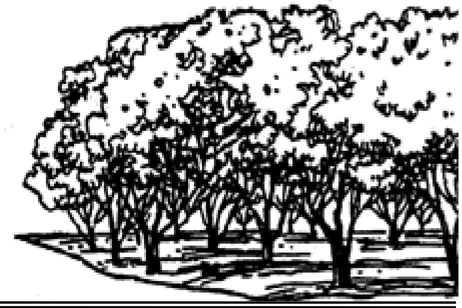
University of California **Cooperative Extension** **Butte County**

Almond Notes



Agriculture & Natural Resources

In this Sacramento Valley Almond News:
- Springtime disease control
- Simple Jar Test – how to evaluate spray compatibility
- Waterlogged orchards
- Implementing Frost Protection

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Springtime disease control

Joe Connell, UC Farm Advisor Butte Co.

Brown rot, jacket rot, shothole, scab, and anthracnose disease control efficacy is presented in the following tables showing relative fungicide effectiveness and appropriate timing for control of these diseases.

Full protection against **all** six diseases usually requires at least two fungicide applications during and shortly after bloom followed by continued treatments as needed if wet weather persists. Moisture from rain, fog, and dew favors all the diseases listed in the table.

Brown rot - This disease is favored by frequent rains accompanied by warm temperatures during bloom. Individual flowers from pink bud to the start of petal fall are susceptible. Flower parts including stigmas, anthers, and petals are all susceptible to infection.

Botrytis blossom blight, jacket rot, and green fruit rot - Infections are usually initiated on senescing floral parts. The fungus progresses from the diseased flower jackets into the developing fruit causing them to rot or drop. This disease is sporadic and associated with moisture and cool conditions during bloom and early nut development. Green fruit rot most commonly affects nuts that are tightly packed together in clusters.

Shothole - Occasionally a few blossom infections are found on the jackets. The primary concern is leaf infections which can lead to defoliation and yield loss. Periods of 10 to 16 hours of continuous moisture are needed for shothole infection of leaves. Therefore, the primary objective of shothole sprays is protection of the foliage from bloom until five weeks after petal fall. Once spore producing sporodoccia form in leaf lesions the disease can become epidemic if subsequent rains occur.

Scab - The scab fungus begins its seasonal cycle by producing spores on old twig lesions from around late March to mid-April. If rain occurs after twig lesions sporulate, an epidemic scab outbreak can be present by June. Scab infections occur on both leaves and hulls ultimately producing oily greyish black spots on both. Severe infections cause premature defoliation. This disease is favored by protracted spring rains. Sprays at five weeks after petal fall have controlled scab. Later sprays have provided additional control in wet springs.

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Leaf blight - With springtime moisture the leaf blight fungus attacks leaf petioles, and by June, infected leaves suddenly wither and die. During late autumn and winter the fungus grows from previously infected petioles into twigs to kill axillary buds. This disease can also be serious following summer rainfall. Sprays used from petal fall to five weeks after, have also controlled leaf blight in most seasons.

Anthracnose – This fungus overwinters as spores in infected mummies left on the tree or in dead twigs resulting from infections the previous year. New infections are initiated when spores are splashed by heavy continuous rains to the bloom or to the developing nuts. Infections can occur as long as rains continue thus requiring extended fungicide protection. Summer infections can occur if sprinkler irrigation contacts the tree canopy.

Spray materials must be **applied with good coverage** and **dried on** before rain to be effective and to reduce the chance of resistance developing. The "best" program for one orchard may not be the "best" for another. Different classes of materials should be rotated in a spray program to reduce the chances of resistance developing (and to reduce the loss of our currently effective materials).

See the UCIPM website, http://www.ipm.ucdavis.edu/PDF/PMG/fungicideefficacytiming.pdf for more information.

ALMOND: TREATMENT TIMING

Note: Not all indicated timings may be necessary for disease control.

