An Analysis of the Feasibility of Providing Federal Multi-Peril Crop Insurance to Nut Tree Growers:

Almonds
Hazelnuts
Pecans
Pistachios
Walnuts

A Report to the Risk Management Agency

from the

Economic Research Service

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Author and Contact:

Susan Pollack
(202) 694-5251

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Executive Summary

The concentration of tree nut production in the United States varies according to the type of crop. Nearly all U.S. commercial almond, pistachio, and walnut acreage is concentrated in the Central Valley area of California. In contrast, production of hazelnuts is limited to the Pacific Northwest, mostly Oregon, where the tree thrives in that state's mild climate. Commercial pecan acreage is scattered across thirteen states in the South, although the greatest concentration of acreage is in Georgia, Texas, and New Mexico.

Across the various types, more almond trees were grown in the United States than any other nut tree in the early- and mid- 1990's. Almond trees produced the highest revenue among all U.S. nut tree crops, totaling over $1 billion in 1996 and averaging to about $923 million annually between 1994 and 1996. The high values associated with this crop have resulted in increased plantings within the last few years. When these almond trees reach bearing age, it is expected that commercial production should increase significantly.

Nut trees are deciduous and produce the highest yields in climates that experience cool weather during November and December, followed by warmer weather in January and February. The cool weather provides the trees with a period of dormancy in the winter, while the warm weather immediately following promotes blossom production. Without a sufficient number of chill hours, bud opening may be delayed, the bloom may be uneven, and a poor crop and branch dieback may occur. For optimal pollination, nut trees are best planted in a climate where frost does not occur after February. Low temperatures at any time during the year--below 12° F to 15° F--can cause serious damage to both the nut crop and the trees.

Hazelnut trees, in particular, do not thrive in either very hot or very cold climates. Cold temperatures--below 15° F--result in reduced nut production. Very hot temperatures cause leaves to dry up and stress to the tree, again reducing crop size. These trees flourish in moderate climates that do not experience either of these extremes.

Although adaptable to many soil types, most nut trees produce the highest yields in deep, light soils that have good drainage. Most nut trees do not tolerate prolonged wet conditions. Such situations can cause root rot, or weaken the anchoring ability of the roots, resulting in susceptibility to toppling during strong wind storms. In extreme cases, excessive wetness can result in the death of the tree. Nut trees are most able to withstand excessive moisture during their dormant period without any serious damage to the trees or to production.

Most nut trees begin bearing nuts within 2 to 4 years after planting. While most trees may produce a small quantity of nuts during the earlier years, at least 6 years are typically required before a nut tree produces a good-sized commercial crop. Once the trees become productive, they can produce high yields for many years. Commercially productive pecan trees exist, for example, that are over 100 years old.

Nut trees generally do not grow true from seed, and therefore are generally propagated by grafting or budding a desirable variety onto a rootstock. The rootstock may be a different variety of that same nut tree, or it may be associated with a related type of tree in the same family. Peach rootstock, for example, may be used in the grafting of almonds. The rootstock variety is chosen because of its hardiness or resistance to certain diseases, but may not produce a nut with desirable characteristics. As a result, the wood of a variety that produces a desirable nut is grafted onto the rootstock (after removing all of the tree's branches) of the hardier variety to achieve maximum production of the best marketable nut.

Most nut trees are harvested with the use of a tree shaker. This machine grips the trunk of the tree and shakes it, causing the nuts to drop. The nuts are either caught by an apron, or fall on the ground where they are then raked up or blown together and gathered. Harvesting occurs in the fall when the nuts are ready to be released and the tree's bark is stable. As a result, trees do not need to be shaken very vigorously and harvesting (when done correctly) is not considered to be harmful to the tree.

Various fungal and bacterial diseases affect nut trees, and generally cause greater damage to the nut crop than to the tree itself. There are a few diseases, however, that can destroy the tree or reduce its productivity to the extent that it is necessary to remove the tree. In most of these cases, it is unadvisable to replant nut trees on that acreage. Many diseases can be controlled with chemical sprays or fumigation. In some cases, however, the chemical most effective in controlling the disease is methyl bromide, the availability and use of which is uncertain over the next several years.

Other perils can also affect nut trees. Frosts or freezing temperatures occurring directly after warm weather can damage buds that may have begun to emerge on the trees. Frost damage can have a ripple affect, reducing the tree's productivity for several years, especially if the frost occurs during the "on-bearing" year. Heavy winds are always a problem for any kind of tree crop if the winds follow long periods of heavy rains or flooding. Wet soil reduces the ability of the root system to anchor the tree, and high winds in such situations are more readily able to cause toppling. Trees infected with root rot diseases (which are also commonly associated with wet conditions) are also more susceptible to toppling in heavy winds.

The demand for insurance appears to vary by type of tree and area. Several farm advisors in California, for example, felt there would be interest in crop insurance for nut trees, especially in areas where flooding and strong winds are likely to occur. Growers may also be interested because of the number of diseases that can affect different trees. Many years are often required before a disease becomes apparent and, in many cases, there are no rootstock that are totally tolerant to a disease. Growers may also want crop insurance for their trees because they may already have coverage for the crop and want to cover their investment in the tree as well.

Pecan growers in Georgia, northern Mississippi, and Alabama are believed to have a fairly high demand for crop insurance to cover their nut trees. The demand for nut tree insurance is, however, thought to be less than the demand for insurance of the nut crop. Many orchards that are producing commercial pecan crops were planted in the 1800's, and some native trees are much older.

The hazelnut extension specialist in Oregon did not believe that demand for crop insurance for hazelnut trees would be significant. The greatest demand would likely emerge from growers most concerned about Eastern Filbert Blight, since the disease can kill an entire orchard in 7 to 10 years. Hazelnuts are hardy and are grown in a mild environment, and many growers are believed not to be very interested in obtaining insurance only for the trees.

Nut Trees: An Examination of the Feasibility of Providing Federal Crop Insurance

This report examines the feasibility of insuring the trees of five U.S. nut crops: almonds, hazelnuts, pecans, pistachios, and walnuts. These crops were chosen for the analysis because they are the primary nut crops produced in the United States, and the trees are not presently covered by Federal multi-peril crop insurance. The availability of insurance for nut tree crops is in varying stages of development. For several crops--almonds, walnuts, and pecans--insurance is available for the nut crops in many areas, but not for the trees themselves. For other crops--hazelnuts and pistachios--insurance is not available for either the nut or the tree in any location.[1] Macadamias, another major U.S. nut, have the most complete availability of coverage currently: insurance is available for both the nuts as well as the macadamia nut tree.

The Nut Tree Industry

Supply

The concentration of tree nut production in the United States varies according to the type of crop. Nearly all U.S. commercial almond, pistachio, and walnut acreage is concentrated in the Central Valley area of California. In contrast, production of hazelnuts is limited to the Pacific Northwest, mostly Oregon, where the tree thrives in that state's mild climate. Commercial pecan acreage is scattered across thirteen states in the South, although the greatest concentration of acreage is in Georgia, Texas, and New Mexico (USDA, NASS).

Across the various types, more almond trees were grown in the United States than any other nut tree in the early- and mid- 1990's (Tables 1 and 2). Almond trees produced the highest revenue among all U.S. nut tree crops, totaling over $1 billion in 1996 and averaging to about $923 million annually between 1994 and 1996. The high values associated with this crop have resulted in increased plantings within the last few years. When these almond trees reach bearing age, it is expected that commercial production should increase significantly.

While pecan trees account for the second largest number of nut trees in production--and for the most acreage of any of the nut tree crops--the value of the pecan crop is lower than for almonds, averaging to $207 million over the 1994-96 period. Unlike most other nut tree crops, a large proportion of pecan acreage produces nuts from native and seedling trees, and not improved varieties.

[1] Prior Economic Research Service (ERS) reports to the Risk Management Agency (RMA) address the feasibility of insuring hazelnuts and pistachios.

Plantings of such native and seedling trees are more sporadic than other tree plantings, and overall productivity per acre is lower.

The bearing acreage associated with walnuts, pistachios, and hazelnuts is smaller than the acreage in almonds and pecans. Pistachio production is relatively new to the U.S. compared to other nut crops, and the trees are generally younger and planted using newer techniques. Hazelnut (filbert) acreage is concentrated in the Willamette Valley of Oregon, and has the smallest acreage of any of the crops discussed in this report. The value of production associated with these three crops over the 1994-96 period averaged to $296 million annually for walnuts, $134 million annually for pistachios, and $23 million annually for hazelnuts.

Table 1--Nut trees, Number of Farms, Acres, and Trees, 1992

Type of Tree	Farms	Acres	Trees
Almonds	6,263	441,700	37,262,330
Pistachios	1,051	69,344	9,142,754
Pecans	21,206	473,426	10,073,078
English walnuts	7,276	214,159	9,188,660

Source: Department of Commerce, 1992 Census of Agriculture.

Table 2-- Nut trees, Bearing Acreage, 1994-96

Tree and State	1994	1995	1996
Hazelnuts:	27,400	27,800	28,350
Oregon	27,200	27,600	28,200
Washington	200	200	150
English walnuts:			
California	171,000	169,000	169,000
Pistachio:			
California	57,500	60,300	64,300

Almonds:			
California	409,000	400,000	405,000

Source: U.S. Department of Agriculture, National Agricultural Statistics Service.

Demand

Although the U.S. Department of Agriculture collects data on bearing acreage in major nut crops, very little information exists on the demand situation. It appears, however, that the U.S. nut tree market is increasingly dependent on export markets. Almond exports, for example, are a major portion of total sales, with the high grower returns and growing demand for almonds in international markets resulting in an increase in plantings in recent years. Pistachio production also appears to be increasing, as witnessed by the recent increase in bearing acreage (Table 2). Again, international demand for American pistachios may be fueling the increased plantings.

Cultivation and Marketing Practices

Climatic Requirements

Nut trees are deciduous and produce the highest yields in climates that experience cool weather during November and December, followed by warmer weather in January and February. The cool weather provides the trees with a period of dormancy in the winter, while the warm weather immediately following promotes blossom production. Without a sufficient number of chill hours, bud opening may be delayed, the bloom may be uneven, and a poor crop and branch dieback may occur. For optimal pollination, nut trees are best planted in a climate where frost does not occur after February. Low temperatures at any time during the year--below 12^{o} F to 15^{o} F--can cause serious damage to both the nut crop and the trees.

Hazelnut trees, in particular, do not thrive in either very hot or very cold climates. Cold temperatures--below 15^{o} F--result in reduced nut production. Very hot temperatures cause leaves to dry up and stress to the tree, again reducing crop size. These trees flourish in moderate climates that do not experience either of these extremes.

Planting and Production Practices

Although adaptable to many soil types, most nut trees produce the highest yields in deep, light soils that have good drainage. Most nut trees do not tolerate prolonged wet conditions. Such situations can cause root rot, or weaken the anchoring ability of the roots, resulting in susceptibility to toppling during strong wind storms. In extreme cases, excessive wetness can result in the death of the tree. Nut trees are most able to withstand excessive moisture during their dormant period without any serious damage to the trees or to production.

