The use of Bt sprays at bloom, preceded by a dormant oil treatment for the control of scale and mite eggs. Also the use of mating disruptants. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow range oils (DS,DD), Esfenvalerate (DS,DD), Diazinon 50wp (DS,DD PB), Spinosad (DS,DD,PB), Methidathion 25wp (DS,DD,PB), Bacillus thuriniensis (BL), Phosmet (PB), Carbaryl (PB)
Fruittree Leafroller	**Organically acceptable methods:** Oil sprays during the dormant season followed by bloom treatments of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Spinosad, Carbaryl 80S Diazinon 50WP, Phosmet 70WP
Green Fruitworm	**Organically acceptable methods**: Sprays of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Spinosad, Carbaryl 80S, Diazinon 50WP, Phosmet 70WP
Orange Tortrix	**Pesticides:** listed in the next column in order of their effectiveness.	Spinosad, Carbaryl 80S, Diazinon 50WP, Phosmet 70WP
Redhumped Caterpillar	**Biological control:** Among the parasites that help prevent redhumped caterpillars from becoming destructive pests are two parasitic wasps*, Hyposoter fugitivus* and a species of *Apantales*. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Spinosad Diazinon 50W, Carbaryl 80S
European Earwig	**Cultural control**: By removing weeds from around the base of trees. Keep orchard clear of pruning or other debris under which earwigs could nest. Remove tree limbs that come in contact with soil. **Pesticides:** listed in the next column in order of their effectiveness.	Carbaryl 80S
Western Tussock Moth	**Organically acceptable methods**: Sprays of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Spinosad, Carbaryl 80S, Diazinon 50W, Phosmet 70WP
Brown Mite	**Biological control**: The western predatory mite and brown lacewing mite are both effective predators, but alone may not control brown mite populations. If possible, avoid pesticides which will kill these natural enemies. **Organically acceptable methods:** Oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow range oils (DS)
Webspinning Spider Mites	**Cultural control:** Mite build ups are encouraged by hot dry dusty conditions, so keep orchards well irrigated , and treat orchard roads if necessary. Proper pruning and adequate amounts of fertilizer to maintain tree vigor will also discourage two spotted and pacific mites. **Biological control;** The most dependable predator is the western predatory mite. Under optimum conditions, this predator can produce a generation in seven days, which allows it to build up rapidly and in many cases control plant-feeding mites. **Organically acceptable methods**:The use of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Clofentezine (SP,SU), Narrow range oils(SP,SU)
European Red Mite	**Organically acceptable methods**: sprays of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow range oil (DS,SP), Clofentezine (SP)
Mealy Plum Aphid	**Biological control**: Important predators include lady beetles, green and brown lacewing, syrphid flies and soldier beetles. However, these predators do not adequately control high populations. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow range oils (DS,DD), Diazinon 50WP (SP)
European Fruit Lecanium	**Biological control**: Parasitic wasps play an important role in controlling these soft scales. **Organically acceptable methods:** Sprays of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow range oils, Diazinon 50WP, Dormant oil, Dormant flowable emulsion
Cribrate Weevil	**Cultural control**: Application of a 3-4 inch band of Stickem on the trunk of young trees to trap crawling adults will prevent most infestations.	
Pacific Flatheaded Borer	**Cultural control**: In young trees, wrap or paint the tree trunk above and 1 inch below the soil line with white, water-based paint or whitewash to protect from sun burn and flathead invasion.	
Peachtree Borer	**Cultural control:** Cover all of tree trunk with insecticide. Remove weeds or anything that may interfere with spray cover.	Endosulfan 50WP
Branch and Twig Borer	**Cultural Control:** Provide sun burn protection and good irrigation to keep trees healthy.	
Shothole Borer	**Cultural control:** Pruning, and healthy tree maintenance will prevent this infestation * Spraying for this insect is not recommended.	

Table B 5. List of major pests (insects and mites) on cherry (Van Steenwyk et al., 2000a)

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Fruittree Leafroller	**Organically acceptable methods:** Sprays of Bt **Pesticides:** listed in the next column in order of their effectiveness.	Carbaryl 80S, Spinosad, Diazinon 50WP, Bt
Green Fruitworms	**Organically acceptable methods**: Sprays of Bt. **Pesticides**: listed in the next column in order of their effectiveness.	Diazinon 50WP, Bt, Spinosad, Carbaryl 80S
Orange Tortrix	**Pesticides**: listed in the next column in order of their effectiveness.	Diazinon 50WP, Spinosad, Carbaryl 80S
Redhumped Caterpillar	**Organically acceptable methods**: Sprays of Bt. **Pesticides**: listed in the next column in order of their effectiveness.	Bt, Spinosad, Diazinon 50WP, Carbaryl 80S, Azinphosmethyl 50WP
European Earwig	**Cultural control**: Remove weeds from around the base of the tree. Keep orchard clear of pruning or other debris that earwigs may exploit for nesting. **Pesticides**: listed in the next column in order of their effectiveness.	Carbaryl 80S
Western Tussock Moth	**Organically acceptable method**: Sprays of Bt. **Pesticides**: listed in the next column in order of their effectiveness.	Diazinon 50WP, Bt, Spinosad, Carbaryl 80S
Eyespotted Bud Moth	**Pesticides**: listed in the next column in order of their effectiveness.	Diazinon 50WP, Carbaryl 80S
Brown Mite	**Biological control**: The western predatory mite and brown lacewing are both effective predators, but alone may not control brown mite populations. **Organically acceptable methods**: The use of oil sprays.	Narrow range oils (DS)
Webspinning Spider Mites	**Cultural control:** Mite build ups are encouraged by hot dry dusty conditions. Keep orchards well-irrigated and treat orchard roads if necessary. Proper pruning and adequate amounts of fertilizer to maintain tree vigor will also discourage two spotted and pacific mites. **Biological control:** The most dependable predator is the western predatory mite. Under optimum conditions, this predator can produce a generation in seven days, which allows it to build up rapidly and in many cases control plant-feeding mites. **Organically acceptable methods**:The use of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Propargite 30WP (SP,SU) , Clofentezine (SP,SU), Dicofol 50WSP (SP,SU), Fenbutatin-oxide 50WP (SP,SU), Narrow range oils (SP,SU).
Black Cherry Aphid	**Pesticides**: listed in the next column in order of their effectiveness.	Narrow range oils (DS,DD), Diazinon 50WP (DS,DD,PF), Chlorpyrifos 4EC (DS,DD)
European Fruit Lecanium	**Pesticides**: listed in the next column in order of their effectiveness.	Narrow range oils(DS,DD), Diazinon 50WP (DS,DD), Chlorpyrifos 4EC (DS,DD)
Black Scale	**Pesticides**: listed in the next column in order of their effectiveness.	Narrow range oils(DS,DD), Diazinon 50WP(DS,DD), Chlorpyrifos 4EC(DS,DD)
San Jose Scale	**Pesticides**: listed in the next column in order of their effectiveness.	Methidathion 25W(DS,DD), Diazinon 50WP(DS,DD), Chlorpyrifos 4EC(DS,DD), Narrow range oil(DS,DD)
Cherry Slug	**Pesticides**: listed in the next column in order of their effectiveness. Not always required.	Diazinon 50WP
Peach Twig Borer	**Organically acceptable method**: The use of Bt at bloom, preceded by a dormant spray oil treatment for scale and mite eggs.. **Pesticides**: listed in the next column in order of their effectiveness.	Methidathion 25W(DS,DD), Narrow range oils(DS,DD), Diazinon 50WP(DS,DD,SP), Chlorpyrifos 4EC(DS,DD), Bt(BL), Carbaryl 80S (SP)
Peachtree Borer	**Pesticides**: listed in the next column in order of their effectiveness	Chlorpyrifos 4EC (PR,PH), Endosulfan 50WP(PH),
Pacific Flatheaded Borer	**Cultural control**: Wrap or paint the tree trunk from 2 feet above to 1 inch below the soil.	
Cribrate Weevil	**Cultural control**: To prevent infestation apply a 3-4 inch band of sticky material on the trunk of young trees to trap crawling adults.	
Branch and Twig Borer	**Cultural control**: Keeping trees healthy helps control infestation since beetles tend to infect unhealthy trees.	
Shothole Borer	**Cultural control**: Keeping trees healthy helps control infestation since beetles tend to infect unhealthy trees.	
American Plum Borer	**Pesticides**: listed in the next column in order of their effectiveness.	Diazinon 50WP, Carbaryl 80S
Mountain Leafhopper	* If any trees are infected with cherry buckskin disease remove them immediately.	Esfenvalerate 0.66EC (PH), Carbaryl 80S (PH), Diazinon 50WP (PH) Azinphosmethyl 50WP (PH)
Cherry Leafhopper	* A serious vector of cherry buckskin disease, and appears to be responsible for severe outbreaks. Remove any trees that are infected with the disease.	Narrow range oil, Chlorpyrifos 4EC, Esfenvalerate 0.66EC, Carbaryl 80S, Diazinon 50WP, Azinphosmethyl 50WP