Disease	Dormant	Bloom			Spring[1]		Summer	
		Pink bud	Full bloom	Petal fall	2 weeks	5 weeks	May	June
Alternaria	----	----	----	----	----	++	+++	+++
Anthracnose[2]	----	++	+++	+++	+++	+++	+++	++
Brown rot	----	++	+++	+	----	----	----	----
Green fruit rot	----	----	+++	----	----	----	----	----
Leaf blight	----	----	+++	++	+	----	----	----
Scab[3]	++	---	---	++	+++	+++	+	---
Shot hole[4]	+[5]	+	++	+++	+++	++	----	----
Rust	----	----	----	----	----	+++	+++	+[6]

Rating: +++ = most effective; ++ = moderately effective; + = least effective; ---- = ineffective

[1] Two and five weeks after petal fall are general timings to represent early postbloom and the latest time that most fungicides can be applied. The exact timing is not critical but depends on the occurrence of rainfall.

[2] If anthracnose was damaging in previous years and temperatures are moderate (63°F or higher) during bloom, make the first application at pink bud. Otherwise treatment can begin at or shortly after petal fall. In all cases, application should be repeated at 7- to 10-day intervals when rains occur during periods of moderate temperatures. Treatment should, if possible, precede any late spring and early summer rains. Rotate fungicides, using different fungicide classes, as a resistance management strategy.

[3] Early treatments (during bloom) have minimal effect on scab; the 5-week treatment usually is most effective. Treatments after 5 weeks are useful in northern areas where late spring and early summer rains occur. Dormant treatment with liquid lime sulfur improves efficacy of spring control programs.

[4] If pathogen spores were found during fall leaf monitoring, apply a shot hole fungicide during bloom, preferably at petal fall or when young leaves first appear. Re-apply when spores are found on new leaves or if heavy, persistent spring rains occur. If pathogen spores were not present the previous fall, shot hole control may be delayed until spores are seen on new leaves in spring.

[5] Dormant copper treatment seldom reduces shot hole infection but may be useful in severely affected orchards and must be followed by a good spring program.

[6] Treatment in June is important only if late spring and early summer rains occur.