Nut trees require supplemental nutrients in order to maintain their productivity. Because most nut trees have an alternate-bearing tendency, they consume significant amounts of nutrients during their heavy crop years, causing the trees to be stressed the next year. Any lack of nutrients mostly affects crop production. Over a short period of time, inadequate fertilization does not generally result in damage to the tree. Depending on the type of tree, applications of nitrogen, potassium, phosphorous, zinc, boron, and magnesium are used to reduce stress. Excess use of any of these nutrients can, however, also be harmful to the tree. Good crop management that provides a level of fertilization adequate to reduce tree stress may also minimize the alternate-bearing nature of the trees.

Propagation and Orchard Management Practices

Most nut trees begin bearing nuts within 2 to 4 years after planting. While most trees may produce a small quantity of nuts during the earlier years, at least 6 years are typically required before a nut tree produces a good-sized commercial crop. Once the trees become productive, they can produce high yields for many years. Commercially productive pecan trees exist, for example, that are over 100 years old.

Nut trees generally do not grow true from seed, and therefore are generally propagated by grafting or budding a desirable variety onto a rootstock. The rootstock may be a different variety of that same nut tree, or it may be associated with a related type of tree in the same family. Peach rootstock, for example, may be used in the grafting of almonds. The rootstock variety is chosen because of its hardiness or resistance to certain diseases, but may not produce a nut with desirable characteristics. As a result, the wood of a variety that produces a desirable nut is grafted onto the rootstock (after removing all of the tree’s branches) of the hardier variety to achieve maximum production of the best marketable nut.

Some exceptions, however, exist to this practice. Because the hazelnut is actually a shrub trained to grow as a tree, it is propagated differently. Hazelnuts are propagated by rooting a part of the tree while it is still attached to the parent tree. New developments in hazelnut production, however, are moving towards grafting onto rootstock. Pecan trees also can provide an exception. Pecans are the only nut tree where some of the crop is produced from seed. Because those trees produced from seed may vary in characteristics from the parent, nut quality and yield are more variable than from the improved varieties.

Nut trees usually require early training and pruning of limbs in order to shape the tree into the proper scaffolding structure. In addition, suckers are removed to maximize nut production. Annually pruning is necessary to remove dead, diseased, or criss-crossing branches. Thinning and pruning also ensure that all branches receive sufficient sunlight to thrive and produce nuts. With some trees, such as hazelnuts, the nuts only grow on new shoots, which makes annual pruning a necessity.

Harvesting and Marketing Practices

Most nut trees are harvested with the use of a tree shaker. This machine grips the trunk of the tree and shakes it, causing the nuts to drop. The nuts are either caught by an apron, or fall on the ground where they are then raked up or blown together and gathered. Harvesting occurs in the fall when the nuts are ready to be released and the tree's bark is stable. As a result, trees do not need to be shaken very vigorously and harvesting (when done correctly) is not considered to be harmful to the tree.

Shaking to thin the size of the crop and increase the size of the remaining nuts is usually done in late summer. During this period, the tree's bark naturally slips, making it easier for the shaking machine to cause wounds that invite insects and diseases. The tree also must be shaken more vigorously in late summer than at harvest in the fall because the nuts are not yet mature and ready to drop. Therefore, any shaking damage usually occurs during thinning and not at the time of harvest (Thompson).

Production Perils

This section provides a general overview of the production perils that affect most nut trees. Additional information is provided for each type of nut tree in the crop-specific sections that appear later in this report.

Hurricanes and High Winds

Because of the geographic location of production, hurricanes are a problem mostly for pecan growers. Pecan production in the Delta areas of Louisiana and Alabama, and in any areas within 150 to 200 miles of the Gulf and Atlantic coasts, are especially susceptible to the dangers caused by hurricanes. The heavy winds brought by hurricanes can cause tree defoliation and limb breakage. Trees may be uprooted, especially if they are planted in sandy soils or if the trees are loaded with nuts. Generally, the extent of damage depends on the soil type, wind speeds, and the nut load on the tree. Most other nut tree crops are planted in locations where hurricanes rarely occur.

Heavy winds, however, are always a problem for any kind of tree crop if the winds follow long periods of heavy rains or flooding. Wet soil reduces the ability of the root system to anchor the tree, and high winds in such situations are more readily able to cause toppling. Trees infected with root rot diseases (which are also commonly associated with wet conditions) are also more susceptible to toppling in heavy winds. Strong winds are more likely to cause limb damage when the trees are in leaf and the nuts are near maturity than when they are bare. If high winds result in significant limb loss, nut production can be affected for several years and, in some cases, the trees may need to be removed.

Excessive Heat and Drought

Most nut trees can withstand periods of prolonged heat or drought without incurring long-term effects, unless they have already been stressed by diseases or insects. Pecan trees, for example, have long taproots that can reach water supplies deep in the soil, and they can withstand droughts fairly easily. In California and Oregon, most nut tree producers irrigate their orchards, mitigating the effects of excessive heat and drought.

Ice Storms

Ice storms can be a problem for pecan growers in the northern parts of Alabama, Georgia, and Mississippi. Ice can form on tree limbs, making them heavy and easily causing breakage. If enough limbs fall, damage to the canopy can cause the tree to become economically inviable. Ice storms rarely kill pecan trees, but cause damage rendering them unproductive and requiring tree removal. Ice storms have occurred in the northern parts of these three states that have caused very severe damage, requiring the removal of entire orchards. Ice storms are not a problem in California or the Pacific Northwest production areas because of milder weather. Hail storms, however, may damage fruit, pitting them and making them unmarketable, but do little damage to the trees.

Frost and Freezing

Frosts or freezing temperatures occurring directly after warm weather can damage buds that may have begun to emerge on the trees. Frost damage can have a ripple affect, reducing the tree's productivity for several years, especially if the frost occurs during the "on-bearing" year.

In addition, freezing temperatures can be a particular problem for young nut trees. If freezing temperatures occur before a tree has had time to acclimate to the cold, tissues can freeze. This type of damage mainly occurs to the lower trunk, which is the final portion of the tree to become acclimated to the cold. In extreme cases, nut trees may die from such injury. For some nut trees, the effects of freezing temperatures can be controlled by good cultural practices and by using rootstock that is cold hardy in areas where freezing temperatures can be a problem.

Lightning

Lightning tends to strike taller trees more often than those that are relatively shorter, and its effects are sporadic. Across an entire orchard, only one tree may be struck, or many trees may be damaged. For a given tree, the extent of the damage depends on how the tree is hit. Damage can be minimal and the tree may grow back, or the tree may be destroyed. In some cases, lightning damage may effectively destroy the canopy of the tree, and although the tree can functionally survive, it may be rendered unproductive.

Diseases

Various fungal and bacterial diseases affect nut trees, and generally cause greater damage to the nut crop than to the tree itself. There are a few diseases, however, that can destroy the tree or reduce its productivity to the extent that it is necessary to remove the tree. In most of these cases, it is unadvisable to replant nut trees on that acreage. Many diseases can be controlled with chemical sprays or fumigation. In some cases, however, the chemical most effective in controlling the disease is methyl bromide, the availability and use of which is uncertain over the next several years.

Insects and Animal Pests

Insects are most damaging to nut trees in their larval form, at which time they burrow into the wood or roots of the tree. Insects can also damage trees by defoliating limbs. Infestations are usually more damaging to young trees than to those that are more well established. Most insects can be controlled with insecticides. Animals also cause the most harm to young trees, and reduce the ability of the tree to thrive by chewing the bark from the trees.

Almonds

The entire commercial almond crop in the United States is grown in California, with most of the state's production concentrated in the San Joaquin and Sacramento valleys. Almonds are California's largest tree nut crop, as measured both by acreage and total dollar value. In 1995, California growers had 400,000 bearing acres in almond trees. Shelled almonds provided the state's second highest revenue among fruit and tree nut crops after grapes, with a value of $888 million dollars. In 1995, almonds ranked fourth in value among California's top export products.

Almond Tree Characteristics

The almond belongs to the same plant family as the peach, plum, nectarine, apricot, and cherry. It is native to western Asia and is adapted to the warmer areas of California. Almond trees are deciduous, and require a period of dormancy between bearing cycles. They have a tendency toward alternate-bearing. Because they do not reproduce true from seed, almonds are propagated through grafting to maintain the desirable characteristics of the tree and the nut.

The bearing cycle of the almond tree follows a typical seasonal pattern. In the fall, buds begin to develop. A chilling period is required in November and December, followed by warmer weather in January and February. The dormant buds begin to grow rapidly in January, producing blossoms in early February through March (www.almond.org). The exact time of blossoming depends on the variety, the amount of winter chill, the exposure to warm temperatures in spring before the bloom, and the threshold temperature at which the buds grow. Almond trees are less hardy and require fewer chilling hours during the winter months than various other bearing trees, including the peach.

Because almond trees are not self-pollinating, at least two different varieties are necessary in a productive orchard. Varieties are typically planted in alternating rows, and bees are typically used to aid in pollination. For optimal bee activity, orchards should be frost-free when the trees bloom, and rainfall should be minimal (www.almond.org). Because the blooming period for many varieties occurs fairly early in the spring, they tend to be more subject to disease problems and poor pollination than if blooming were later in the spring. In addition, temperatures are critical during the budding stage. Chilling is important, and winters that are too warm can delay bud opening and may reduce yields.

After the flower petals drop in the spring and the tree begins to produce leaves, the first signs of the fruit appear. The hull of the nut hardens and matures as the months pass, and in July, the hull begins to split open. The split continues to widen through late October, exposing the shell and allowing the kernel to dry. The nut and stem separate, and shortly before harvest, the hull opens completely (www.almond.org.). Six to eight months are required from full bloom until nut maturity.

Varieties

The major varieties of almond trees planted in California include "Nonpareil," "Carmel," "Mission" (Texas), "Merced," "Ne Plus Ultra," "Price," "Peerless," "Butte," "Monterey," "Ruby," "Sonora," "Padre," and "Fritz" (Micke). "Nonpareil" is the most popular variety, accounting for 49 percent of California's almond acreage in 1997. In terms of value of production, "Nonpareil" accounted for 47 percent of total receipts in 1997; "Carmel," for 20 percent; "Mission," for 5 percent; "Price," for 5 percent; "Butte," for 5 percent; and "Ne Plus Ultra," for 2 percent (Almond Board of California).

While "Carmel" ranks second in popularity, its susceptibility to noninfectious bud failure may reduce future plantings. "Mission," "Peerless," and "Ne Plus Ultra" are also planted less frequently than in the past. Because of noninfectious bud failure, there is now little new planting of "Merced," "Harvey," "Jordanolo," and "Yosemite." Difficulty in nut harvesting has reduced the popularity of "Merced," "Thompson," "Drake," "Le Grand," "Davey," and "Milow." Other factors have limited planting of the following varieties: "IXL," "Hasham," "Jeffries," "Sauret #1," "Sauret #2," "Kapareil," "Milow," "Carrion," "Solano," and "Norman." Newer varieties being planted include "Mono," "Tokyo," "Livingston," "Aldrich," "Woods," "Colony," and "Rosetta."