Table B 6. List of major pests (insects and mites) on prune (Pickel et al., 2000b)

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Peach Twig Borer	**Biological control**: There are about 30 species of natural predators. **Organically acceptable method**: The use of Bt sprays at bloom, preceded by a delayed dormant oil treatment for the control of scale and mite eggs. **Pesticides:** listed in the next column in order of their effectiveness.	Diazinon 50WP (DS,PB) Chlorpyrifos 4EC (DS), Esfenvalerate (DS,PB), Spinosad (DS,PB), Methidathion 25W (DS), Bt (Bloom), Phosmet 70WP (PB), Carbaryl 80S (PB) , Azinphosmethyl 50WP (PB)
Fruitree Leafroller	**Biological control**: A number of general predators exist, such as the lacewing and lady beetle larvae, and parasites. **Organically acceptable methods**: dormant oil sprays followed by bloom spray of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Dormant flowable emulsion (DS), Narrow range oils (DS), Diazinon 50WP (DS), Chlorpyrifos 4EC (DS), Esfenvalerate (DS), Bt (BL), Diazinon 4EC (PB), Azinphosmethyl 50WP (PB), Carbaryl 80S (PB), Spinosad (PB), Bt (PB)
Orange Tortrix	**Cultural control**: Remove weed host such as mustard. The use of grass cover crops helps reduce overwintering hosts. **Biological control**: Several parasites and predators attack orange tortex. Parasites include the wasps Apanteles aristolidae, Exochus sp., and Hormius basalis and a tachinid fly, Nemerilla pyste. Predators include spiders and brown lacewing larvae Hemerobius pacificus. **Organically acceptable methods**: Sprays of bacillus thuringiensis Pesticides: listed in the next column in order of their effectiveness	Diazinon 50WP, Carbaryl 80S, Azinphosmethyl 50WP, Bt
Obliquebanded Leafroller	**Organically acceptable methods**: Dormant oil spray followed by bloom sprays of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Dormant flowable emulsion (DD), Narrow range oils (DD), Chlorpyrifos 4EC (DD), Esfenvalerate (DD), Bt (BL), Diazinon 50WP, 4EC (Postbloom), Carbaryl 80S (PB), Azinphsmethyl 50WP (PB), Spinosad (PB), Bt (PB)
Green Fruitworms	**Organically acceptable methods**: Dormant oil spray followed by bloom sprays of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Spinosad
Codling Moth	**Cultural control**: Remove abandoned or unsprayed apple, pear, plum, apricot, and walnut trees near the prune orchards. **Biological control**: Natural enemies do help control codling moth but are unable to keep it below economic injury. **Pesticides:** listed in the next column in order of their effectiveness.	Phosmet 70WP, Azinphosmethyl 50WP, Carbaryl 80S, Esfenvalerate
Tent Caterpillars	**Organically acceptable methods**: Bt sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Diazinon 50WP, 4EC, Azinphosmethyl 50WP, Carbaryl 80S
Western Tussock Moth	**Organically acceptable methods**: Bt sprays.	Bt
Redhumped Caterpillar	**Cultural control**: On small trees, cut out and destroy infested twigs. **Organically acceptable methods**: Bt sprays.	Bt
Cankerworms	**Cultural control**: On small trees, cut out and destroy infested twigs. **Organically acceptable methods**: Bt sprays.	Bt(BL,PB)
Fall Webworm	**Cultural control**: On small trees, cut out and destroy infested twigs. **Organically acceptable methods**: Bt sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Diazinon 50WP, 4EC, Azinphosmethyl 50WP, Carbaryl 50WP
Brown Mite	**Biological control**: There are several species of wasps that parasitize brown mites, but have little effect on the population. **Pesticides:** listed in the next column in order of their effectiveness.	Dormant flowable emulsion, Narrow range oils, Fenbutatin-oxid 50WP (SP,SU), Narrow range oil (SP,SU), Dicofol 50WSP (SP,SU)
European Red Mite	**Organically acceptable methods**: Sprays of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Dormant flowable emulsion (DS),Narrow range oil (DS), Fenbutatin-oxide 50WP (SP,SU), Dicofol 50WSP (SP,SU)
Webspinning Spider Mites	**Cultural control**: Mite build ups are encouraged by hot dry dusty conditions. Keep orchards well irrigated, and treat orchard roads if needed. Proper pruning and adequate amounts of fertilizer to maintain tree vigor will also discourage two spotted and pacific mites. **Biological control**: The most dependable predator is the western predatory mite. Under optimum conditions, this predator can produce a generation in seven days, which allows it to build up rapidly and in many cases control plant-feeding mites. **Organically acceptable methods**:The use of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Fenbutatin-Oxide 50WP, Narrow range oils (SP,SU) Formetanate hydrochloride, Dicofol 50WSP
Eriophyid Mites	**Biological control:** Light to moderate populations are suppressed by predaceous mites. **Pesticides:** listed in the next column in order of their effectiveness.	Wettable sulfur (Dust), Fenbutatin-oxide 50WP
Mealy Plum Aphid	**Biological control**: There are many natural enemies that feed on mealy plum aphid; however, fruit size may be reduced and fruit cracking may occur before natural enemies bring the aphids under control. **Pesticides:** listed in the next column in order of their effectiveness.	Dormant flowable emulsion (DS), Narrow range oils (DS), Diazinon 50WP,4EC (DS), Chlorpyrifos 4EC(DS), Esfenvalerate (DS), Diazinon 50WP, 4EC (SP), Endosulfan 50WP (SP), Narrow range oil (SP), Formetanate (SP), Neem oil (2%) (SP), Neem oil (2%) (SU)
Leaf Curl Plum Aphid	**Biological control**: There are many natural enemies that feed on leaf curl plum aphid; however, fruit size and fruit cracking still may occur and curled leaves will not uncurl after aphids are suppressed. **Organically acceptable methods**: include biological control and oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Dormant flowable emulsion (DS), Narrow range oil (DS), Diazinon 50WP, 4EC (DS), Chlorpyrifos 4EC (DS), Esfenvalerate (DS), Diazinon 50WP, 4EC (SP), Endosulfan 50WP (P), Narrow range oil (4-6%) (SP), Formetanate (SP), Neem oil (2%) (SP), Neem oil (2%) (SU)
San Jose scale	**Biological control**: Many parasites and predators have been observed feeding on San Jose Scale. However, in situations where heavy scale populations exist, these parasites and predators cannot exert sufficient controlling pressure. **Organically acceptable methods**: include biological control and oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Methidathion (DS), Dormant flowable oils (DS), Narrow range oils (DS), Diazinon 50WP, 4EC (DS), Chlopyrifos 4EC (DS), Carbaryl 80S (DS), Narrow range oil (May), Diazinon 50Wp, 4EC (May), Carbaryl 80S (May)