ALMOND: FUNGICIDE EFFICACY

Fungicide	Resistance risk (FRAC)[1]	Brown rot	Jacket rot	Anthracnose	Shot hole	Scab[3]	Rust[3]	Leaf blight	Alternaria leaf spot[3]	PM-like[5]	Silver leaf
Adament	high (3/11)[3]	++++	++	++++	+++	+++	+++	ND	++	+++	----
Bumper/Tilt[4]	high (3)	++++	+/---	++++	++	++	+++	ND	++	+++	----
Distinguish**	high (9/11)	++++	++++	++++	++	ND	ND	ND	ND	ND	----
Indar	high (3)	++++	+/---	+++	++	++	NL	ND	+	ND	----
Inspire[4]	high (3)	++++	+	ND	++	+++	ND	ND	+++	+++	----
Inspire Super*	high (3/9)	++++	++	ND	++	+++	ND	ND	+++	ND	----
Luna Sensation*	medium (7/11)[3,7]	++++	++++	++++	++++	++++	+++	ND	+++	+++	----
Pristine	medium (7/11)[3,7]	++++	++++	++++	++++	++++	+++	ND	+++	+++	----
Quash	high (3)	++++	++	++++	++	+++	++++	ND	+++	+++	----
Quadris Top*	medium (3/11)[3]	++++	++++	++++	+++	++++	+++	ND	+++	+++	----
Quilt Xcel	medium (3/11)[3]	++++	++++	++++	+++	++++	+++	ND	+++	+++	----
Rovral + oil[8]	low (2)	++++	++++	----	+++	+/---	++	ND	+++[9]	ND	----
Scala[3]	high (9)[3, 7]	++++	++++	ND	++	----	ND	ND	+	----	----
Tebuzol (Elite*)	high (3)	++++	+/---	+++	++	++	+++	ND	+	ND	----
Topsin-M/T-Methyl/ Thiophanate-Methyl[2]	high (1)[2, 7]	++++	++++	----	----	+++[8]	+	+++[6]	----	++	----
Vangard	high (9)[3, 7]	++++	++++	ND	++	----	ND	ND	+[9]	----	----
Abound[4]	high (11)[3, 7]	+++	----	++++	+++	++++	+++	+++	+++[10]	+++	----
Elevate	high (17)[7]	+++	++++	----	+	ND	ND	ND	ND	ND	----
Gem[4]	high (11)[3, 7]	+++	----	++++	+++	++++	+++	+++	+++[10]	+++	----
Laredo	high (3)	+++	----	++	++	----	+	+++	----	+++	----
Rovral/Iprodione/Nevado	low (2)	+++	+++	----	+++	----	----	ND	++[9]	----	----
Bravo/Chloro-thalonil/Echo /Equus[11,12]	low (M5)	++	NL	+++	+++	+++	NL	NL	NL	----	----
Captan[4,12]	low (M4)	++	++	+++	+++	++	----	+++[6]	+	----	----
CaptEvate*	low (M4/17)	+++	+++	+++	+++	+++	----	+++	+	----	----
Maneb**	low (M3)	++	+	++	++	++	+++	++	----	----	----
Ph-D/Endorse*	medium (19)	++	++	----	++	----	ND	ND	+++	----	----
Rally[13]	high (3)	++	----	++	+/---	----	+	+++	----	+++	----
Ziram	low (M3)	++	+	+++	+++	+++	----	++	+	----	----
Copper[14]	low (M1)	+/---	+/---	----	+	+[15]	----	----	ND	----	ND
Copper + oil[14]	low (M1)	ND	ND	----	+	+++[15]	----	----	ND	----	ND
Lime sulfur[12]	low (M2)	+/---	NL	----	+/---	++[15]	++	NL	NL	----	NL
Sulfur[4,12]	low (M2)	+/---	+/---	----	----	++	++	----	----	+++	----
PlantShield	low	----	----	----	----	----	----	----	----	----	+++***

Rating: ++++ = excellent and consistent; +++ = good and reliable; ++ = moderate and variable; + = limited and/or erratic; +/--- = minimal and often ineffective; ---- = ineffective; NL = not on label; ND = no data

*** Registration pending in California**

****Not registered, label withdrawn or inactive**

*** Section 24C (special local needs) registration approved in California.

1 Group numbers are assigned by the Fungicide Resistance Action Committee (FRAC) according to different modes of actions (for more information, see http://www.frac.info/). Fungicides with a different group number are suitable to alternate in a resistance management program. In California, make no more than one application of fungicides with mode of action Group numbers 1, 4, 9, 11, or 17 before rotating to a fungicide with a different mode of action Group number; for fungicid with other Group numbers, make no more than two consecutive applications before rotating to fungicide with a different mode of action Group number.

2 Strains of the brown rot fungi *Monilinia laxa* and *M. fructicola* resistant to Topsin-M and T-Methyl have been found in some California almond orchards. MBC-resistant strains of the jacket rot fungus, *Botrytis cinerea* and powdery mildew fungi, have been reported in California on crops other than almond and stone fruits and may have the potential to develop in almonds with overuse of fungicides with similar chemistry. MBC-resistant strai of the scab fungus, *Cladosporium carpophilum*, have been found in California.

3 Field resistance of *Alternaria* sp. and *Cladosporium carpophilum* to QoI and SDHI fungicides has been detected in almond orchards. AP-resistant populations of *Monilinia* spp. have been found on other stone fruit crops in California.

4 Of the materials listed, only sulfur, Abound, Gem, and some of the DMI fungicides (FRAC Group No. 3) are registered for use in late spring and early summer when treatment is recommended.

5 PM-like refers to a powdery mildew-like disease on almond fruit that is managed with fungicides with activity against powdery mildew fungi.