Varieties should be selected according to a variety of factors, including: time of bloom, pollen compatibility, time of maturity, ease of nut removal, yield, pest resistance, marketability of the nut, and nut quality. Most almond varieties are not self-pollinating and require compatible bloom varieties in order to pollinate. The closer the timing of bloom across varieties, the better the opportunity for cross-pollination and crop set. When the trees bloom at the same time, there is better overlap of flower receptivity and bees tend to fly between the trees at a similar stage of bloom. Trees in an orchard also need to be chosen based on the timing of nut maturity and removal. Marketability is also important because it is important not to mix different varieties of nuts at harvesting time. Further, some varieties tend to be more susceptible to insects, including the navel orangeworm and the peach twig borer, which cause wormy kernels (Table 3) or noninfectious bud failure, a genetic disorder (Table 4) (Micke).

Table 3--Industry Rejection of Kernels by Tree Variety in the 1980's

Less than 2 percent	2 to 4 percent	Over 4 percent
Butte	Fritz	Harvey
Carmel	Monterey	LeGrand
Mission	Ne Plus Ultra	Merced
Peerless	Nonpareil	Thompson

Price	Ruby	

Source: Micke, Warren. Technical Editor. *Almond Production Manual*. University of California Division of Agriculture and Natural Resources, Pub. 3364.

Table 4--Varieties Affected by Noninfectious Bud Failure and Severity When Present

Variety	Relative Prevalence	Relative Severity when Present
Jordanolo	high	high
Merced	high	high
Yosemite	high	high
Harvey	moderate to high	moderate to high
Carmel	moderate to high	moderate to high
Nonpareil	moderate	moderate
Peerless	low	moderate to high
Price	low	moderate
Carrion	low	moderate
Sauret # 1	low	moderate
Thompson	low	high
Mission	low	high
Norman	low	unknown*

*Insufficient data to rate.
Note: Instances have not been observed in Butte, Padre, Sonora, Ne Plus Ultra, Fritz, Monterey, Mono, and Tokyo to rate.

Source: Micke, Warren. Technical Editor. *Almond Production Manual*. University of California Division of Agriculture and Natural Resources. Pub. 3364.

Rootstocks

The most popular rootstocks use peach or peach-almond varieties (Sibbett; Almond Board of California). There is no one best almond rootstock that consistently produces the highest yield. Currently, the most commonly used include "Nemaguard" (peach), "Nemared" (peach), "Lovell" (peach), "Marianna 2624" (plum), various peach-almond hybrids, and almond itself (often "Mission").

Rootstock can be either grown from seedlings or vegetatively propagated. When "Lovell," "Nemaguard," "Nemared," and almond are used, the rootstocks are seedlings. With propagated rootstock, such as "Marianna 2624" and "Hansen" hybrids, source trees are maintained and cuttings are taken from them to produce the rootstock. Peach-rooted trees bear earlier than almond-rooted trees, but they are shorter-lived (Micke).

"Nemaguard" is the most popular rootstock for almond, and is used most frequently in the San Joaquin Valley. It was bred to be resistant to root knot nematodes. It is propagated from seed and develops a vigorous root system of moderate depth. "Nemaguard" is compatible with all almond varieties. It is somewhat tolerant of heavy soils and excess water, but is affected by crown gall, oak-root fungus, and crown rot. "Lovell" is the second most popular rootstock for almonds, and is preferred by growers in the Sacramento Valley. This area has a lower incidence of root knot nematode, heavier soils, and higher rainfall than the San Joaquin Valley, making the "Lovell" variety a better choice. "Lovell" is susceptible to nematodes, oak-root fungus, crown rot, and crown gall.

Almond seedlings used for almond production are rarely planted in California today, except in areas without irrigation. The almond rootstock provides more drought tolerance than peach or plum stock, and produces large, long-lived, deep-rooted trees requiring deep, well-drained soils. In deep soil, almond stock can withstand water stress at harvest-time better than other rootstocks. Almond is considered to be the most sensitive of all the rootstocks to wet soil conditions, and is the most tolerant of high lime and boron content in the soil. Almond is affected by nematodes, crown rot, crown gall, and oak-root fungus.

"Marianna 2624" is noted for its vigor and ease of propagation from hardwood cuttings. It is most valued for its ability to tolerate heavy, wet soils and soils infested with oak-root fungus. While not immune to the fungus, it can be successfully planted where the fungus is present.
Due to its vigor, this rootstock allows almonds to be planted under poorer conditions than other rootstock. It does not, however, perform well in heavy clay soils or those subject to prolonged wet conditions. "Marianna 2624" is resistant to root knot nematodes and is moderately resistant to crown gall. It is planted mostly in northern California, especially near the Sacramento River. Trees grown on "Marianna 2624" are significantly smaller than those grown on almond rootstock. When planted 10 percent closer than the spacing used for peach rootstock, yields are compatible. The major drawback of "Marianna 2624" is that it is not compatible with the "Nonpareil" variety of almond tree, the most popular variety. Only "Nonpareil" planted on "Marianna 2624" rootstock with an interstock such as "Havens 2B" plum will survive. "Marianna 2624" is also susceptible to bacterial canker (Micke).

Propagation and Planting

Almond trees are planted in the field at one year of age. The rootstock is budded onto the selected variety in June, and the young tree grows throughout the season. The trees are then sold to growers for commercial production at the end of the year, with planting in fields occurring in the following June through March (Sibbett). Almond trees begin bearing an economic crop in the fourth year after planting, becoming fully mature in about seven years (Asai, Hendricks, Klonsky, and Livingston).

Tree spacing depends on the vigor of the variety and rootstock, the location of the planting, soil fertility, the equipment used in the orchard, vegetation management, and irrigation method. Wider spacing is recommended for vigorous types of variety/rootstock combinations, and in fertile soils where trees tend to grow larger. Wider spacing is also recommended where cross-cultivation is used for irrigation preparation and vegetation management. Tree spacings of 24 by 24 feet are common in the San Joaquin Valley. Spacings of 22 by 22 feet or 22 by 20 feet are sufficient for a mature orchard on shallow, less fertile soil. On the most fertile loam soils, trees need to be spaced wider, as even 26 and 28 feet spacings may be crowded. Wide spacing permits trees to spread to their ultimate size without crowding, allowing for easier pruning in mature orchards, and aiding tree vigor into old age. Because nut production is determined by the number of trees planted per acre, many growers opt for about 24 foot spacings in deep, fertile soil, and 20 to 22 foot spacings in less fertile soils (Micke).

Traditionally, plantings consisted of two rows of "Nonpareil," then a row of a pollinator variety. However, when weather conditions are unfavorable and varieties do not have adequate bloom overlap, this arrangement can result in reduced set and yield. Today, the common arrangement is of a single row of a variety, maximizing exposure to a pollinator to maximize yields (Micke).

Cultivation and Management Practices[2]

Almond tree rootstock are planted in heavy soils such as loams and clay loams, as well as sandy soils. Soils require site preparation to reduce the hardpan to a depth of at least 5 or 6 feet to allow for root formation. Sandy soils often have higher nematode populations, and may have stratified layers or hardpans. Backhoeing and fumigation helps reduce root lesion and ring nematodes. Present rootstock are only tolerant to root knot nematodes (Micke).

Soil texture and drainage are important considerations when selecting rootstock varieties. Peach rootstocks tolerate poorly drained soils better than almond (seldom used today) and peach-almond hybrids. "Marianna 2624" plum is more tolerant of wet conditions (Micke).

Harvesting

Almond trees are harvested mechanically. Mechanical tree shakers knock the unshelled nuts to the ground, where they are allowed to dry before they are swept into rows and picked up by machine. After the shelled nuts are picked up, they are transported to carts and transported for hulling (Almond Board of California).

Trees generally are not shaken until they are in their fourth growing season. Before that time, the shaking machines could damage the trees. Trees need to be properly trained from planting throughout the early nonbearing years to prevent tree injury from shakers. The tree should be trained to keep a vertical trunk, and to allow for quick placement of shaker clamps (Micke). Damage to the tree increases if the operator has to adjust clamps for tight spots or trunks that lean. Low hanging branches that hide the trunk also need to be removed to increase visibility and reduce potential damage to the trunk from the shakers. Suckers also need to be removed. If a sucker or low branch gets caught in

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[2] For cost of production budgets, see the appendix.

the shaker, it may cause bruising and bark tearing (Micke).

Harvesting should take place about two weeks after the final pre-harvest irrigation to minimize bark damage from trunk shaking. The time between irrigation and harvesting can be reduced if using low-volume irrigation. As soil moisture is depleted, bark tightens and is less likely to be damaged from the shaker. Also, as the season advances, the bark adheres more tightly to the trunk. When harvesting early in the season, growers must be especially careful to avoid bark damage (Micke).

Shakers can cause both direct and indirect damage to a tree. Direct damage can cause torn, stripped, or compressed bark. Severe trunk damage can cause root dieback. Minor damage may cause calluses around the wound, with the tree healing eventually. Indirect damage occurs when disease organisms, such as fungi or bacterial diseases, enter the tree through wounds caused by the shaker.

Production Perils

Most natural perils affecting almond trees, including diseases and insects, can generally be controlled either through the application of pesticides or other management practices. Some perils, however, are quite serious. Very hot summers and flooding, for example, can kill a tree or cause it to become unproductive in future years.

<u>Bud Failure</u>

Very hot summers, especially in August, tend to promote "noninfectious bud failure" ("crazy top"), a genetic disorder affecting almond trees. The "Nonpareil" and "Carmel" varieties are moderately to highly susceptible. Bud failure is not caused by a virus, nor is it contagious. When bud failure occurs, tree buds do not mature in the following year. Bud failure does not kill the tree, but renders it unproductive. The only way to reduce the risk of bud failure is to plant less susceptible varieties (Sibbett; Freeman).

<u>Flooding</u>

Flooding can be a problem to almond trees. Highly saturated soils may result in the death of the tree, or promote the development of fungal diseases. In addition, almond trees are often shallow-rooted, and the combination of flooding and heavy winds can result in toppling. Almond trees are especially susceptible to toppling if they are fully leafed (Sibbett).

<u>Diseases and Insects</u>

Several diseases can affect almond trees, although few are fatal by themselves unless they are combined with stressful weather conditions. The most common diseases affecting almond trees include bacterial canker, crown gall, Armillaria root rot, leaf blight, Phytophthora root and crown rot, scab, and shothole. Insects and nematodes also damage almond trees, but can usually be controlled.

Diseases

Bacterial Canker (*Pseudomonas syringae*)--This disease survives on plant surfaces, and is spread by splashing rain. Bacterial canker tends to occur in the spring, and is favored by excess moisture and low temperatures. When present, it tends to affect low and/or sandy spots in the orchard to the greatest extent.

The symptoms of bacterial canker include limb dieback, accompanied by rough cankers and an amber-colored gumlike substance. Leaf spot and blast may also affect the young flowers and shoots. Although the sour sap phase of bacterial canker may not produce gum and cankers, the inner bark is brown, fermented, and sour smelling. Flecks and pockets of bacterial invasion may also appear on the bark outside the canker margins. When the disease is present, almond trees frequently producer suckers.

Vigorous trees are less susceptible to bacterial canker than those that are in a weakened state. Young trees, generally ranging from 2 to 8 years of age, are most commonly affected. The disease rarely occurs in the first year of planting, and is uncommon in nurseries. To discourage secondary invasion by wood rot organisms, infected trees should be pruned to remove cankered or dead scaffold limbs (UC Pest Management Guidelines).