European Fruit Lecanium	**Organically acceptable methods**: are oil spraying. **Pesticides:** listed in the next column in order of their effectiveness	Dormant flowable emulsion, Narrow range oil, Diazinon 50WP, 4EC, Chlorpyrifos 4EC
Italian Pear Scale	**Organically acceptable methods**: Bordeaux treatments, oil sprays, or oil and lime sprays during the dormant season. **Pesticides:** listed in the next column in order of their effectiveness.	Bordeaux 10-10-100 or Fixed Copper, Dormant flowable emulsion, Narrow range oils
Peachtree Borer	**Pesticides:** listed in the next column in order of their effectiveness.	Endosulfan 3EC
Pacific Flatheaded Borer	**Cultural control**: Flat headed borers have an affinity for unhealthy trees. If the cultural maintenance of the orchard is on par, then infestation will not occur.	
Shothole Borer	**Cultural control**: Maintaining healthy tree is necessary since these tend to infest unhealthy trees. * There are no known insecticide treatments.	
Branch and Twig Borer	**Cultural control**: Maintaining healthy tree is necessary since these tend to infest unhealthy trees. * There are no known insecticide treatments.	
American Blum Borer	**Pesticides:** listed in the next column in order of their effectiveness.	Diazinon 50WP, Carbaryl 80S

Table B 7. List of major pests (insects and mites) on apple (Pickel et al., 2000c).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Codling moth	**Cultural Control**: Remove all host trees in nearby or abandoned orchards to destroy reservoirs of the codling moth. **Biological control**: Natural enemies alone are not able to keep codling moth populations below economic levels. However, augmentative releases of the tiny parasitic wasps can be used to supplement control with mating disruptants. **Organically acceptable methods**: mating disruptants, and oil sprays. **Pesticides:** listed in the next column in order of their effectiveness	Trichogramma, Mating Disruptants, Tebufenozide 2F, Azinphosmethyl 50WP, Carbaryl 80S, Phosmet 70WP, Narrow Range Oils
Apple pandemis	**Organically acceptable methods**: Sprays of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oils, Chlorpyrifos 4EC, Diazinon 50WP (DD), Chlorpyrifos 50WP, Bt(SU)
Orange Tortrix	**Cultural control:** Thin fruit to one or two per cluster to reduce available habitat. Remove and dispose of mummy fruit to reduce overwintering populations. **Biological control:** Several parasites and predators attack orange tortix. But in times of high population can not keep populations. **Organically acceptable methods:** Bt sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Bt
Fruittree Leafroller	**Organically acceptable methods:** Application of narrow range oils and Bt sprays **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oil (DS), Diazinon 50WP, Chlorpyrifos 4EC, Methidathion 2EC (DD), Bt, Tebufenozide 2F (PF)
Obliquebanded Leafroller	**Organically acceptable methods:** Application of narrow range oils and Bt sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Chlorpyrifos 50WP, Azinphosm 50WP, Diazinon 50WP, Bt, Tebufenozide 2F
Omnivorous Leafroller	**Cultural control:** Remove fruit mummies and destroy both the fruit and potential overwintering weed host. **Biological control:** A number of parasites attack the omnivorous leafroller. Preservation of natural enemy populations is an important part of keeping leafroller numbers low. Use selective materials that are least disruptive of biological control when treating other pests **Organically acceptable methods:** Applications of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt
Western Tussock Moth	**Organically acceptable methods:** Applications of Bt. **Pesticides:** listed in the next column in order of their effectiveness	Diazinon 50WP, Azinphosmethyl 50WP, Bt
Green Fruitworms	**Organically acceptable methods:** Applications of Bt. **Pesticides:** listed in the next column in order of their effectiveness	Bt. Azinphosmethyl 50WP, Diazinon 50Wp, Chlorpyrifos 50WP, Tebufenozide 2F
Leafminers	**Biological control**: Parasitic wasps are very important in controlling leafminers. **Pesticides**: listed in the next column in order of their effectiveness.	Oxanyl
European Red Mite	**Cultural control:** Minimize the potential for mite problems by reducing dusty conditions within the orchard and keeping the trees well irrigated. **Biological control:** If European mite populations are managed at low levels by treating with dormant oil, predators can effectively help maintain low levels through out the season. **Organically acceptable methods**: Applications of narrow range oils. **Pesticides**: listed in the next column in order of their effectiveness.	Narrow Range oil (DD), Fenbutatin-Oxide 50WP
Webspinning Spider Mites	**Cultural control**: Mite build ups are encouraged by hot dry dusty conditions. Keep orchards well irrigated , and treat orchard roads if necessary. Proper pruning and adequate amounts of fertilizer to maintain tree vigor will also discourage two spotted and pacific mites. **Biological control:** The most dependable predator is the western predatory mite. Under optimum conditions, this predator can produce a generation in seven days, which allows it to build up rapidly and in many cases control plant-feeding mites **Organically acceptable methods**:The use of narrow range oils. **Pesticides:** listed in the next column in order of their effectiveness.	Fenbutatin-Oxide 50WP
Rosy Apple Aphid	**Organically acceptable methods:** applications of narrow range oils **Pesticides:** listed in the next column in order of their effectiveness.	Dormant flowable Emulsions, Narrow Range Oils, Chlorpyrifos 4EC, Diazinon 50WP, Diazinon 50WP, Narrow Range Oils, Azadirachtin
Green apple aphid	**Biological control:** There are many natural enemies which feed on aphids. It is important to try to preserve these enemies to keep populations in check. **Organically acceptable methods:** Sprays of insecticide soaps. **Pesticides:** listed in the next column in order of their effectiveness.	
Wooly Apple Aphid	**Biological control:** Aphelinus mali is a parasite that can completely control aerial colonies. In the absence of this of this parasite there can be large increases of aerial colonies and wooly aphids can be found in the calyx of the apple. Outbreaks of wooly apple aphids are most common following the use of pyrethroids, which destroy its natural enemies. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oil, Chlorpyrifos 4EC, Diazinon 50WP (DD), Diazinon 50WP
Leafhoppers	**Pesticides:** listed in the next column in order of their effectiveness	Carbaryl 80S, Endosulfan 50WP, Diazinon 50WP, Imidacloprid 1.6F
San Jose scale	**Biological control**: Predators and parasites may be helpful in reducing scale populations, but insecticides used during the growing season for other pests disrupt this natural control and scale populations increase rapidly. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oil, plus Diazinon 50WP, or Chlorpyrifos 4EC, Methidalion 2EC (DD), Diazinon 50WP
Italian Pear Scale	**Organically acceptable methods**: Lime treatments. **Pesticides:** listed in the next column in order of their effectiveness.	Hydrated Lime (DS), Narrow Range Oil, plus Diazinon 50WP, or Chlorpyrifos 4EC (DD)
Stink Bugs	**Cultural control:** Eliminate weed host plants within and adjacent to the orchard to minimize stink bug problems. **Pesticides:** listed in the next column in order of their effectiveness.	Dimethoate E267, Formetanate SP, Endosulfan 3EC (PB), Dimethoate E267, Endosulfate 50WP (PR)
Lygus Bugs	**Cultural control:** Eliminate or suppress weed host plants before fruit forms on trees and thereafter throughout the season to minimize lygus bug populations. **Pesticides:** listed in the next column in order of their effectiveness.	Dimethoate E267, Formetanate SP
Apple Maggot	**Pesticides:** listed in the next column in order of their effectiveness.	Azinphosmethyl 50WP, Phosmet 70WP, Diazinon 50WP
Cribrate Weevil	*No insecticides have been shown to be effective against this species.	