6 Excellent control obtained when combinations of Topsin-M or T-Methyl and Captan are used.

7 To reduce the risk of resistance development start treatments with a fungicide with a multi-site mode of action; rotate or mix fungicides with different mode of action FRAC numbers for subsequent applications, use labeled rates (preferably the upper range), and limit the total number of applications/season.

8 Oil recommended is a "light" summer oil, 1-2% volume/volume.

9 Not registered for use later than 5 weeks after petal fall.

10 Efficacy reduced at high temperatures and relative humidity; experimental for Alternaria.

11 Bravo Ultrex, Bravo WeatherStik, Echo, Echo Ultimate, and Chlorothalonil are currently registered.

12 Do not use in combination with or shortly before or after oil treatment.

13 Efficacy is better in concentrate (80-100 gal/acre) than in dilute sprays.

14 The low rates necessary to avoid phytotoxicity in spring reduce the efficacy of copper.

15 "Burns out" scab twig lesions when applied at delayed dormant.

ALMOND: SUGGESTED DISEASE MANAGEMENT PROGRAMS BY FUNGICIDE FRAC[1] GROUPS

Note: Not all indicated timings may be necessary for disease control (*see* Treatment Timing Table). If treatments are needed based on host phenology, weather monitoring, inoculum models, or environmental-disease forecasting models, suggested fungicide groups are listed for each timing.

How to use this table:

1. Identify the disease(s) that need(s) to be managed. Know the disease history of the orchard especially from the previous season.
2. Select one of the suggested fungicide groups. *Numbers separated by slashes are pre-mixtures, whereas numbers grouped by pluses are tank mixtures.* If several diseases need to be managed, select a group that is effective against all diseases. Refer to fungicide efficacy table for fungicides belonging to each FRAC group. Group numbers are listed in numerical order within the suggested disease management program.
3. Rotate groups for each application within a season and, if possible, use each group only once per season, except for multi-site mode of action materials (e.g., M2) or natural products/biological controls (NP/BC).

Disease	Dormant	Bloom			Spring		Summer	
		Pink bud	Full bloom	Petal fall	2 weeks	5 weeks	May	June
Alternaria	----	----	----	----	----	2	3, 3/11 7/11 11 19	3, 3/11 7/11 11 19
Anthracnose	----	3, 3/11	3, 3/11 7/11 11	3, 3/11 11 M3 M4	3, 3/11 7/11 11 M3 M4	3, 3/11 7/11 11 M3 M4	3, 3/11 7/11 11 M3 M4	3, 3/11 7/11 11 M3 M4
Brown rot	----	1[2] 2 (+oil) 3, 3/11 9	1[2] 2 (+oil) 3, 3/11 9 7/11 11	1[2] 2 (+oil) 9 7/11	----	----	----	----
Green fruit rot	----	----	1[2] 2 (+oil) 9 7/11	----	----	----	----	----
Leaf blight	----	----	1[2] 2 3, 3/11 11	1[2] 2 3, 3/11 11 M3 M4	3, 3/11 11 M3 M4	----	----	----
Scab[4]	M1+oil, M2[3]	----	----	1[2] 7/11[2] 11[2] M3 M4 M5	1[2] 7/11[2] 11[2] M3 M4 M5	3, 3/11 7/11[2] 11[2] M2[3] M3 M4	M2[3] M4	----
Shot hole	M1	2 3, 3/11 9	2 3, 3/11 7/11 9 11	2 3, 3/11 7/11 9 11	7/11 11 M3 M4 M5	7/11 11 M3 M4 M5	----	----
Rust	----	----	----	----	----	3, 3/11 7/11 11 M3	3, 3/11 7/11 11	3, 3/11 7/11 11

[1] Group numbers are assigned by the Fungicide Resistance Action Committee (FRAC) according to different modes of actions (for more information, see http://www.frac.info/). Group numbers are listed in numerical order within the suggested disease management program. Fungicides with a different group number are suitable to alternate in a resistance management program. Refer to the fungicide efficacy table for fungicides belonging to each FRAC group.