Crown Gall (*Agrobacterium tumefaciens*)--Crown gall is a bacteria that survives in gall tissue and in the soil. It enters the tree only through wounds, causing rough, abnormal galls on the roots or the trunk. The galls are soft and spongy, and the decay appears in the centers of old galls. Young trees become stunted, and older trees often develop secondary wood rots. Crown gall is most damaging to young trees, and can appear either in nurseries or new orchard plantings. Peach-almond hybrid rootstocks are more susceptible to crown gall than almonds that use a "Nemaguard" peach rootstock. To prevent crown gall, trees should be purchased from reputable nurseries and handled carefully to avoid injury, both during planting and in the orchard. A preplant chemical treatment can be used to reduce the likelihood of infection (UC Pest Management Guidelines).

Armillaria root rot (*Armillaria mellea*)--Armillaria root rot infects tree roots, producing a white or yellowish fan-shaped mycelial mat between the bark and the wood in the roots. Dark brown or black rhizomorphs at times can be seen on root surfaces. All stonefruit rootstocks are susceptible to Armillaria root rot. “Marianna 2624,” a plum rootstock, has some tolerance and may be used in some situations. The Armillaria fungus can, however, survive on dead roots.

Before a field can be treated, infected trees, stumps, and large roots (greater than 1 inch in diameter) must be removed. Healthy-appearing trees adjacent to those exhibiting symptoms are often infected, and extension specialists advise removal of these trees and fumigation of the soil. Infected tree material should be burned at the site or in areas where the remains cannot be washed to agricultural lands.

Complete eradication of this disease is rarely achieved, and retreatment may be necessary in localized areas. If the soil is wet, or if it has extensive layers of clay to the depths reached by the roots, fumigant treatment may not be successful. The greatest opportunity for eradication occurs on shallow soils less than 5 feet deep. Methyl bromide has been used for treatment from late summer to early fall (UC Pest Management Guidelines).

Leaf Blight (*Seimatosporium lichenicola*)--Leaf blight is a fungus that survives on dead petioles. The fungal spores are spread by rain, and the disease favors wet spring weather. When present, leaf blight causes the leaves at the base of the shoots to wither and die in early summer. The dead areas then spread to the base of the petioles. The disease rarely destroys more than 20 percent of the leaves in a season. Repeated early leaf death, however, causes weakened trees, and may result in yield losses. Losses are not usually severe or widespread. Fungicides can be used to help control leaf blight (UC Pest Management Guidelines).

Phytophthora Root and Crown Rot (*Phytophthora spp*.)--This disease is favored when the soil is saturated for periods of 24 hours or more, which is common with flood irrigation in California. Good soil drainage and frequent (but shorter) irrigations reduce the risk of infection. Rootstocks vary in susceptibility to the different Phytophthora species, but none are resistant to all species. Therefore, the success of a rootstock may depend in part on the species of Phytophthora present in the orchard. Plum rootstocks, especially "Marianna 2624," tend to be more resistant than peach or apricot rootstocks to Phytophthora.

The symptoms appearing when Phytophthora is present depend upon the extent of root or crown tissue infection. Usually, phytophthora rots advance rapidly and the trees die soon after the first warm spring weather. The leaves of infected trees wilt, dry, and remain attached to the tree. Some phytophthora root infections, however, cause slow growth and early senescence and leaf drop. These trees may be unproductive for several years before finally succumbing to the disease. Phytophthora infections typically kill young trees because their root systems and crown areas are small when compared to mature trees.

Proper water management is the most important aspect in controlling root and crown rot. Water should not be allowed to accumulate or stand around the crowns of the trees. In addition, adequate drainage must be provided in low spots in orchards, in areas that flood frequently, and in areas where water penetration is extremely poor. Trees that are replanted where phytophthora is present should be planted as shallowly as possible on small mounds, or on broad ridges (8 to 10 inches high), with the upper roots near the soil level. Planting depth should be no deeper than in the nursery, and the graft union should be well above the soil line (UC Pest Management Guidelines).

Scab (*Cladosporium carpophilum*)--Scab is a fungus that survives in twig lesions. The spores are spread by wind and rain. Prolonged wet spring weather, prevalent in the Sacramento Valley, provides favorable conditions for scab growth. Scab appears as grayish-black, soft-looking spots on leaves, fruit, and twigs. Young lesions are indistinct small, yellow specks, which can be seen most easily when the leaves are held up to the light. The lesions are not visible until late spring or early summer. Severe scab infections cause early defoliation. If left uncontrolled for several years, infected trees become weakened. The disease often occurs in sprinkler-irrigated orchards where water falls upon the foliage. Scab can be treated with fungicides (UC Pest Management Guidelines).

Shothole (*Wilsonomyces carpophilus*)--Shothole is a fungus that survives on infected twigs and as spores on healthy buds. The spores are moved by water to new sites. As a result, lengthy periods of wetness, either caused by rainfall or sprinkler irrigation, promote development of the disease. Shothole causes spots to appear on the leaves, fruit, twigs, and flowers. Flower and twig lesions, however, tend to be relatively scarce or difficult to find. Leaf lesions begin as tiny, red specks that enlarge into spots that have tan centers and purplish margins. The fruiting structure of the spore appears as a small, dark speck in the center of the spot. Spots on young leaves usually fall out, leaving a "shothole" effect. Older leaves retain their lesions. The spots on the fruits are small with purplish margins, are slightly corky and raised, and are found on the upper surfaces of the fruit. Heavy infestations may cause distortion or gumming on the fruit. Shothole can cause losses in yield, defoliation, and weakened trees. Fungicides can be used as a protectant against the disease, but they will not eradicate the fungus. Fungicides should be applied to foliage and fruit before a wet period in order to protect the tree (UC Pest Management Guidelines).

Insects

San Jose Scale (*Quadraspidiotus perniciosus*)--When this insect is present, the egg stage is not visible. Rather, the scales are first present, emerging as nymphs. The crawlers are bright yellow and tiny (about the size of the sharp end of a pin), with well developed eyes, antennae, and legs. After locating a feeding site, the crawler begins feeding; loses its antennae, legs, and eyes; and becomes immobile. It secretes a waxy substance that covers its body. Initially, the waxy covering is white (white cap), but then turns darker (black cap). Males have a more elongated covering than the females, molting four times, while females have a rounder covering and molt twice. The male emerges as a winged adult and the female remains wingless. Three to four generations of scales can breed per season, averaging about 7 to 8 weeks per generation.

Scales suck plant juices from twigs and limbs, and inject a toxin, resulting in loss of tree vigor, growth, and productivity, and possible death of limbs. A red halo is produced around a feeding site on 1-year-old wood. Untreated infestations can kill fruit and scaffold wood within 1 to 3 years. Scale can be controlled with the proper use of insecticides or dormant oil sprays (UC Pest Management Guidelines).

Tenlined June Beetle *(Polyphylla decemlineata*)--The larvae of this beetle feed on tree roots, and can cause severe injury and death to mature almond trees. Adults cause no damage. The larvae are cream-colored grubs with a brown head capsule. They live in the soil and are about one inch long at maturity. One generation appears every 2 years, with the adults emerging from the soil between late June and August. Currently, no registered pesticides can be used to control this pest after the trees are planted. Control requires the removal of infested trees and soil fumigation with methyl bromide or chloropicrin before replanting. All infested trees, plus one or two uninfested trees on all sides of the infested trees, should be removed to eliminate the beetle (UC Pest Management Guidelines).

Tree Borers (the Prune limb borer: *Bondia comonana* and the American plum borer: *Euzophera* *semifuneralis*)--Tree borers are sporadic pests that can infest young almond orchards. They are present from Tehama to Merced counties and can affect all major almond cultivars. The "Carmel" and "Price" varieties are most susceptible. The borers have grey forewings with brown and black marks, and a wingspan of about 0.75 inch. They overwinter in cocoons within the tree, and adult moths emerge in April and May. The mature larvae are about 1 inch long, and have a dull white or pinkish body. The females lay eggs near pruning wounds, in the scaffold crotches of young trees, near graft unions, or on crown galls.

The larvae of this pest bore into the trees, leaving reddish-orange debris and gum pockets. The boring is most damaging to the scaffold crotches or graft unions of young trees. Vigorous trees can heal over borer damage. When heavy, prolonged infestations occur, however, scaffold branches may break in the presence of high winds or a heavy crop. The damage is most severe on the "Carmel" and "Sonora" varieties. Pesticide spraying is used to help control tree borers (UC Pest Management Guidelines).

<u>Western Tent Caterpillar</u> (*Malacosoma californicum*)--These caterpillars overwinter in the egg stage, hatching in the spring and early summer. They are hairy and dull yellow-brown with rows of blue and orange spots on the tops of their bodies. One generation of caterpillars appears each year. Tent caterpillars can cause serious damage to individual trees and along orchard edges, but their effects are usually scattered randomly throughout the orchard. Young orchards are usually the most severely affected.

In April and June, tent caterpillars build large, silken tents over the leaves on which they are feeding. Because they do not eat the leaf veins, damaged leaves are skeletonized. Other types of caterpillars can cause similar damage, but do not produce the silken webbing. To control for tent caterpillars, infested twigs of small trees should be removed and destroyed. Spraying for other insects often reduces caterpillar populations. Usually, localized treatment on infested trees is sufficient (UC Pest Management Guidelines).

<u>Nematodes</u>

Nematodes affecting almond trees include: root knot (*Meloidogyne spp*.), root lesion (*Pratylenchus vulnus*), ring (*Criconemella xenoplax*), and dagger (*Xiphinema americanum*) nematodes. The rootstocks used in grafting almonds differ in their response to various plant-parasitic nematodes. "Nemaguard" peach rootstock, almond-"Nemaguard" hybrids, and "Marianna 2624," all of which are resistant or immune to most common and injurious root knot nematodes, are susceptible to ring and root lesion nematodes. Other peach rootstocks (such as "S-37") offer resistance to some types of root knot species, but not others. Almond rootstock is susceptible to root knot, root lesion, and ring nematodes.

The use of rootstocks resistant to certain types of nematodes may be limited by soil and horticultural considerations. Before planting, soils should be sampled for nematodes, especially if the area previously was planted to an orchard or vineyard. If any of the nematodes that affect almonds are present, preplanting fumigation is necessary (UC Pest Management Guidelines).

Animals

Animals such as gophers and voles can cause severe damage to young almond trees, and may result in plant death. Animals can chew the bark from young trees, damaging them to the extent that they are unable to thrive (Freeman).

Hazelnuts

U.S. hazelnut planted area totaled 32,674 acres in 1992, with nearly 99 percent of the total located in Oregon (Census of Agriculture). Washington reported 387 acres, while all other states combined reported 34 acres. Oregon's Willamette Valley is uniquely suited for hazelnut production because of the climate-moderating effects of the nearby Pacific ocean. Extreme winter cold or extreme summer heat reduces hazelnut yields, and production is commercially unprofitable in many other traditional nut-producing areas of the country.