Table B 8. List of major pests (insects and mites) on citrus (Grafton-Cardwell et al., 2000).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
California Red Scale and Yellow Scale	**Cultural control:** Parasitic wasps play an important role iin controlling California red scale but their effectiveness depends on good pest management. **Organically acceptable methods:** Petroleum oil sprays along with brushing or high pressure washing in the packing house. **Pesticides:** listed in the next column in order of their effectiveness.	Aphytis Melinus, Narrow Range Oil, Chlorpyrifos 4EC, Pyriproxyfen 0.86EC, Carbaryl 80S & Narrow Range Oil, Methidathion 25WP & Narrow Range Oil
Purple Scale	**Biological control:** Parasites usually provide good control of purple scale. Because this parasite is not commercially available, conserve naturally occurring population of beneficial in the grove. **Organically acceptable methods**: Petroleum oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oil, Chlorpyrifos 4EC, Carbaryl 80S & Narrow Range Oil, Methidathion 25WP & Narrow Range Oil
Brown Soft Scale	**Biological control:** The most effective parasite of the brown soft scale is *Metaphycus luteolus*, which destroys the scale in its early instars before it can reproduce or cause substantial injury. **Organically acceptable methods:** Petroleum oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oil, Chlorpyrifos 4EC, Carbaryl 80S, Narrow Range Oil with Carbaryl, Methidathoin 25WP, Narrow Range Oil with Methidathoin, Malathion
Black Scale	**Organically acceptable methods:** Petroleum oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Metaphycus Helvolus, Narrow Range Oil, Carbaryl 80S, Carbaryl with Narrow Range Oil, Methidathion 25WP, Methidathion with Narrow Range Oil, Malathion (8 spray), Malation with Narrow Range Oil.
Citricola Scale	**Organically acceptable methods:** Petroleum oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oil (Light Infestations), Chlorpyrifos 4EC (Moderate to Heavy Infestations), Along with Methidathion 25WP, Malathion, Carbaryl 80S
Cottony Cushion Scale	**Biological control:** Two natural enemies effectively control the cottony cushion scale. The *Vedalia beetle, Rodolia cardinalis*. The parasitic fly *Cryptochaetum iceryae*, is a very effective predator of the scale in coastal areas. **Pesticides:** listed in the next column in order of their effectiveness.	Vedalia Beetles, Malathion, Methidathion 25WP, Carbaryl 80S
Citrus Thrips	**Biological control:** Predaceous mite, *Euseius tularensis*, spiders, lacewings, dustywings, and minute pirate bugs. **Organically acceptable methods**: Sabadilla sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Sabadilla, Spinosad with Narrow Range Oil, Abamectin with Narrow Range Oil, Cyfuthrin 2E, Formetanate Hydrochloride Formetanate 92SP , Dimethoate 4EC
Greenhouse Thrips	**Cultural control:** Planning for an early harvest in severely affected fields can minimize amount of damage. **Biological control:** Only one effective predator is known, the minute larval parasite, *Thripobius semiluteus*. **Pesticides:** listed in the next column in order of their effectiveness.	Pyrethrin (repeat application may be needed)
Fruittree Leafroller	**Biological control:** General predators prey on small larvae, and *Trichogramma* spp. may parasitize eggs. **Organically acceptable method:** sprays of Bt.	Bt,. Cryolite 96, Chlorpyrifos 4E, Carbaryl 4F, Naled 8E, Methomyl 2.4, Carbaryl 80S
Cutworms	**Biological control:** Two parasites attack citrus cutworm larvae and are highly effective. **Organically acceptable method:** Sprays of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Cryolite 96, 96WP, Chlorpyrifos 4E, Carbaryl 4F, Naled 8E, Methomyl 2.4, Carbaryl 80S
Beet Armyworm	*Treatment of the beet armyworm is rarely required.	
Loopers	*Teatment for loopers on citrus is rareley required	
California Orangedog	**Cultural control:** California orange dog prefers sweet fennel, which may be interplanted as a trap crop in strips with citrus and mowed regularly after the egg laying peak in each generation. **Biological control:** A parasitic wasp, *Hyposoter* spp. is effective. **Organically acceptable methods:** applications of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Cryolite 96
Orange Tortrix	**Biological control:** Two wasps*, Apanteles aristolidae* and *Exochus* sp. are effective predators. **Organically acceptable methods**: applications of Bt. **Recommended pesticdes** listed in the next column in order of their effectiveness.	Bt, Cryolite 96, Chlorpyrifos 4E, Carbaryl 4F, Naled 8E, Methomyl 2.4, Carbaryl 80S
Omnivorous Leafroller	**Biological control:** Several parasites attack the larvae of leafrollers. The most common are a tachinid fly, *Erynnia tortricis*, and *Elachertus proteiteratis*. **Organically acceptable methods:** applications of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Cryolite 96, Chlorpyrifos 4E, Carbaryl 4F, Naled 8E, Methomyl 2.$, Carbaryl 80S
Western Tussock Moth	**Biological control:** A dernestud egg predator, *Trogoderma sternale*, is common in some areas of southern California. Also, a small parasitic wasp, *Dibrachys* spp. **Organically acceptable methods:** applications of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Cryolite 96, Chlorpyrifos 4E, Carbaryl 4F, Naled 8E, Methomyl 2.4, Carbaryl 80S
Amorbia (Western Avocado Leafroller)	**Biological control:** One of the most effective egg parasites is the tiny wasp, *Trichogramma platneri*. Organically acceptable methods: applications of Bt. **Pesticides:** listed in the next column in order of their effectiveness.	Bt, Cryolite 96, Chlorpyrifos 4E, Carbaryl 4F, Naled 8E, Methomyl 2.4, Carbaryl 80S
Pink Scavenger Caterpillar	*Treatment is rarely needed.	
Citrus Red Mite	**Cultural control:** Good irrigation reduces mite outbreaks. **Biological control:** Predaceous mites, predaceous insects are important in mite regulation. **Organically acceptable methods:** Petroleum oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oil (Highest rate in July & August), Fenbutatin Oxide 50WP, Propargite CR, Dicofol 4E, Pyrdaben WSB
Twospotted Spider Mite	**Cultural control:** Adequate irrigation will reduce the impact of spider mite feeding. **Biological control:** . Predators include, *Scolothrips sexmaculatus*, the spider mite destroyer, *Stethorus picipes*, minute pirate bugs, Orius spp., and the beneficial mite, *Euseius tularensis*. **Organically acceptable methods:** Petroleum oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Narrow Range Oil (highest rate during July and August), Fenbutatin Oxide 50WP, Abamectin, Propargite 30W, Dicofol 4E
Broad Mite	**Organically acceptable methods:** Wettable sulfur sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Wettable sulfur, Dicofol 4E, Chlorpyrifos 4E
Citrus Bud Mite	**Organically acceptable methods**: Oil sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Fenbutatin Oxide 50W with Narrow Range Oil, Abamectin 0.15 EC, Narrow Range Oil, Chlorpyrifos 4E with Narrow Range Oil
Citrus rust mite (silver mite)	**Organically acceptable methods:** Wettable sulfur sprays. Pesticides: listed in the next column in order of their effectiveness.	Fenbutatin Oxide 50W, Wettable Sulfur 45-60 lbs./acre
Yuma Spider Mite	**Organically acceptable methods:** Wettable sulfur sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Wettable Sulfur 60 lbs/ acre, Dicofol 4E

Sixspotted Mite	**Organically acceptable methods:** Wettable sulfur sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Wettable Sulfur 45-60 lbs/ acre, Dicofol 4EC
Citrus Flat Mite	**Organically acceptable methods:** Wettable sulfur sprays. **Pesticides:** listed in the next column in order of their effectiveness.	Wettable Sulfur 60 lbs./ acre, Dicofol 4EC
Aphids	**Biological control:** A number of naturally occurring predators parasites and fungal diseases usually keep aphid populations under control. A small aphid population should be considered beneficial. **Organically acceptable method:** Sprays of pyrethrin / rotenone. **Pesticides:** listed in the next column in order of their effectiveness.	Pyrethrin/Rotenone, Pyrethrin/Rotenone with Narrow Range Oil, and Dimethoate 4E
Ants	**Cultural controls:** Use of sticky materials to keep aunts off tree. **Biological control:** No effective natural enemy of the Argentine ant are known. **Pesticides:** listed in the next column in order of their effectiveness.	Sticky Polybutene Materials, Abamectin 0.0.11%, Chlorpyrifos 4E
Fuller Rose Beetle	**Cultural control:** Skirt pruning and trunk treatment. **Biological controls:** Include an egg parasite, *Fidiobia citri.* **Pesticides:** listed in the next column in order of their effectiveness.	Sticky Polybutene Materials, Cryolite 96 Carbaryl 80S
Katydids	**Pesticides:** listed in the next column in order of their effectiveness.	Cryolite 96, Spinosad, Naled 8E, Chlorpyrifos 4EC, Dimethoate 4
Mealybugs	**Biological control**: Naturally occurring parasites provide good control of the mealy bugs. **Pesticides:** listed in the next column in order of their effectiveness.	Cryptolaemus Montrouzier, Chlorpyrifos 4E with Narrow Range Oil (1.2-1.4 gal/100 acre
Potato Leafhopper	**Organically acceptable methods:** hydrated lime sprays.	Hydrated Lime (15-30 gal/ 100gal)
Whiteflies	**Cultural control:** Pruning and controlling dust. **Biological control:** through natural enemies.	Bt
Brown Garden Snail	**Cultural control**: Skirt Pruning, trunk banding. **Pesticides:** listed in the next column in order of their effectiveness.	Rumina Decollata, Copper Bands, Copper Sulfate, Metaldehyde G, Iron Phosphate G, Azinphosmethyl 2L