[2] Strains of *Monilinia fructicola* and *M. laxa* resistant to Topsin-M, and T-Methyl are present in some California almond orchards. Resistant strains of the jacket rot fungus, *Botrytis cinerea*, and powdery mildew fungi have been reported in California on crops other than almond and stone fruits and may have the potential to develop in almond with overuse of fungicides with similar chemistry.

[3] Use liquid lime sulfur in dormant applications and wettable sulfur at and after pre-bloom.

[4] Apply petal fall treatments based on twig-infection sporulation model.

Simple Jar Test – how to evaluate spray compatibility

Franz Niederholzer, UC Farm Advisor, Sutter/Yuba Counties and Rhonda Smith, UC Farm Advisor, Sonoma County

Insecticides, fungicides, plant growth regulators, foliar fertilizers, and adjuvants--all can have a place in spray applications to orchards and vineyards. But do they all have a place in the same spray tank? Getting sludge from an incompatible mix out of a spray tank and hoses can be a dangerous, time-consuming and expensive process. Worse than that is a complex tank mix that sprays out, but doesn't do the job because of physical or chemical interactions in the tank that has changed the pesticide product in such a way that performance is compromised.

Will a convenient tank mix save you the time and cost of a second application? Or will it be a clumpy disaster in the tank? Do a jar test to find out before you spray. Most labels call for a jar test if there are compatibility questions with the mix, but many give limited instructions. If a detailed jar test is described on the label, follow those instructions. However, if the label says something vague like "add the proportionate amounts to a quart of water", follow the guidelines presented here.

The basic strategy for a jar test is to add ingredients in the order of most difficult to disperse first, stir/shake vigorously, and see what the mixture looks like. The following is a starting point and not the only way to perform a jar test. The following information comes from page 94 of the University of California's ANR Publication 3324 and input from scientists at Syngenta Crop Protection.

Add a pint of spray water -- from the water source you will use to fill the tank -- to a clean, one quart glass jar.

1. Check spray water pH.
2. If needed, adjust the spray water pH to the range required by pesticide label(s).
3. Add the materials to the jar you plan to use <u>in the order</u> listed below. After adding each ingredient, stir or shake and observe the results. Do not add all materials and then shake. Shaking gives the best test as certain incompatibilities don't appear until a lot of energy is added – as in vigorous agitation. Use personal protection when shaking a jar of pesticides. Take notes so you can learn what works and what doesn't. Notes also save time next year.

Material	Order of mixing	Material amount to add to jar*
Water Soluble Pouches (WSP)	1	1 tbs per <u>*pound*</u>
Wettable powders (WP; W)	2	1 tbs per <u>*pound*</u>
Dry flowables/water-dispersible granules (DF; WDG)	3	1 tbs per <u>*pound*</u>
Suspension concentrates (SC) / Flowables (FL/F) Capsule suspensions (CS)	4	1 tsp per <u>*pint*</u>
Emulsifiable concentrates (E; EC)	5	1 tsp per <u>*pint*</u>
Soluble Liquids (SL)	6	1 tsp per <u>*pint*</u>
Soluble Powders (S; SP)	7	1 tsp per <u>*pound*</u>
Surfactants, oils, remaining adjuvants	8	1 tsp per <u>*pint*</u>
Fertilizers	9	1.1 gm** per <u>*pound*</u>

*Equivalent to underlined unit of pesticide or fertilizer per 100 gallons of final spray solution.