Hazelnut Tree Characteristics

The hazelnut plant grows naturally as a bush or a multi-trunked, shrubby tree. In Turkey and other countries in southern Europe, hazelnuts have been grown in this manner for centuries (Baron, et al.). In Oregon, however, hazelnuts usually are trained to grow as single-trunked trees, and may attain a height of 30 feet with proper management and good soil.

While the tree itself is quite hardy, it requires a relatively moderate climate for successful nut production. Extremely low temperatures kill the pollen-producing catkins (the male flowers), reducing or preventing pollination. Catkins freeze at about 15^{o} F, while the female flower buds are destroyed at about 10^{o} F. Extreme summer heat also is detrimental to hazelnut trees. The leaves dry up during hot, dry days, which stresses the tree and reduces nut production.

Hazelnut trees may produce nuts during their second or third year, but require about six years before producing commercial-sized yields. Mature orchards may produce up to a ton-and-a-half of dry nuts per acre. A well-managed orchard generally averages at least 1,500 pounds of dry nuts annually, and remains productive for at least 40 years. The average U.S. hazelnut yield can vary widely from year to year, but has been trending upward.

Hazelnut flowers form more than a year before harvest. In a typical season, the pollen-producing catkins begin to form in April or May, and mature in December or January. The female flowers, in contrast, begin to form in late summer, and are first seen only in November or early December. The peak pollination period occurs during January and February, when the female flower clusters appear as bright red tufts of feathery stigmas that peak from beneath bud scales.

At the time of pollination, the female flower has not yet produced the egg cells from which the young nuts will grow. Rather, the female flowers store the captured sperm until a mature ovary containing an egg cell develop. Only then, during May or June, does fertilization occur. Thus, a period of 4-5 months lapses between pollination and fertilization of the egg cells. In contrast, fertilization in most plants follows pollination by a few hours or a few days.

Varieties

Hazelnuts are self-incompatible, which means that the pollen from a given variety will not fertilize the female flowers of the same variety. Certain combinations of varieties also are cross-incompatible, meaning that the pollen from one variety is ineffective in setting nuts on the other. Consequently, compatible pollinating trees must be planted among the principal variety to assure good nut set. Six or seven trees per acre of a compatible pollinating variety, evenly distributed throughout the orchard, usually provide adequate pollination (Baron).

"Barcelona" is the primary variety planted in Oregon, and accounted for over 77 percent of total hazelnut plantings in 1993 (Oregon Agricultural Statistics Service). It is a slow-growing tree that produces large, high-quality nuts good for the in-shell market. "Barcelona" is susceptible to a nut disorder called brown stain, but is reportedly somewhat tolerant to a devastating fungal disease known as eastern filbert blight (EFB) (Pinkerton). A number of the newer orchards are being planted with other varieties.

"Ennis" has become the second most-popular hazelnut variety, accounting for nearly 11 percent of tree plantings in 1993. Like "Barcelona," "Ennis" produces large hazelnuts and is grown as a nut producer rather than as a pollinator. This variety is moderately susceptible to EFB.

The third most widely-grown hazelnut variety in 1993 was "Daviana," accounting for less than 5 percent of total plantings. "Daviana" is an excellent pollinator for "Barcelona" and has been grown primarily for that purpose. It produces less desirable nuts than the other varieties, and is highly susceptible to EFB and to an insect called "big bud mites."

The remaining varieties account for a small share of hazelnut plantings. "Casina," which is a relatively new variety in Oregon, accounted for about 3 percent of tree plantings in 1993. It is grown as a nut producer and, like "Barcelona," is considered to be moderately tolerant of EFB. "Duchilly," "Butler," and "Royal" collectively accounted for less than 3 percent of tree plantings. "Duchilly" produces long, large, good-quality nuts, but they are slow to drop and difficult to husk. "Royal" produces large, early-maturing nuts and is typically pollinated by "Daviana." "Butler" is more productive than "Daviana" and is recommended as a pollinator for "Barcelona" (Baron).

Propagation and Planting

Hazelnuts are propagated by layerage, which means that the plant is rooted while it is still attached to the parent plant. Suckers from an orchard tree or stems from a "mother" plant in a stool bed are bent into an S-shape so that one bend is under ground while the tip end of the stem remains above ground. Roots develop on the underground portion of the "S" and form the new tree. Recently, hazelnuts have also been grafted, which involves grafting desirable varieties onto nonsuckering rootstocks.

Hazelnut trees are planted in early winter. The earlier in the season that a tree is planted, the more its roots develop before it develops leaves in the spring. The roots of newly-planted trees grow even during January and February, as long as soil temperatures are at 40° F or above. Young trees with well-developed root systems grow more vigorously than ones with fewer roots, and they are better able to survive drought stress during their first years.

The trunks of young hazelnut trees are easily sunburned, especially near the surface of the soil. Sunburn (also known as sun scald) deforms the young trees and opens wounds into which bacterial blight infections can enter. Painting newly-planted trees with a dilute solution of white paint or surrounding them with tree protectors provides protection against sunburn.

Growers may intercrop newly-planted hazelnuts for the first few years. When trees are inter-cropped, another crop (such as strawberries or beans) is planted between the rows of trees. When the land is irrigated, inter-cropping can reportedly promote growth of new trees (Baron).

Cultivation and Management Practices[3]

Soil Requirements

Soil quality is one of the most important factors in choosing an orchard site for hazelnuts in western Oregon. Good hazelnut land is deep (8-10 feet or more), well drained, and neither extremely clayey nor extremely sandy. Deep soils are better able to provide a large supply of water and adequate plant nutrients during dry seasons than are shallower soils. Hazelnuts trees that are planted on shallow soils may grow well for several years. After 8 to 10 years, however, the orchard may become a poor producer because soil depths restrict the development of deep roots that are needed by larger trees (Baron).

Climate

The ideal climate for hazelnuts is one with relatively long, mild winters. Mild winters are a necessity because hazelnut catkins die at temperatures below 15° F. As a result, production is not feasible in areas where winter temperatures drop below this critical level.

Good air drainage is also a factor in locating orchards, due to the damage that late spring frosts can cause to flower clusters and succulent green shoots. Trees planted on sloping land with good air drainage are less likely to be damaged by such late spring frosts than are those planted in low-lying areas. Cold air tends to flow from sloping land into surrounding low-lying areas, where it accumulates and forms "frost pockets." As a rule, such frost damage to hazelnuts is unusual in Oregon (Mehlenbacher, 1997a).

Although varying by cultivar, hazelnuts have a fairly high winter "chilling requirement," which precludes production in subtropical areas of the country. The chilling requirement is the minimum number of accumulated hours with temperatures between freezing and 45° F which the plant needs before the leaf buds break in the spring (Mehlenbacher, 1990). Hazelnut flower buds also have

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[3] For cost of production budgets, see the appendix.

minimum chilling requirements, but they tend to be shorter than for leaf buds.

Training

Young hazelnut trees must be trained to develop a strong system of major scaffold limbs. Training begins at planting when the young tree is cut back to a height of 30-36 inches. Then, during the first two to three years of growth, all except 3 to 5 of the side shoots are removed. These shoots become the tree's scaffolding on which fruiting wood develops. Also, all sucker growth is removed to force the plant to grow as a single-trunked tree rather than following its natural tendency to develop as a multi-stemmed shrub.

Orchard Floor Management

Hazelnut growers commonly use a combination of herbicide sprays and mechanical flailing to maintain most orchard floors. Typically, herbicides are used to kill vegetative growth within the tree rows, while flailing is used to control the ground cover between the rows. In addition to cutting weeds and grass down to ground level, flailing helps chop up leaves and small twigs in the spring, as well as blank nuts that have dropped to the ground before harvest in the fall. Flailing may begin as early as March, and is usually required four to six times per season. Growers may also flail the orchard floor following harvest to mulch leaves and eliminate any remaining old crop nuts which can attract rodents.

Irrigation

Most hazelnut trees rely on natural rainfall for water, and less than 10 percent of Oregon's orchards are irrigated. Orchards that are irrigated are usually those on sandy soils or plantings of young trees (Jossy). Although most hazelnut roots are located in the first two feet of soil, active root systems can penetrate to depths of 8-10 feet in deep soils. The cost of irrigation relative to its benefits is an important consideration for growers. Shallow soils are often poorly drained, and irrigation does not necessarily improve the suitability of such soils for hazelnuts. The greatest benefit of irrigation is in establishing a young orchard, where it promotes the rapid development of large trees (Baron).

Pruning

Hazelnuts are produced on new wood, and it is important that trees produce an abundant amount of new growth. Vigorous pruning promotes the growth of these new shoots. An added benefit of proper pruning is that it reduces limb breakage from ice and snow. One guideline for pruning is to remove one-half of the fruiting area from one-fifth of the trees annually, while leaving as large a framework as possible (Riggert). Pruning mature trees also helps suppress the alternate-year bearing tendency of hazelnuts.

Hand pruning permits more precise cutting and removal of desired wood than mechanical pruning. Nevertheless, mechanical hedging and topping are widely used to speed up the operation and reduce costs. Since mechanical pruning involves indiscriminate cuts, growers may follow up with hand pruning to further thin out interior growth.

Sucker Control

Hazelnut trees are prone to producing sucker growth (shoots sprouting from the base of the plant), and will develop as a bushy shrub rather than as a tree if the suckers are not removed. Most growers use chemical herbicides to control suckers, spraying when the shoots become six to nine inches tall. If the suckers grow more than nine inches, chemical herbicides may not kill them. In this case, they must be removed by hand. Typically, orchards require three to four herbicide treatments per year to control suckers.

Orchard Nutrition

Major plant nutrient requirements for hazelnuts include nitrogen, potassium, magnesium, and boron. Nitrogen promotes vegetative growth, with mature trees usually requiring 1½ to 2 pounds of nitrogen annually. Younger trees require smaller applications. Potassium promotes leaf growth and nut development, and growers may apply up to 10 pounds per tree in the form of potash. Potassium is usually applied when leaf and soil analysis results indicate such a need. Hazelnut trees use very little phosphorus, and deficiencies have not been indicated in Oregon. Applying phosphorus fertilizer reportedly does not increase hazelnut yields in Oregon (Baron).
Hazelnut trees may also require the application of magnesium and/or boron for maximum growth. These elements are usually applied as a foliar spray when tissue analysis indicates a need.

Excessively acid soils can limit hazelnut tree performance because pH levels below 5.6 reduce the availability of soil nitrogen and magnesium to the trees. If the soil profile is too acid for hazelnuts, growers can apply agricultural or dolomitic lime to raise the soil pH.

Moss and Lichen Control

The most serious problem caused by moss and lichens is that they result in extra snow and ice accumulating on the limbs during winter storms. At times, this additional weight can cause excessive limb breakage. Moss and lichen growth on limbs can be controlled by applying copper and lime sulfur sprays during the winter or early spring.

Preharvest Care

Growers flail the orchard floor one last time just before filled nuts begin to drop in early September. The flailing action grinds up blank nuts and twigs that have fallen early, and puts the orchard floor in proper condition for harvesting. Ethephon, an abscision chemical, is at times sprayed on the trees in late August or early September to hasten nut drop.