Table B 9. List of major pests (insects and mites) on corn (Godfrey et al., 2000)

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Seedcorn Maggot	**Cultural control**: Fields can be plowed or disced early to make it less attractive to egg laying adults. **Pesticides:** listed in next column in order of their effectiveness.	Lindane, Chlorpyrifos 50SL, Diazinon 50W
Wireworms	**Pesticides:** listed in next column in order of their effectiveness.	Lindane 75, Chlorpyrifos 50SL
Cutworms	**Cultural control**: Eliminate weeds two weeks before planting. **Pesticides:** listed in next column in order of their effectiveness.	Permethrin 2E, Chlorpyrifos 4E, Carbaryl
Flea Beetles	**Cultural control**: Keep fields free of weeds. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl XLR, 4F, 50W
Grasshoppers	**Pesticides:** listed in next column in order of their effectiveness.	Carbaryl 80S, XLR plus, Malathion 8E
Aphids	**Biological Control:** Parasites and predators can effectively keep populations down. These include the parasite, *Lysiphlebus testaceipes* and predators such as lacewings, lady beetles, and syriphid flies. **Pesticides:** listed in next column in order of their effectiveness.	Dimethoate 400, Esfenvalerate, Endosulfan 3EC, Chlorpyrifos 4E
Spider Mites	**Cultural control:** Keep field parameter clear of weed hosts **Biological control**: Use of predatory mites. **Pesticides:** listed in next column in order of their effectiveness.	Propargate
Thrips	**Cultural control:** Keep fields free of weeds. **Biological Control:** Minute pirate bugs. **Pesticides:** listed in next column in order of their effectiveness.	
Armyworms	**Pesticides:** listed in next column in order of their effectiveness.	Methomyl, Bt, Esfenvalerate, Permethrin 3.2EC
Corn earworms	**Cultural control:** Early planting in sweet corn. **Biological control:** Predators such as *Trichogamma* spp. **Pesticides:** listed in next column in order of their effectiveness.	Methomyl, Esfenvalerate, Permethrin 3.2EC, Chlorpyrifos 4E, Bt
Cucumber Beetles	**Biological control**: Parasitic tachinid fly, *Celatoria diabroticae*.	Treatment is rarely required.
Corn Stunt Leafhopper	**Cultural control**: Leafhopper populations will be greatly reduced if planting is coordinated with low population times.	

Table B 10. List of major pests (insects and mites) on Tomato (Zalom et al., 2001).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Tomato fruitwom	**Biological control:** Parasitic wasp can keep the worm population down to acceptable level **Pesticides**: listed in next column in order of their effectiveness.	Esfenvalerate .66ec, Fenpropathrin 24ec, Methomyl 90wsp, Spinosad, Bt, Methamidophos 4ec, Carbaryl 80s, Trichogramma, Pyrethrin
Stink bug	**Biological control:** Parasitic wasp can keep the worm population down to a acceptable level. **Pesticides** in the next column may be applied with best results coming from a ground spray rather than air	Methamidophos 4ec, Dimethoate E267, Methomyl 90wsp, Endosulfan 3ec, Imidaclorpid 2f, Insecticidal soap,
Lygus bug	*Treatment not recommended unless large numbers of lygus bugs are detected	Fenpropathrin 2.4ec, Endosulfan 3ec, Methomyl 90wsp, Malathion , Dimethoate E267
Beet armyworm	**Organically acceptable methods:** Bt sprays **Pesticides:** listed in next column in order of their effectiveness	Methomyl 90wsp, Bt, Esfenvalerate .66ec, Fenpropathrin 2.4ec, Spinosad, Tebufenozide
Tomato pinworm	**Biological control:**Egg parasites can be important in controlling pinworm populations **Pesticides:** listed in next column in order of their effectiveness	Mating disruptants, Methomyl 90wsp, esfenvalerate .66ec, Pyrethrin, Pyrethrin/Rotenone Abamectin .15ec
Yellowstripped armyworm	**Organically acceptable methods**: Bt sprays **Pesticides:** listed in next column in order of their effectiveness	Methomyl 90wsp, Esfenvalerate .66ec, Bt, Tebufenoxide
Green peach aphid and other early season aphids	**Biological control**: Lady beetles, Lace wing larvae, and syrphid larvae	Lambda-Cyhalothrin T, Dimethoate E267, Oxamyl L, Malathion, Endosulfan 3ec, Insecticidal soap, Pyrethrin, Pyrethrin/Rotenone
Potato aphid	**Biological control:** Naturally occurring parasites and predators of the potato aphid are common and can provide control. Avoid sprays that will disrupt these natural predators. **Organically acceptable methods:** Insecticidal soap or pyrethrin. **Pesticides:** listed in next column in order of their effectiveness *ground spray recommended.	Dimethoate E267, Methamidophos 4ec, Lambda-Cyhalothrin, Fenpropathrin 2.4ec, Endosulfan 3ec, malathion, Insecticidal soap, Pyrethrin, Pyrethrin/Rotenone
Tomato russet mite	**Organically acceptable methods:** Sulfur sprays.	Sulfur dust
Loopers	**Biological control:** Naturally occurring parasites and predators of the Loopers are common and can provide control. Avoid sprays that will disrupt these natural predators. **Organically acceptable methods:** Bt sprays. **Pesticides:** listed in next column in order of their effectiveness. *Spot treatment is recommended to preserve natural parasites.	Bacilllus thuringiensis, Esfenvalerate .66ec, Methomyl 90wsp
Leafminers	**Pesticides:** listed in next column in order of their effectiveness. *The success of applications depends largely on which species is present.	Abamectin .15ec, Cyromazine wsp, Spinosad, Oxamyl l, Esfenvalerate .66ec, Metamidophos 4ec,
Beet leafhoppers	**Pesticides:** listed in next column in order of their effectiveness. *Insecticide applied directly to fields do not prevent leafhoppers from transmitting curly top virus and do not reduce the incidence of disease.	Carbaryl 80s
Hornworms	**Biological control:** Naturally occurring parasites and predators of the Hornworm are common and can provide control. Avoid sprays that will disrupt these natural predators. **Organically acceptable methods:** Bt sprays **Pesticides**: listed in next column in order of their Effectiveness. *Spot treatment is recommended to preserve natural parasites.	Bt, Esfenvalerate .66ec, Carbaryl 80s,
Whiteflies	**Cultural control:** Plant tomatoes one half mile upwind of key silver leaf whitefly host such as melons, cole crops, and cotton also, adult whiteflies are repelled by silver or aluminum colored mulches. **Biological control:** Several wasp, bigeyed bugs, lacewing larvae, and lady beetle larvae are all natural predators of the white fly. **Pesticides:** listed in next column in order of their effectiveness.	Imidacloprid 2f, Oxamyl, Esfenvalerate .66ec, Endosulfan 3ec
Flea beetles	**Cultural control:** If possible rotate tomatoes with a non-host crop. **Pesticides:** listed in next column in order of their effectiveness. *Spot treatment is recommended to preserve natural parasites.	Carbaryl 80s, Azinphosmethyl 2l, Endosulfan3ec
Cutworms	**Cultural control:** Tillage at least two weeks before planting will help destroy plant residue that could harbor larvae. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl (bait 5 %)
Wireworms	**Pesticides:** listed in next column in order of their effectiveness.	Imidaclorpid 2f
Garden symphlyans	**Cultural control:** Reduce the amount of plant material or manure that is applied to the soil, but has not yet been composted. **Pesticides:** listed in next column in order of their effectiveness.	Dizinon AG 600wbc