** Use an inexpensive postal scale to measure this amount (Walmart, etc.)

If the label calls for 2 pounds of WP per acre and you will be spraying at 100 gallons of spray per acre, add 2 tablespoon (tbs) of the WP to the jar. If the label calls for less than a pound WP per acre at 100 gallons per acre (gpa), add a tablespoon to the jar -- even though this makes a very concentrated solution that may not match the final concentration if you end up putting it in the spray tank. Even if you are using less than 100 gpa of spray volume, add the same amount of pesticide to the jar as if you were using 100 gpa. Why? This is a simple, conservative jar test intended to work in most situations -- for aerial (low volume) as well as ground applications. If the mix is compatible under the concentrated conditions of this test, then it should work without a hitch under more dilute, field conditions. If you want to do a jar test using material to water ratios that are more representative of your field conditions, you will have to do your own calculations to determine how much pesticide to add to how much water.

4. Stir the entire mixture. Feel the sides. A warm mixture suggests a chemical reaction occurred, which could degrade the pesticide(s) and potentially reduce pest control. If the mixture is smooth and free of visible clumps or particles then the ingredients are physically compatible and can be mixed and applied. If you can see ANY clumping after stirring and shaking, then you probably have a problem.

The order of listing above is a general approach that should work in most cases – but not all. If the mixture doesn't work following the above order and you really want to make the mixture work and the label offers no specific advice on mixing, change the mixing order and try again. Triple rinse and discard the jar when the test is finished.

Waterlogged orchards

Bill Krueger, UC Farm Advisor, Glenn County

A saturated soil profile can damage orchards in two ways. First, tree roots respire and require oxygen. Saturation in the root zone can suffocate roots resulting in damage or death. Second, *Phytophthora*, a water mold fungus, requires saturated soil conditions to infect trees. *Phytophthora* colonizes tree roots and crowns killing the cambium, resulting in root damage or death. The amount of damage resulting from prolonged periods of soil saturation is dependent on many things including tree age and species, the presence or absence of *Phytophthora*, temperature, duration of saturation, and stage of development.

Most of the tree crops are susceptible to root suffocation and *Phytophthora*. Almonds, walnuts, peaches, and cherries are among the more susceptible. Prunes, olives, pears, pistachios and pecans are more resistant. *Phytophthora* is widely distributed because it can be moved about by water. It is generally present in areas which are prone to flooding or have been irrigated by surface water sources. Young trees are at greater risk of dying because roots and crowns are smaller and are more easily killed or girdled.

Since respiration rates are lower and fungus activity is reduced during cooler winter conditions, trees will tolerate longer periods of saturation at that time. Shorter periods are tolerated as the temperatures warm. Dormant trees will tolerate longer periods of soil saturation than will actively growing trees. An example of this would be an almond orchard which experiences greater losses on earlier blooming varieties than on the later blooming varieties. Additionally, water that's flowing is believed to be less damaging than stagnant water, presumably because of greater amounts of dissolved oxygen.

In summary, trees at greatest risk are actively growing young trees of a susceptible species that are standing in stagnant water during warming temperatures.

Implementing frost protection

Joe Connell, UC Farm Advisor, Butte County

Mild, **radiation frosts** occur on still, clear nights, usually with the development of a strong inversion. Cold air accumulates in low spots or in areas where air drainage is blocked. Under these conditions, a few degrees of frost protection may be all that's needed and it can be provided by running water, by flying helicopters, or by running wind machines in narrow valleys.

Advection freezes are more severe and often result in damage. They occur when cold air blows into a field from outside the orchard. Usually they are associated with wind greater than 4 mph. Formation of an inversion under these conditions is unlikely making successful frost protection extremely difficult.

Frost sensitivity. If water is used for frost protection, critical temperatures for frost damage help us know when to turn irrigation systems on or off. Buds showing pink are more resistant to cold compared to flowers at the full bloom stage, which are in turn more resistant than small nuts. Estimated frost damage is shown in the following table.