Harvesting

Commercially-grown hazelnuts in the United States are harvested mechanically. After 90 percent or more of the nuts have dropped to the ground, they are raked from beneath the trees with either an air blast machine or mechanical rake, and deposited into a swath between the tree rows. A pickup machine following the rake lifts and separates the nuts from the leaves, twigs, and other trash and deposits the cleaned nuts into a tote box. When the tote boxes are filled, a driver with a forklift tractor moves them out of the orchard. With such a system in place, 15 tons or more tons of nuts can reportedly be harvested per day (Riggert).

A modern harvesting system requires a large capital investment, and neighbors may work together to use their equipment more fully. In addition, smaller orchards may use less expensive harvesting systems that have lower harvesting capacity. Increasingly, however, growers are cash renting or share cropping several orchards to expand the size of their hazelnut operations and to capture the economies of size from their investment in harvesting equipment.

Production Perils

Several natural perils may cause yield losses in hazelnuts, the most serious of which are extremely cold temperatures and excessive rain during pollination. A number of other perils can reduce yields, although growers have some degree of control over the extent of damage. Virtually no weather perils have occurred in the Willamette Valley that kill or permanently disable hazelnut trees. The major threat to hazelnut trees is the Eastern Filbert Blight (Mehlenbacher, 1997b).

<u>Eastern Filbert Blight (EFB)</u>

Eastern filbert blight is a relatively new disease to the Pacific Northwest which infects the stems and twigs of the hazelnut tree. Infections girdle the branches, and the leaves beyond the infected area wither. Severely infected trees develop perennial cankers, which eventually girdle entire scaffold limbs. Trees are usually killed a few years after the cankers spread to the main trunk. The disease is spread within the orchard and beyond by spores carried by wind and rain. Most cultivars are susceptible to this disease in varying degrees. “Daviana,” “Butler,” and “Duchilly” are highly susceptible. “Barcelona” is considered somewhat tolerant, as infected trees of this variety can remain productive for several years before they eventually die (Mehlenbacher, 1990). “Casina” reportedly has about the same EFB tolerance as “Barcelona” (Pinkerton). EFB disease has been present in the eastern United States for many years, and the native American hazel reportedly is a natural host of the disease. This native species, however, appears tolerant of infections, suffering little or no ill effects.

The first infections in the Pacific Northwest were discovered in Washington in about 1970 (Pinkerton). The disease has gradually moved southward since that time into the main hazelnut area in Oregon. The movement of the disease southward appears to be slowed by the prevailing direction of the wind in western Oregon. The disease’s spores are released during rainy weather and are carried by the wind. However, during the rainy season, the prevailing wind is from the southwest, and this tends to carry the spores back northward towards Washington. Currently, the disease has spread about 35-40 miles southward into the Willamette Valley.

Growers with infected orchards have been able to manage EFB with additional fungicide sprays and continuous scouting and pruning, but at an increase in cost. Once the disease is in the orchard, growers must apply 2-4 additional fungicide sprays annually and must continually scout the trees for infections, pruning out infected wood. These scouting and pruning activities are labor intensive operations and add substantially to production costs. Progress is being made in developing resistant varieties, but varietal development is a long-term process that requires many years before a new variety can be tested and its yields proven under commercial production conditions.

Bacterial Filbert Blight

Bacterial blight, commonly known as filbert blight, is also a serious hazelnut disease in Oregon, particularly among young trees. The most serious damage occurs to trees less than 5 year old. Infections cause trunk girdling and kill young plants. Trunks of older trees are seldom infected, but buds and nut-bearing twigs in the tops may be killed, thereby reducing yields. The disease is most prevalent after heavy fall rains and is most serious when a wet fall is preceded by another fall season with heavy rains.

Copper sprays or copper dust applied in late August or early September (before the first heavy rains) usually control filbert blight. In seasons with heavy and prolonged rainfall, a second application may be necessary after the trees have shed some of their leaves. Avoiding unnecessary tree damage helps reduce infections by preventing the blight organism from entering the tree.

Animals

Deer are particularly damaging to young hazelnut trees in orchards next to wooded areas, as they browse on the foliage and new shoots. The use of deer fencing around the entire orchard is an effective, but expensive, solution. Chemical and other repellents have proven only partially effective at reducing deer damage.

Gophers may kill young hazelnut trees by gnawing on the roots. They are often attracted to the orchard by the succulent roots of a cover crop, but turn their attention to the hazelnut trees after the cover crop is turned under. Control measures include the use of toxic bait, burning sulfur with a weed burner down the gopher hole, and trapping.

Meadow mice can damage hazelnut trees by girdling the roots and stems. Eliminating any ground cover around the trees minimizes this damage. Poison baits also provide economical and effective control.

Weeds

Weeds are controlled by the combined use of herbicide applications and flail chopping. Herbicides are used to control weeds within the tree row or in circles around individual trees, while weeds between trees are controlled by flailing.

Moss and Lichen

The most serious problem caused by moss and lichen is additional limb breakage during heavy, wet snows and ice storms. A good pruning program, combined with fertilization and other management practices that encourage vigorous tree growth, usually keep moss and lichen damage under control. Sprays also can be effective in controlling these bark parasites.

Pecans

In terms of production value, pecans rank third-highest among tree nut crops grown in the United States, following almonds and walnuts. In 1995 and 1996, U.S. pecan output averaged 245 million pounds and had a farm value of over $200 million. Although pecans are produced across the southern United States, Georgia and Texas are the leading states.

According to the Census of Agriculture, 21,206 farms grew pecans in the United States in 1992. Pecan trees covered 473,426 acres in 27 states. Texas and Georgia accounted for more than half of the total area, with 35 and 27 percent of U.S. acreage, respectively. Other states with substantial pecan acreage in 1992 include Oklahoma, Alabama, New Mexico, Mississippi, Arizona, Florida, and Louisiana.

Output levels are not only influenced by alternate bearing patterns, but also by the type of pecan trees that are grown. Some types regularly produce more nuts than others. There are two major classifications of U.S. pecans--native (seedling) varieties and improved varieties. Native pecan trees result from seeds, while improved varieties result from budding or grafting. Managed native stands generally produce fewer, smaller, and lower-quality pecans than improved varieties.

Pecan Tree Characteristics

Pecan trees are deciduous, dropping all their leaves in the fall. They require a period of dormancy between bearing cycles. Mature pecan trees can become very large and are long-lived. Pecan trees do not produce nuts for 5-10 years after planting, but can continue producing for over a hundred years.

Because pecans do not reproduce true from seed, improved varieties have been developed that are propagated by grafting to maintain the desirable characteristics of the tree and nut. Most pecan orchards are planted to at least four cultivars to aid in pollination. The nuts produced by each cultivar are usually very distinct in size, shape, and color, and the trees may be planted in separate rows to facilitate harvesting only one variety at a time.

Pecan trees have a pronounced tendency toward alternate-year bearing. A typical pecan-growing season begins with bud-break in April, followed by pollination in May, and nut sizing in June. Nuts are developing and growing on the tree until shuck split in October, and harvesting may not occur until mid-December. Good orchard management can discourage alternate-bearing tendencies by alleviating conditions that stress trees. Factors such as soil fertility, over-crowding, variety, and the age of the tree also influence bearing patterns.

Varieties

Pecan orchards usually contain several cultivars that are carefully chosen for their yields, nut quality, and tolerance of insects, diseases, and cold temperatures. Most of the pecans planted in Southeastern orchards before 1950 were the “Stuart,” “Schley,” “Moneymaker,” or “Success” cultivars. Orchards planted within the last forty years may contain the “Desirable,” “Cape Fear,” “Cheyenne,” and “Elliot” cultivars. In the Southwest, “Western” and “Wichita” are important cultivars. Cultivars with Indian names have been developed by USDA.

Stuart

“Stuart” is the old-standard pecan cultivar of the South, and begins to bear 8-10 years after planting. It originated as a superior seedling tree discovered in Mississippi in 1886. This variety comprised about one-fourth of all commercially-producing trees in Georgia in 1989, and is probably still the dominant variety.

“Stuart” trees have only mediocre scab resistance and are susceptible to downy spot and phylloxera. “Stuart” is one of the most consistently high-yielding cultivars, although the nuts are rather small and thick-shelled, with medium-to-low kernel percentages. Nut quality is average, but demand is usually good for this variety and prices for “Stuart” pecans are relatively high.

Schley

Like “Stuart,” “Schley” is another older pecan cultivar. It was planted extensively after its introduction in 1898, and there are still many “Schley” trees throughout the Southeast. The nuts are oblong, with a thin, brittle shell and a golden-colored, high-quality kernel. The yield-per-acre is usually low, however, and “Schley” is susceptible to scab and bunch disease. The nuts may need to be hand picked since mechanical harvesting can damage the thin shells.

Moneymaker

“Moneymaker,” introduced in Louisiana in 1896, was at one time planted throughout the Southeast. Georgia still has many “Moneymaker” trees. The nuts are fairly small, light colored, and round with moderately-thick shells. The trees are high yielding and have a strong alternate-bearing tendency. “Moneymaker” is moderately susceptible to scab, but is resistant to bunch disease.

Success

The “Success” cultivar was introduced in 1903 in Mississippi. It is less widely planted in older orchards in Georgia than in other Southeastern states. The short, round trees produce large nuts that have a tendency to retain part of the shuck after harvest. Yields can be high, but nut quality is extremely variable. The "Success" cultivar is susceptible to vein spot, shuck dieback, stem-end blight, and scab.

Elliot

"Elliot" originated from a seedling and was introduced in Florida in 1925. It is a very scab-resistant cultivar that provides a favorite rootstock and is a good pollinator. The nuts are small, but of high quality. The tree has a tendency to become increasingly alternate bearing as it matures. It is also susceptible to cold injury and aphid infestations.

Desirable

"Desirable" was introduced in 1930 in Mississippi and has been widely planted throughout the Southeast since the 1950's. It is one of the most widely-grown cultivars and continues to be recommended for new plantings. "Desirable" replaced "Schley" as the second most-important variety in Georgia in the late-1980's. This cultivar is known for its consistent production of large, high-quality nuts, and it rarely over-produces. The nuts have a light-colored shell with peppery markings. "Desirable" has only moderate resistance to scab and other diseases, however, and is susceptible to winter injury. The tree has a weak structure and its limbs break easily. As a result, it requires careful training.

Cape Fear

"Cape Fear" was developed from a "Schley" seedling. It was introduced in 1941 in North Carolina, and has recently regained popularity. The nuts are of good quality with dark shells and bright (golden) kernels. The variety has adequate scab resistance, but is susceptible to leaf scorch and angular leaf spot. The trees begin to produce marketable crops about 5 years after planting. They are a good early- and mid-season pollinator that produces high yields, and can be planted successfully in all the Southeastern states.

Cheyenne

"Cheyenne" was released by USDA in 1970, and is recommended for planting in seven Southeastern states, from South Carolina to east Texas. Planting of Cheyenne is not, however, recommended in Georgia or Alabama. It has an early pollen shed that may enhance yields in some orchards (depending on other cultivar plantings), and it is very resistant to pecan scab. Although "Cheyenne" begins bearing 5 years after planting, the tree is slow-growing. It is also prone to alternate bearing, and is susceptible to aphid infestations. "Cheyenne" produces medium-sized, high-quality nuts that are bright-colored and wrinkled, with near-perfect halves.