Table B 11. List of major pests (insects and mites) on Cucurbits (Godfrey et al., 2001).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Cutworms	**Cultural Control:** Eliminate weeds from surrounding fields two weeks prior to planting. Destroy plant residue from previous crops. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl (5 % Bait), Diazinon 14g, Diazinon 50w, Diazinon AG500, Esfenvalerate, Methomyl 90sp
Seedcorn Maggot	**Cultural Control:** Disc or plow early in the season to incorporate residues from the previous crops and allow time for residues to completely decompose. Speed up germination with moist soil and shallow planting depths. The longer the germination the greater the risk of infestation. **Pesticides:** listed in next column in order of their effectiveness.	Lindane F, Chlorpyrifos 50sl, Metan Sodium
Wireworms	**Cultural Control:** Disc or plow early in the season to incorporate residues from the previous crops and allow time for residues to completely decompose. Do not plant seeds in cold moist soil. **Pesticides:** listed in next column in order of their effectiveness.	Lindane f, Diazinon 14g, diazinon 15w, Metam Sodium
Cucumber Beetle	**Biological Control:** Cucumber beetles have a number of natural enemies, the most important being a parasitic tachinid fly. However natural enemies are rarely effective in controlling these populations. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl 4f, Esfenvalerate, Endosulfan 3ec, Cryolite, Pyrethrin/Rotenone
Green Peach Aphid	**Cultural Control:** Place row covers over the seed bed following planting and remove after first bloom (**this is not recommended in the san joaquin valley**). Silver reflective plastic mulches applied at planting are effective. **Biological Control:** Naturally occurring populations of the covergent lady beetle may provide effective control in the spring; However, release of this bug has been shown to not be effective. **Organically Acceptable Methods:** Insecticidal soaps and certain narrow range oils. **Pesticides:** listed in next column in order of their effectiveness.	Methomyl lv, Oxydemeton Methyl,Insecticidal soap,Narrow range oils
Melon Aphid	**Cultural Control:** Remove and bury severely infested plants as they appear in spring, this will help prevent rapid spreading. Silver reflective mulches. Avoid over fertilizing with nitrogen **Biological Control:** Naturally occurring populations of the covergent lady beetle may provide effective control in the spring; however, release of this bug has been shown to not be effective. **Organically Acceptable Methods:** Insecticidal soaps and certain narrow range oils. **Pesticides:** listed in next column in order of their effectiveness.	Imidaclorpid 2f, Bifenthrin 2ec-cal, Endosulfan 50wp, Methomyl lv, Insecticidal soap, Narrow Ranre oils
Leafhoppers	**Cultural Control:** After harvest destroy crop residue as soon as possible to destroy breeding areas. **Pesticides:** listed in next column in order of their effectiveness.	Esfenvalerate, Oxydementon Methyl, Diazinon, Dimethoate, Methomyl lv, Pyrethrin/Rotenone
Leafminers	**Cultural Control:** Cutting forage crops and deep plowing after harvesting crop. Plants that are not stressed for moisture can better tolerate this pest. **Biological Control**: The destruction of beneficials by frequent applications of organophosphorus, carbmates, and pyrethroids applied to control other pest can result in leafminer outbreaks.. **Pesticides:** listed in next column in order of their effectiveness.	Abamectin .15ec, Cyromazine, Esfenvalerate, Oxamyl, Dimethoate e267, Diazinon 50w, Diazinon ag500
Spider Mites	**Cultural Control:** Minimize dust and encourage naturally occurring predators and parasites by limiting chemical rates and the number of applications. **Biological Control:** Preserving natural predators by limiting chemical rates and the numbers of applications **Organically acceptable methods**: Sulfur sprays. **Pesticides:** listed in next column in order of their effectiveness.	Dicofol 35, Sulfur
Squash Bug	**Cultural Controls:** Destroy crop residues and reduce overwintering hiding places. **Pesticides:** listed in next column in order of their effectiveness.	Esfenvalerate, Endosulfan 3ec
Whiteflies	**Cultural Control:** Delaying planting or using host free periods may reduce severity of attack. **Biological Control**: Several species of wasp parasitize whiteflies. Whitefly nymphs are also preyed upon by bigeyed bugs, lacewing larvae, and lady beetles. **Organically Acceptable Methods:** Insecticidal soaps and certain oil sprays. **Pesticides:** listed in next column in order of their effectiveness.	Bifenthrin 2ec-cal, Permethrin 3.2ec, Endosulfan 3ec, Oxamyl, Esfenvalerate, Azinphosmethyl 50wp, Imidacloprid, Insecticidal Soap, Narrow Range oils
Beet armyworm	**Biological Control:** Parasitic wasp are important in controlling populations of this pest. **Organically Acceptable Methods:** Bt sprays. **Pesticides:** listed in next column in order of their effectiveness.	Bacillus thuringeinsis, Methomyl 90sp
Yellowstriped armyworm	**Biological Control:** Parasitic wasps are important in controlling populations of this pest. **Organically Acceptable Methods:** Bt sprays. **Pesticides:** listed in next column in order of their effectiveness.	Bacillus Thuringeinsis, Methomyl
Cabbage Loopers	**Biological Control:** The cabbage loopers have many natural enemies that will keep it numbers under control unless they are killed by insecticidal applications. **Organically acceptable methods:** Sprays of Bt. **Pesticides:** listed in next column in order of their effectiveness.	Bacillus Thuringeinsis, Cryolite,Esfenvalerate, Methomyl 90
Crickets	**Cultural Control:** Immediate post harvesting disking of fields aids area control as long as crickets are not allowed to migrate. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl (5 % Bait)
Darkling Beetles	**Cultural control:** Keep fields and ditches free of weeds. Reduce organic matter in soil by fallowing. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl (5 % Bait), Malathion 8e
European Earwig	**Cultural Control:** Keep the tops of beds dry during the last irrigation. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl (5 % Bait)
Flea Beetles	**Cultural Control:** Eliminate plant stress from insufficient moisture and powdery mildew. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl 80s, Endosulfan 3ec, Methomyl 90sp, Pyrethrin/Rotenone, Cruolite
Grass Hoppers	**Cultural Control:** Keep fields and surrounding areas weed free. **Pesticides:** listed in next column in order of their effectiveness.	Carbaryl (5 % Bait), Sevlin xlr plus, Esfenvalerate, Malathion
Thrips	**Cultural Control:** Disking weeds before they flower can lessen attraction to the fields to the thrips. **Pesticides:** listed in next column in order of their effectiveness.	Diazinon 50w, Diazinon ag500, Dimethoate 267ec
Driedfruit Beetle	**Cultural control**: When possible remove or disc rotten fruit. **Pesticides:** listed in next column in order of their effectiveness.	
Vinegar Flies	**Cultural Control**: Remove or disc under decaying fruit.	
Green Stink Bug	**Pesticides:** listed in next column in order of their effectiveness.	Esfenvalerate
False Chinch Bug	**Pesticides:** listed in next column in order of their effectiveness.	Endosulfan 50wp