Estimated percentage frost damage to almond flowers and small nuts exposed for 30 minutes to cited temperatures at the indicated growth stages.[1]

	Temperature - °F							
Variety and Stage	**29°**	**28°**	**27°**	**26°**	**25°**	**24°**	**23°**	**22°**
Peerless								
Showing Pink	--	--	--	25	50	75	100	--
Full Bloom	--	25	45	75	100	--	--	--
Small Nut[2]	25	50	100	--	--	--	--	--
NePlus & Mission								
Showing Pink	--	--	--	--	--	60	80	100
Full Bloom	--	--	25	50	75	100	--	--
Small Nut	25	50	100	--	--	--	--	--
Nonpareil								
Showing Pink	--	--	--	--	--	--	10	20
Full Bloom	--	--	--	--	20	40	60	75
Small Nut	25	50	100	--	--	--	--	--

[1] Source: Harry B. Hansen, U.S. Weather Bureau, Chico, circa mid-1950's.
Note: dashes indicate that data are not available; the amount of damage may increase with the duration at the minimum temperature.

[2] Once petals have fallen and nuts are left exposed, all varieties respond essentially the same (25 percent expected injury after 30 minutes at 29°F, and close to 100 percent kill at 27°F).

Our work with artificial freezing in 1990 indicated that the early varieties Peerless, NePlus, and Sonora are all similarly susceptible in the small nut stage. Peerless is the most sensitive at full bloom and Sonora is hardier. This was especially so at pink bud when Peerless is still very sensitive while NePlus is intermediate. Of the mid-blooming varieties Nonpareil, Carmel, and Price, Carmel is the most sensitive, with Price intermediate and Nonpareil the most tolerant. Among the late blooming varieties Mission, Padre, and Butte, the Mission is most sensitive while Padre and Butte are similar with Butte possibly being slightly more sensitive than Padre. This summarizes our current knowledge of variety hardiness.

Soil and groundcover condition

Groundcover condition affects orchard minimums with any cover taller than 4 inches in height generally being colder. Soil heat storage is reduced because sunlight is reflected and water is evaporated. Keeping groundcovers cut short to 2 inches or less during frost season allows sunlight to reach the soil surface, and increases soil heat storage resulting in a warmer orchard through the night.

Bare, firm, moist soil is warmest, but this is true only when the surface is moist. If pre-frost conditions are dry and windy and a dry crust forms on the surface, then, bare soil can be colder than a surface with a short (less than 2 inch) groundcover that tends to keep the surface moist with dew from the grasses and weeds. The ground surface must be moist for bare ground to be warmest.

Dry or recently cultivated soil has many air spaces, lower heat storage capacity, and low heat conductivity resulting in colder minimum temperatures. Moist soil stores more heat due to water content, has higher conductivity, and will have higher minimum temperatures. Irrigation should ideally wet the top foot over the entire orchard surface, soil moisture should be near field capacity, and these conditions should be achieved in advance to gain the most advantage. A light irrigation to moisten the soil the morning before a frost will help obtain the greatest heat storage.

Water for frost protection

Sprinklers and micro-sprinklers

Under tree sprinklers provide protection because heat contained in water is released into the orchard system. As water cools and freezes, it releases a great deal of latent heat. This sensible heat is **radiated and/or convected** into the trees, thus providing protection. Sprinklers can be safely turned off when the wet bulb temperature upwind of the protected orchard is above the critical damage temperature for the stage of the crop or when all the ice melts.

In some orchards, frost protection is limited by the amount of water or pipe available. To learn more about **moveable pipe placement** we ran an experiment comparing protection with sprinkler lines in every middle, every other middle or every fourth middle. Air temperatures in all sprinkled areas were 1 to 2^{o}F warmer than the unsprinkled control and there were no differences between these spacings. Soil surface temperatures were colder the further from the sprinklers with the dry centers between the lines in every fourth middle as cold as the unsprinkled control. Line spacing directly affects soil surface temperature but air movement evens out the benefits. Without some air movement, protection will fail between widely spaced pipelines. Limited amounts of water may provide some protection from mild frosts but protection will fail as frosts become more severe.