Western

This cultivar was known as “Western Schley” when it was first developed from progeny of a native pecan found near the junction of the San Saba and Colorado Rivers in Texas in the 1870's (Hancock). “Western” is the standard pecan variety of west Texas, due to its tolerance of heat and drought. The nuts are medium-sized and ripen in mid-to-late season. Early freezes occuring before the shuck is completely open can cause the shuck to adhere to the nut (McEachern). In addition, “Western” has been seriously affected with what is believed to be a stress problem that occurs when the shuck fails to open to release the mature nut (Stein).

Wichita

“Wichita” was developed in an early breeding program established in Brownwood, Texas. With good management, this cultivar can be vigorous and very productive. The nut is medium-sized, with a high percentage kernel and excellent kernel color. If any of its soil, space, climatic, or other requirements are lacking, however, “Wichita” will develop poor foliage cover and be low yielding. “Wichita” is also susceptible to cold injury. In addition, it can only be grown in the arid Southwest because it is highly susceptible to scab (McEachern).

Propagation and Planting

Pecans are described as either "native and seedling" or "improved varieties" depending on the method of propagation. A native pecan tree differs from its parent because it developed from a seed that resulted from cross-pollination. Therefore, each native tree is really a unique variety. In contrast, improved varieties are propagated by grafting a bud or shoot from a named cultivar onto a rootstock. The upper portion of the tree, above the graft line, is identical to the parent. Improved varieties are selected for superior disease and insect resistance, nut yields, quality, and other desirable characteristics. A new pecan cultivar requires about 25 years for development.

Cultivation and Management Practices

Most pecan trees have an alternate bearing characteristic. Although less pronounced in some varieties, the trees produce a large crop during the “on” year, depleting the tree's nutrient reserves. Since pecan trees carry nuts for most of the growing season, there is little time after the nuts drop in the fall for the tree to build up reserves before dormancy. Consequently, the tree uses the next season to recuperate and produces fewer nuts in that year. Good management practices, including adequate water and nutrients and control of crop size, can avoid tree stress and minimize alternate-year bearing.

Soil

Pecans grow as native plants in river valleys where the nutrient-rich alluvial soil deposited by flooding is well-suited to their needs. The soil must have good water storage capacity, as well as good drainage. Upland soils, especially sandy loams, are also suitable if several feet of loose, permeable top soil are present, and there are no compacted layers to hinder root growth. Pecans should ideally be located where a permanent, static water table runs 10 to 25 feet below ground, providing deep water that can be reached by long tap roots and used when the tree is stressed by drought. Surface water should be regularly provided by rainfall or irrigation. Upland soils should typically be irrigated.

Pecan trees are both drought resistant and tolerant of limited water saturation. The long tap roots allow the pecan tree to tolerate drought conditions, although drought stress reduces nut yields. At the same time, the tree is capable of surviving floods and can stand in water for several weeks. Pecan trees are more tolerant of standing water during the winter months, when the oxygen levels in the water are high, than in the summer. Pecan trees cannot tolerate continuous saturation in the summer months, and tree death due to excessive waterlogging may result (Thompson; Wood).

Temperature

Pecan-growing areas in the U.S. generally have growing seasons of 240- to 280- days. Summer temperatures between 75º F and 85º F, with little difference in day time and night time temperatures, are the most conducive to tree growth and nut production. The minimum growing temperature is about 50º F. Although pecan trees have adapted to colder climates, the minimum winter temperature in its native habitat is 0º F to -10º F, and the average winter temperature is 45º F. Some studies have indicated that pecan trees have a chilling requirement of at least 400 hours at 45º F or below (Wolstenholme).

Pruning and Thinning

Young trees require training during the first five years to develop a strong central leader and to eliminate narrow limb crotches which will split easily when subjected to strong winds and heavy crops. Thinning and pruning are required as the orchard matures to ensure that all branches receive sufficient sunlight to thrive and produce nuts. For trees that are more than 20 years old, pruning is usually a less effective way to raise the yield per tree than through the use of thinning. If the limbs of pecan trees touch, or if the orchard floor has less than 40 percent sunlight at noon, the orchard should be thinned by removing trees.

In the Southeast, pecan trees are planted 30 to 40 feet apart and are thinned so that 10-15 year-old trees are spaced 60-80 feet apart. The space required by pecan trees increases with the diameter of the trunk. Young trees that have diameters of 12-13 inches should be planted 30 feet apart, which results in a tree density of 36 trees per acre. When the trunk diameter reaches 20 inches, the tree spacing should increase so that there are about 15 trees per acre. Large trees, with 30-inch trunks, require 80 feet of space and there should be only 6 or 7 trees per acre (O'Barr).

Pecan trees in the Southwest are slower-growing and more compact than in the Southeast, making closer tree spacing possible. In west Texas, mature pecan trees are usually spaced 50 feet apart (Pena).

Pollination

Pecan trees are dichogamous, producing both male (staminate) and female (pistillate) flowers that mature at different times on the same tree. If pollen-shed occurs before the female flowers are receptive, the cultivar is classified as Type I (protandrous) and, if the reverse occurs, Type II (protogynous). Both types of pecan cultivars are needed in an orchard for successful cross-pollination. When no overlap in the period of receptivity occurs, completely dichogamous trees cannot pollinate. Dichogamy is actually a desirable trait of pecans, since self-fertilization usually results in fewer and smaller nuts.

Cross-pollination occurs when the pollen-shed period of one cultivar overlaps with the stigma-receptivity period of the other. Cultivars with six or more days of overlap have a very good chance of cross-pollination. Comparing usual overlap times indicates that “Cape Fear” will pollinate “Desirable,” “Desirable” will pollinate “Elliot,” and “Elliot” will pollinate “Stuart” and “Cape Fear.” Horticulturists recommend at least four cultivars in the orchard--two Type I and two Type II varieties.

Fertilization

The most common plant nutrient deficiencies in pecan orchards are nitrogen, potassium, magnesium, phosphorous, and zinc. Horticulturists recommend that growers use a foliar analysis to determine specific plant nutrient needs before fertilizer applications. Excessive applications of plant nutrients can be as harmful as shortages.

In the Southeast, lime and magnesium (in the form of dolomitic limestone) are generally needed every 3-5 years to raise the soil pH. Magnesium deficiencies are more likely in the sandy, acidic soils of the Southeast than in the higher pH, alkaline soils of the Southwest.

The largest plant nutrient requirement is usually nitrogen, since nut production uses large quantities of this nutrient. In addition, nitrogen is transient in the soil and leaches during periods of heavy rains. Nitrogen deficiency causes the foliage to fade, first to light green and then to yellow. In addition, nut production is limited by aborted flowers and reduced nut size. Nitrogen-deficient trees are likely to defoliate early in the fall, reducing the amount of carbohydrates stored for winter. Heavily-producing trees require approximately 100 pounds of nitrogen per acre, while younger trees need a half-pound of nitrogen for each inch of trunk diameter.

Potassium deficiency may be triggered by an overdose of nitrogen. Such an imbalance of nutrients gives rise to a condition known as "scorch." When this condition is present, the leaves first develop dime-sized, dark-brown areas that then turn yellow. As the leaves become yellow, the symptoms of potassium deficiency brought on by excess nitrogen can resemble the signs of nitrogen deficiency.

Zinc and lime imbalances may also cause stress. A zinc deficiency can cause "rosette," which is characterized by chlorosis and the curling or twisting of young leaves. Low zinc levels can cause poorly-filled nuts, and the tree may have small leaves and reduced cold tolerance. Too much lime (or high levels of calcium and magnesium) in the soil can induce a zinc deficiency by inhibiting zinc absorption. Foliar applications are routinely used to supply zinc to pecans trees in the Southwest.

Ground application is used in the Southeast, where soils are more acidic. Zinc must be present while the trees are leafing in the spring to prevent rosette.

Pesticides

Scab is a widespread disease problem in the Southeast, and must be controlled through preventive fungicide applications for successful pecan production. The scab spray program typically involves 2 or 3 fungicide applications at 10-14 day intervals, beginning at bud break, followed by five or more applications at 21-day intervals. A total of eight sprays, sometimes more in rainy seasons or with susceptible cultivars, may need to be applied. The fungicides that control scab usually also control other fungi as well. Because of the arid climate, routine spraying for fungal diseases is not required in the Southwest.

Insecticides are usually not applied until damage is evident or scouting reveals that insect populations have risen to a threshold level. Insecticide applications should be timed to control insects at a vulnerable stage in their life cycle.

Irrigation

Adequate moisture is a critical requirement in pecan production. Insufficient soil moisture from April through the shell-hardening stage in early August may cause the tree to abort nuts and cause small nuts among those remaining on the tree. Drought during August and September can cause the nuts to be poorly filled. In addition, dry conditions late in the season can also prevent the shucks from opening, as well as hinder the tree's ability to store carbohydrates for the winter.

All pecan orchards in New Mexico, Arizona, and west Texas, and about half of those in Georgia, are irrigated (Pena; Hubbard). Fewer than half the pecan trees in other Southeastern states are irrigated, and less than 10 percent of Oklahoma's pecan trees are irrigated (Goff; Smith).

Pecan trees in the Southeastern states require about 50 inches of water during the growing season. Although rainfall in many pecan-growing areas averages about 50 inches annually, the distribution of rainfall does not always coincide with the orchard's needs. Supplemental irrigation during the critical growing period helps assure consistent yields. A 6- to 8-year-old pecan tree in the Southeast, for example, may need up to 10 gallons of irrigation water per day during June. A 15-year-old tree may need up to 52 gallons, and a 60-year-old tree, as much as 208 gallons daily. Water needs drop during October, to about half of the levels required in June.

Water requirements vary somewhat by area. In central and west Texas, a mature pecan orchard consumes 0.25 acre-inches of water a day during peak periods, and supplementary water is required 50 to 90 days a year. A young, bearing pecan tree in Texas requires 30-40 gallons of water a day during peak growth periods (Pena).

Harvesting

U.S. pecans are harvested primarily during October and November. The splitting of the pecan shucks marks the start of the harvesting season. The shucks begin to split in some areas by the end of September, but most cultivars grown in the Southeast begin to open in mid-October. If mechanical shakers are not used, the pecan nuts drop to the ground naturally over a 3 to 4 month period. Commercial growers in the Southeast shake the trees when about half of the shucks are open (about the end of October) and gather the nuts immediately. The trees are shaken and the nuts gathered again about three weeks later (Goff). Pecan harvesting may begin earlier in Georgia than in other states, and is usually finished by mid-December (Crocker).

The mechanical harvesting equipment consists of tree shakers, nut sweepers, vacuum harvesters, and trash separators. Shakers have padded jaws that clamp the trunk and shake the entire tree. For taller trees, a boom is attached to the shaker and large limbs are shaken one by one. Shaking trees during harvest-time is not considered harmful to the tree. The shaker simply vibrates the tree and the tree survives well (Thompson).

Shakers, however, are being increasingly used in August to thin the crop. There is some question as to the impact of shaking on the tree at this time of year. In August, the tree's bark slips. Also, the tree needs to be shaken harder than during the fall months to remove the fruit because it is not yet ripe and ready to drop. If care is not taken under these conditions, the bark could be damaged, allowing insect and disease entry, potentially killing the tree (Wood).