Table B 12. List of major pests (insects and mites) on sugarbeets (Godfrey et al., 2001).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Green peach aphid	**Cultural Control:** Following the planting dates established by the grower and processor agreement which avoid periods of major aphid flights. A second and equally important factor in reducing the virus spread is good field sanitation. **Biological Control:** The green peach aphid is attacked by a number of common predators and parasites and is susceptible to the fungus disease that commonly attacks aphids. **Pesticides:** listed in next column in order of their effectiveness.	Imidaclorpid 75st, Phjorate 20g, Endosulfan 50wp, Oxydemeton-methyl SC, Aldicarb 15g
Bean aphid	**Cultural Control:** Following the planting dates established by the grower and processor agreement which avoid periods of major aphid flights. A second and equally important factor in reducing the virus spread is good field sanitation **Biological Control:** The green peach aphid is attacked by a number of common predators and parasites and is susceptible to the fungus disease that commonly attacks aphids **Pesticides:** listed in next column in order of their effectiveness.	Imidaclorpid 75st, Phorate 20g, Diazinon 50w, Methomyl SP, Endosulfan 50wp, Oxydemeton-Methyl SC, Chlorpyrifos 4e
Other aphids	**Cultural Control:** Infested fields should be thoroughly worked immediately following harvest and all ground keepers (Sugarbeets left in the field) destroyed. **Biological Control:** Sugar beet root aphid is attacked by the larvae of a predatory fly and is susceptible to a fungus disease. *****There are no pesticides for this insect	
Sugarbeet root aphid	**Cultural Control:** Infested fields should be thoroughly worked immediately following harvest and all ground keepers (Sugarbeets left in the field) destroyed **Biological Control:** Sugar beet root aphid is attacked by the larvae of a predatory fly and is susceptible to a fungus disease. *****There are no recommended pesticides for this insect	
Beet leafhopper	**Pesticides:** listed in next column in order of their effectiveness.	Phorate 20g, Aldicarb 15g
Empoasca Leafhoppers	**Pesticides:** listed in next column in order of their effectiveness.	Phorate 20g, Oxydemeton-methyl SC, Naled
Armyworms	**Biological Control:** Army worm larvae are attacked by parasitic wasp. **Pesticides:** listed in next column in order of their effectiveness.	Methomyl LV, Chlorpyrifos 4e, Bacillus Thuringeinsis
Webworms	**Cultural Control:** Injury and defoliation appear to be worst in weedy fields. Therefore , keep fields weed free particularly from pigweed and lambsquarter. **Pesticides:** listed in next column in order of their effectiveness.	Bt, Methomyl lv, Endosulfan 50wp,
False Celery Moth	*There are no economic thresholds established for false celery moth. No chemicals are registered for control of the false celery moth.	
Saltmarsh Catepillar	**Biological Control:** The eggs are attacked by a number of predators and parasites. **Pesticides:** listed in next column in order of their effectiveness.	Bt
Cutworms	**Cultural Control:** Spring plowing and disking are useful in keeping the numbers of cutworms down. Field should also be kept weed free. **Biological Control:** Cutworms are attacked by a number of predators, parasites and diseases, but for now these are not to be considered good ways to control cut worm populations. **Pesticides:** listed in next column in order of their effectiveness.	Bt, Chlorpyrifos 4e, Methomyl lv, Carbaryl 4f
Spider Mites	**Cultural Control:** Mites are more serious on stressed plants, particularly water stressed or dust covered plants. Observe good cultural practices including adequate nutrition and irrigation. **Biological Control:** Natural enemies can keep spider mites populations in check and may bring spider mites under control. **Pesticides:** listed in next column in order of their effectiveness.	Naled, Sulfur dust Microionized sulfur
Wireworms	**Cultural Control:** In fields known to contain wireworm larvae, fallow during the summer with frequent tillage Pesticides: listed in next column in order of their effectiveness.	Diazinon 14g, Diazinon 50w, Diazinon ag500,
Whiteflies	**Cultural Control:** When possible plant sugar beets ½ mile upwind of host crops. Maintain good sanitation. **Biological Control:** Several species of wasps are natural enemies of the whiteflies. **Pesticides:** listed in next column in order of their effectiveness.	Endosulfan 3e, Insecticidal soap, Narrow range oils
Pea Leafminer	**Biological Control**: Several species of wasps are natural enemies of the pea leafminer. Some of these species are available on the commercial market. * At this time there are no known pesticides for this insect	
Maggots	**Pesticides:** listed in next column in order of their effectiveness.	Phorate 20g, Diazinon 14g, Chlorpyrifos 15g
Flea Beetles	**Cultural Control:** Fields should be kept weed free. Heavily damaged fields should be replanted. **Pesticides:** listed in next column in order of their effectiveness.	Imidacloprid 75st, Methomyl lv, Carbaryl 4f
Grasshoppers	*A large contingent of natural enemies serve to hold grasshopper populations in check most years. However, in outbreak years and particularly after an invasion, other intervention will likely be needed. **Pesticides:** listed in next column in order of their effectiveness.	Malathion 57ec

Table B 13. List of major pests (insects and mites) on cotton (Godfrey et al., 2001).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Webspinning spider mites	**Cultural Control:** Water stressed plants stimulate spider mite outbreaks. In addition sprinkler irrigation has been observed to suppress spider mites. **Biological control:** Managing spider mites requires preserving biological control as long as possible by avoiding early season broad spectrum insecticide applications. **Organically acceptable methods:** Biological control as releases of predatory mites and sprays of insecticidal soap , oils, and sulfur. **Pesticides:** listed in next column in order of their effectiveness.	Abamectin, Dicofol MF, Propargite, Aldicarb 15g, Phorate 20g, Hexytiazox 50wp, Amitra 1.5ecz, Sulfur dust, Insecticidal soap, Narrow Range oils
Lygus bugs	**Cultural Control:** Closely watch cotton fields that are downwind from lygus infested crops. **Pesticides:** listed in next column in order of their effectiveness.	Aldicarb 15g, Dimethoate 267, Methamidophos 4ec, Oxamyl C-LV, Methidathion 25wp, Acephate75s, Imidacloprid 1.6f, Bifenthrin 2ec-cal, Cyfluthrin, Zeta-cypermethrin 1.5ew, Tralomethrin
Silverleaf whitefly	**Cultural Control:** When possible plant cotton at least ½ mile upwind from other key white fly host such as melons and cole crops. Maintain good sanitation in areas of winter/ spring host crops and weeds by destroying and removing all crop residue as soon as possible. **Biological Control:** Several wasp parasitize whiteflies. Whitefly nymphs are also preyed upon by bigeyed bugs, lacewing larvae, and lady beetles. However these predators of the whitefly do not below damaging numbers. **Pesticides:** listed in next column in order of their effectiveness.	Buprofezin 70wp, Pyriproxyfen .86ec, endosulfan 3ec, Bifenthrin 2ec-cal, oxamyl C-LV, profenofos 8e, Chlorpyrifos 4e, Acephate 90s, Fenpropathrin 2.4ec, Amitraz 1.5ec, Insecticidal Soap, Narrow range oils, Azadiractin
Cotton aphid	**Cultural Control:** Higher aphid populations consistently develop on late planted cotton rather than earlier planted cotton. **Biological control:** During the pre-squaring period of the crop natural control of aphids is generally strong. **Organically acceptable methods:** Spraying of insecticidal soaps, oils, and azadirachtin. **Pesticides:** listed in next column in order of their effectiveness.	Imacloprid 1.6f, Imacloprid 75st, Aldicarb 15g, Endosulfan 3ec, chlorpyrifos 4ec, Oxydemeton-methyl, Prophenofos 8e, Amitraz 1.5ec, Oxymyl C-LV, Naled, Methomyl, Carbofuran 4f, Insecticidal soap, Narrow range oils, azadirachtin
Beet armyworm	**Biological control:** Many predators and parasites combine to substantially maintain armyworm populations at low levels. Insecticide sprays for other pest will disrupt natural control. **Organically Acceptable Methods:** Spraying with Bt. **Pesticides:** listed in next column in order of their effectiveness.	Bt, Tebufenozide 2f, Spinosad, Indoxacarb, Diflubenzuron 25w, Chlorpyrifos 4ec, Profenofos 8e, Thiodicarb 3.2, Bifenthrin 2ec-cal, Esfenvalerate .66ec, Methomyl
Cotton bollworm	**Cultural control:** Cotton bollworms are attracted to rank growing plants; keep water, fertilizer, and plant density at recommended levels to avoid rank growth. **Biological Control:** There are many naturally occurring predators of the cotton bollworm. Insecticide sprays for other pest may disrupt this natural control and may result in severe outbreaks. **Organically acceptable methods**: Bt sprays. **Pesticides:** listed in next column in order of their effectiveness.	Bt, Methamidaphos 4ec, Methomyl
Tobacco budworm	**Cultural control:** Tobacco budworms are attracted to rank growing plants; keep water, fertilizer, and plant density at recommended levels to avoid rank growth. **Biological Control:** There are many naturally occurring predators of the Tobacco budworm. Insecticide sprays for other pest may disrupt this natural control and may result in severe outbreaks. **Organically acceptable methods:** Bt sprays. **Pesticides:** listed in next column in order of their effectiveness.	Bt, Esfenvalerate .66ec, Prophenofos 8e
Alfalfa and cabbage loopers	**Cultural Control:** The use of Bt cotton **Biological Control**: There are many naturally occurring predators of the loopers. Insecticide sprays for other pest may disrupt this natural control and may result in severe outbreaks. **Organically acceptable methods:** Bt sprays. **Pesticides:** listed in next column in order of their effectiveness.	Bt, Tebufenozide 2f, Indodoacarb, Acephate 75s, Methomyl
Western yellowstriped armyworm	**Organically acceptable methods:** Sprays of Bt. **Pesticides:** listed in next column in order of their effectiveness.	Bt, Tebufenozide 2f,Indoxacarb, Spinosad, Acephate 75s, Methomyl
Saltmarsh catepillar	**Cultural Control:** The use of BT cotton **Organically acceptable methods:** Bt sprays. **Pesticides:** listed in next column in order of their effectiveness.	Bt, Spinosad, Tebufenozide 2f, Carbaryl 80s, Methomyl
Cotton leaf perferator	**Cultural Control:** The use of BT cotton **Pesticides:** listed in next column in order of their effectiveness.	Aldicarb 15g, Esfenvalerate .66ec
Omnivorous leafroller and false celery leaftier	**Pesticides:** listed in next column in order of their effectiveness.	Carbaryl 80s, Methomyl
Pink Bollworm	**Cultural Control:** The use of BT cotton. Eliminate food for the pink bollworm by cutting of irrigation early enough to stop production of green bolls by early September. Regardless of when cotton is terminated, immediately shred the cotton plants following harvest . Winter irrigations can reduce populations by 50-70% . **Organically acceptable methods:** The use of mating disruptants. **Pesticides:** listed in next column in order of their effectiveness.	Gossyplure, Chlorpyrifos 4ec, Cypermethrin 2,5ec, Esfenvalerate .66ec
Stink bugs	**Pesticides:** listed in next column in order of their effectiveness.	Endosulfan 3ec
Thrips	**Pesticides:** listed in next column in order of their effectiveness.	Acephate 75s
Cutworms	**Cultural Control:** Keep fields free of weeds and cover crops for at least three weeks before planting. **Pesticides:** listed in next column in order of their effectiveness.	Chlorpyrifos 4ec
Darkling Beetles	*Currently there ae no bait products registered for the control of darkling beetles.	
Seedcorn maggots	**Pesticides:** listed in next column in order of their effectiveness.	Chlorpyrifos 50sl, Lindane, Acephate
Wireworms	**Pesticides:** listed in next column in order of their effectiveness.	Lindane
Field crickets	*Currently there are no bait products listed for the control of field crickets	
False chinch bug	**Cultural Control:** Early season control of cruciferous weed host well before planting will eliminate the probability of this pest occurring in cotton	
Leafhoppers	**Pesticides:** listed in next column in order of their effectiveness.	Aldicarb 15g, Malathion 8e, Methamidophos 4ec
Grasshoppers	**Pesticides:** listed in next column in order of their effectiveness.	Carbaryl 80s, Malathion 8e, Naled 8ec