In our experiments with **micro-sprinklers,** applying 15, 25, and 40 gallons per minute per acre resulted in little difference in observed air temperatures. However, exposed temperatures were 1 to 2 ^{o}F warmer at the higher water rates. Exposed temperature is what the buds experience as they are exposed to radiation from the orchard floor. The fact that the low water application gave a lower exposed temperature indicates that protection with under tree micro-sprinklers is coming mostly from direct radiation from the warmer wet spots under the trees rather than through convection of warmer air. We found a greater separation in exposed temperatures between the low and medium/high rates on the colder nights. Thus, micro-sprinkler application rate had little effect on air temperature but did affect the temperature of exposed buds and flowers. The low application rate gave less protection than the higher rates and the higher soil surface temperatures from higher application rates led to more radiation heating. Under windy advection freeze conditions this may be even more important since convection heating is negatively affected by wind but radiation is unaffected.

Drip irrigating in advance of a frost can help keep the orchard slightly warmer by increasing soil heat storage particularly if the soil surface is dry. Running the system during a frost may provide slight benefits due to radiation heating from the wetted area beneath the trees. **Flood irrigation** for frost protection works in a similar fashion but due to larger water volumes it will provide more protection.

Moving air for frost protection

Wind machines

Effectiveness of wind machines for frost protection depends on the strength of the inversion. When the atmosphere 40 to 50 feet above ground is at least 13^{o}F warmer than it is a few feet above the soil surface, the temperature inversion is considered strong. When the temperature difference is less than about 5^{o}F the inversion is considered weak. The temperature response from wind machine operation is often small and depends on the difference between the inversion temperature and the orchard temperature.

An interesting observation made during wind machine research in Chico was that even under ideal conditions, a 36 inch tall cover crop appeared to reduce the wind machine response in the lowest part of the trees canopy. Wind machines can provide economical frost protection, but only in favorable locations; primarily narrow valleys with strong inversions and low ceilings. The weak inversions usually found in orchards on the floor of the Sacramento Valley limit the usefulness of wind machines for frost protection in much of our area.

Helicopters

The helicopter is usually effective for frost protection under the same conditions as those effective for wind machine operation. A warm inversion layer is needed. With the helicopter, the operator has the advantage of being able to choose the level in the inversion where the temperature is most beneficial.

During a radiation frost night an inversion forms and temperature increases with height. At the ceiling height, the temperature reaches a maximum and then begins to decrease. During a strong inversion with a low ceiling, temperatures increase rapidly with height. Under these conditions helicopters can be used successfully for frost protection. Under advection freeze conditions, helicopters are usually ineffective since there may be no inversion at all. If there is a weak inversion, the ceiling is very high and protection with helicopters is difficult.

During the day, pilots should be shown the location of cold spots and hazards must be identified (towers, buildings, etc.). The periphery of the area to be protected should be marked with strobe lights so the pilots know where to fly and the lights can be differentiated from other lights on the ground. If you use helicopters for frost protection, stay in communication with your pilots. Nighttime fatigue of pilots has been identified as a major problem.

Larger helicopters push more air and hence protect a larger area. Adding weight to the helicopter by filling water tanks also increases the thrust and hence the protection afforded. In general, a small helicopter can protect 50 to 100 acres under most mild radiation frost conditions. For colder conditions, one helicopter may be needed for each 40 acres.

The area that needs protection should be covered every 30 minutes. Thermostatically controlled lights can be very useful because they indicate when a pass has been effective and they identify cold spots. Communication with a ground crew can also help identify cold spots.

One method of identifying flying height is to place an electronic thermometer outside the helicopter and fly where the temperature reading is the highest (the ceiling). The other method is to have the ground crew measure the change in temperature at the lower canopy level with passes at various heights until the optimum height for a good temperature response is found.

Helicopter protection can be stopped when the sun rises and the air temperature upwind from the protection site has risen above the melting point, 32^{o}F, or, if the plant tissue is wet, when the wet bulb temperature upwind from the orchard is above the critical damage temperature for the crop.

For a more complete discussion of frost protection see the UC DANR publication #3364, Almond Production Manual, Chapter 23, Frost Protection.