Table B 14. List of major pests (insects and mites) on alfalfa (Summers and Godfrey et al., 1999).

Common Name	Control Methods	Pesticide formulation if treatment is necessary
Alfalfa Caterpillar	**Cultural Control:** Damage may be avoided by early cutting of the crop. This cutting should be timed to maximize yield, but to also avoid serious pest damage. **Biological Control:** An important parasite of the alfalfa caterpillar is Cotesia Medicaginis, a dark brown to black wasp. **Pesticides** listed in the next colum in order of their effectiveness	Bacillus Thuringiensis
Alfalfa Weevil	**Cultural Control:** After larvae begin to appear, fields should be checked at 2 to 4 day intervals. Cutting the crop as soon as most of the plants are I bud stage can sometimes prevent serious damage. **Biological Control:** The parasitic wasp Bathyplectes Curculionis is present throughout the range of the alfalfa weevil, but is no longer able to control populations. **Pesticides** listed in the next colum in order of their effectiveness	Cabofuran 4F, Chlorpyrifos 4EC, Malathion 8E, Phosmet 70W, Cyfluthrin 2E, Lambda-Cyhalothrin 2E
Beet Armyworm	**Cultural Control:** Early cutting will give satisfactory control if infestation occurs late in the cutting cycle. **Biological Control:** Natural enemies can provide good control of armyworms in many fields. **Pesticides** listed in the next colum in order of their effectiveness	Methomyl 90SP, Bacillus thuringiensis
Blue Aphid and Pea Aphid	**Biological Control:** The common aphid predator, Hippodamia Convergens, and other lady beetles attack and consume both of these aphid species. **Pesticides** listed in the next colum in order of their effectiveness	Chlorpyrifos 4EC, Dimetoate 2.67EC
Cowpea Aphid	**Biological Control:** Two common aphid parasites, Lysiphelbus and Diaraetialla have been identified from both high and low desert. Although parasitism as high as 95% has been documented, population levels are so high that enough nonparasitized individuals remain to cause significant injury. **Pesticides** listed in the next colum in order of their effectiveness	Chlorpyrifos 4EC, Dimethoate 2.67EC
Egyptian Alfalfa Weevil	**Cultural Control:** Serious damage can sometimes be prevented by cutting the crop as soon as most of the plants are in bud stage. **Pesticides** listed in the next colum in order of their effectiveness	Carbofuran 4F, Chlorpyrifos 4EC, Malathion 8E, Phosmet 70W, Cyfluthrin 2E, Lambda-Cyhalothrin
Grasshoppers	**Pesticides** listed in the next colum in order of their effectiveness	Carbaryl 80SP, Carbaryl 5% bait, Malathion 8E
Leafhoppers	**Cultural Control:** If alfalfa is within a few day of harvest, early cutting will control leafhoppers **Pesticides** listed in the next colum in order of their effectiveness	Carbofuran 4F, Permethrin 3.2EC, Carbaryl 4F, Dimethoate, Chlorpyrifos 4EC
Mormon Cricket	**Cultural Control:** Because the insect can not fly, linear barriers of 10-inch strips of 28 to 30 gauge galvanized iron, held on edge with stakes driven into the ground may stop swarms. **Pesticides** listed in the next colum in order of their effectiveness	Carbaryl 5% bait
Sow Bugs or Pillbugs, and Crickets	**Pesticides** listed in the next colum in order of their effectiveness	Carbaryl 5% bait
Spider Mites	**Cultural Control:** Although spider mite infestations rarely occur, damaging populations are most commonly encountered under stress conditions. Minimizing those conditions through improved irrigation and proper cultural practices is the best method of control.	N/A
Spotted Alfalfa Aphid	**Biological Control:** Common reddish lady beetles attack and consume this aphid. Green lacewings can also be important in controlling aphids and many other predators. **Pesticides** listed in the next colum in order of their effectiveness	Chlorpyrifos 4EC, Dimethoate 2.67EC
Variegated and other Cutworms	**Cultural Control:** Tillage is important in controlling cutworm populations **Pesticides** listed in the next colum in order of their effectiveness	Carbaryl 5% bait
Webworm	**Cultural Control:** Early cutting may give satisfactory control.	N/A
Western Flower Thripes	* UC recommends that thrips not be treated in alfalfa. The destruction of natural enemy species by applications of chemicals is far more costly than any minor yield losses induced by thrips.	N/A
Western Yellow striped Armyworm	**Cultural Control:** Fields may be cut to avoid damage. Armyworms will often move out of cut fields, causing damage to adjacent fields. Migration can be avoided by placing barriers around fields. **Biological Control:** Natural enemies can provide good control of armyworms in many fields. **Pesticides** listed in the next colum in order of their effectiveness	Methomyl 90SP, Carbaryl 80SP

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