Production Perils

The productivity of the pecan tree is directly related to its health. Stresses from weather, insect, and disease perils can reduce production for several years, or cause the tree to enter into a vegetative state. A heavy crop load or lack of sun can also affect productivity, sometimes for several years after the stressful situation occurs. Heavy winds, hurricanes, and tornadoes can cause sufficient damage to the tree's canopy to make it unproductive for many years. Damage can also be caused by soil problems, such as high levels of boron and sodium.

Excessive Rain or Cloudiness

Excessive rain during the growing season can reduce the effectiveness of fungicides, and can cause losses due to fungal diseases, especially pecan scab. Late in the season, cloudy weather can diminish photosynthetic activity and reduce the nutrients available to the tree. Events that reduce nutrient availability interfere with the tree's ability to produce nuts the following season. Although pecans can withstand excessive rain fairly well, extreme situations can result in the death of the tree.

Frosts and Freezes

Both pecan trees and the nut crop are susceptible to cold damage. Although pecans are one of the last trees to open their buds in the spring, late spring freezes can kill newly emerged flower buds. Frost is a particular hazard if it follows a period of unusually warm weather. Warm weather causes the trees to bud-out earlier than usual, increasing the chance that they will encounter frost. Early fall and late spring freezes can affect the productivity of the trees for the next several years, having a ripple effect on production. If the freeze damages the tree on an "on" year, when nut production should be high, growers could experience poor crops in that year, as well as in subsequent years due to the alternate bearing nature of the tree (Wood).

Pecan trees are most susceptible to cold injury in the fall, before they have acclimated to low temperatures. Young trees are more likely to be damaged by freezing temperatures than are older trees. Before acclimating to colder temperatures, pecan tree tissues freeze at temperatures below 30^{o} F. When a tree is completely dormant, it can withstand mid-winter temperatures as low as -40^{o} F. Most cold injury occurs on the lower trunk, which is the last part of the tree to become acclimated, and the first to emerge from dormancy (Goff). Prolonged cold temperatures may, however, result in death of the tree (Wood).

The most striking cold injury to trees is sunscald, which occurs when the sun heats the tree trunk on cold winter days, drying out and killing plant tissues. When sunscald occurs, the bark on the sunny side of the tree splits longitudinally or forms a sunken spot. Sometimes, no damage is visible and the weakened tree may live for several years.

Cold damage can be minimized by choosing an orchard site with good air flow and cold-hardy cultivars, and planting trees that were budded or grafted high (not low) on the trunk. In addition, trees should be maintained to promote their health, and pruning should be delayed until the danger of frost is minimal, about two weeks before the trees begins to come out of dormancy. Painting young tree trunks with white latex paint or using light-colored, reflective trunk wraps can also reduce freeze damage.

Excessive Wind

The strong winds and hail that accompany thunderstorms may defoliate pecan trees and diminish their ability to accumulate energy reserves. Winds also increase limb breakage, and even moderate winds can be very destructive to pecan trees carrying a heavy load of nuts. This is especially a problem in August and September, when the crop load is heaviest. During these months, severe wind storms and tornadoes could also uproot a tree, especially the taller trees in the orchard (Wood). Once a sufficient number of limbs have broken off a pecan tree, the tree's canopy will be destroyed and the tree will not produce again until the canopy is replaced, which can take several years (Thompson).

Pecan trees located near the Gulf Coast--such as near Mobile, Alabama--are susceptible to damage from hurricanes. Because pecan trees require approximately ten years to reach peak productivity, extension specialists suggest that they should not be planted within about 20 miles of hurricane-prone areas (Thompson). Hurricane season extends into August and September, when the trees are loaded with nuts and very vulnerable to the strong winds associated with hurricanes (Wood).

Ice Storms

Ice storms tend to be a problem mostly in the fringe areas of pecan production, including the northern parts of Mississippi, Alabama, and Georgia. In these areas, cold and rainy weather can cause icing on tree limbs, which may result in breakage. In northern Mississippi and northeast Louisiana, limbs as large as 6 to 8 inches in diameter have fallen due to ice storms. Downed limbs decrease productivity in that year, and if the canopy is affected, yields may be reduced for several years until the canopy grows back. In the coastal plains, where most pecan production occurs, ice storms are less of a problem (Wood).

The cost of cleaning up after ice storms can be very expensive, with estimates of $200 to $1,000 an acre to clean up and properly prune the trees. While limb loss and pruning may cause the tree to enter a vegetative state for up to 4 to 5 years, the orchard still must be maintained, increasing the costs of the loss even further (Thompson). Severe ice storms can tear trees apart and prompt growers to remove entire orchards. Such severe damage is, however, uncommon (Wood).

Lightning

As pecan trees become larger, lightning damage increases as a threat. When a tree is hit by lightning, the extent of damage varies depending on the specific circumstances. The tree may be able to grow back from the roots after several years, or it may be killed. When lightning strikes, only a few trees in an orchard are lost (Thompson; Wood).

Drought

Drought can kill a pecan tree if it occurs when the tree is stressed. This is especially likely to happen after a tree has produced a large crop. Typically, few trees in an orchard are killed by drought, although productivity may be lowered for several years. In such cases, there may be no crop the year after the drought. The second year may produce an exceptionally heavy crop, with a high proportion of unfilled kernels. This pattern may continue for 4 to 10 years, causing the orchard to become uneconomical.

Growers will often wait out the effects of drought because of the long time it takes for a new tree to become productive. Good management practices can aid recovery (Wood). Planting trees in soil with good water retention is an important management practice reducing the effects of drought. If soil has good water-holding capability, the long taproots of the pecan tree can help the tree survive a drought (Pena).

Excessive Boron and Sodium in the Soil

Excessive levels of boron and sodium in the soil can poison a pecan tree’s roots, killing the tree. This is mainly a problem in the arid West, from central and western Texas to New Mexico, Arizona, and California. Pecan production in these states is entirely irrigated. Irrigation causes boron and sodium levels to increase, increasing the chances of such poisoning.

Diseases

Scab is the most widespread and serious disease affecting pecans in the Southeast. Fungal diseases are most serious in humid regions and during periods of excessive rainfall. In the more arid areas of west Texas and New Mexico, shuck disorders are a more serious problem than scab.

Scab

Scab is the most important disease affecting pecan trees. It is a fungus that attacks the leaves and nuts of the tree, causing black spots. Scab infections may cause pecan trees to become defoliated, debilitating the tree and eventually causing its death. Even before death occurs, scab makes the tree unhealthy and it reaches a point where it cannot produce nuts. At such a time, the tree must be removed.

Scab is a difficult disease to control because of its changing nature. Cultivars that may once have been resistant to scab become increasingly susceptible over time. The continual development of new cultivars that resist scab, at least initially, is the only way to keep pecan production continuing east of the Mississippi. Creating new cultivars, however, is a long process, taking about 25 years (Thompson).

Cotton Root Rot

Cotton root rot is a fungus that lives in the soil. The fungus attacks the roots and causes death of the tree. There are no chemical methods of control that are available presently to combat this disease.

Shuck Dieback (Decline)

The exact cause of shuck dieback is not known and no effective control has been found. Shuck dieback is associated with “Success” cultivars, appearing wherever this cultivar or its progeny are grown. It seems to be related to tree stress and becomes most severe on trees with large crops and trees that are crowded.

Shuck dieback does not usually appear until September or October in Alabama, and about one to two weeks before normal shuck split in Texas. When this disease is present, the shuck begins to turn black and die at, or near, the tip of the nut. As the black area spreads, the shuck may flare open. Damaged nuts have no kernel or are poorly filled.

Shuck dieback can kill young trees (those 15 years and younger) if they are already under stress. In such situations, the tree may look healthy during the winter. By spring, the tree may begin to appear damaged by cold injury, but in actuality, is dying (Wood).

Crown Gall

The tumorous growths characteristic of crown gall usually arise on the roots and bases of pecan trunks, but can appear on the lower limbs of young trees. The galls are wart-like growths varying in size from a few inches to a foot or more in diameter. Crown gall is caused by the bacterial pathogen *Agrobacterium tumefaciens*, which can live in the soil for many years. It enters the pecan tree's roots and stems through wounds caused by insects, grafting, and cultivation. Hosts include apple, peach, pecan, walnut, and grape. Galls reduce tree vigor by retarding the flow of water and nutrients.

The incidence of crown gall is reduced by planting only disease-free nursery trees that have been dipped in a solution of an antagonistic bacterium. Preventing entry wounds is important since crown gall has been found to be present in 25-60 percent of the 40- to 60-year-old orchards in Georgia.

Insects

Insects often affect the productivity of a crop of pecans, but few threaten the life of the tree. An exception is the Paranous root borer, which burrows into the root system and eventually kills the tree. For a tree to be affected by the root borer, however, it first needs to be stressed by some other factor, reducing its resistance (Wood).

Unknown Factors

Pecan trees occasionally die due to unknown causes. Typically, only a few trees in an orchard are affected. One of these unknown causes is called “mouse ear.” Mouse ear affects young trees, keeping them from growing and becoming productive. It may be the result of a fertility problem, although the exact cause is uncertain. Mouse ear strikes an orchard at random. It occurs less than one percent of the time in newly planted orchards, but usually occurs when trees are planted in missing spaces in an established orchard (Wood).

Pistachios

Pistachios are a relatively new crop to the United States, and virtually all production is located in California. According to the Census of Agriculture, slightly more than 1,000 farms had pistachio trees under commercial cultivation in California in 1992. In 1996, bearing acreage is estimated at 64,300 acres.

Pistachio Tree Characteristics

Pistachio trees are related to cashew and mango trees, as well as to poison ivy, oak, and sumac. Pollination occurs during April and harvest of the nuts is in September. The trees are deciduous, dropping their leaves in November, and require a dormant period between bearing cycles. Like other nut trees, pistachio trees are alternate-bearing.

Pistachio trees are either male or female ("dioecious"). Consequently, trees that produce nuts do not produce pollen. The cultivars used as pollinators are male, while those that produce the nuts are female. Pistachio trees produce nuts about six years after planting and reach full-bearing potential in 12 to 15 years. The fruits of the pistachio tree are nuts that grow in clusters along the distal portions of branches that are produced during the previous season.

Varieties

A given pistachio tree produces either male or female flowers, but not both. Cultivars tend to be identified as female or male because all of that cultivar's trees have been propagated with buds from trees of the same sex. "Kerman" and "Joley" are the preferred female (nut-bearing) cultivars, while "Peters" and "Gazvin" are the primary male (pollinator) cultivars.

<u>Kerman</u>

The "Kerman" variety was introduced in 1957 by USDA for trial purposes, and was selected from a group of seedlings grown from seeds imported from Iran. In 1994, "Kerman" comprised 92.5 percent of California pistachio acreage (California Agricultural Statistics Service). It produces exceptionally large nuts with excellent kernel quality. The trees, however, have a pronounced alternate-bearing tendency and, despite relatively high yields, produce a high percentage of blank nuts and nuts with non-split shells.

<u>Joley</u>

"Joley" is a new pistachio cultivar grown in California and New Mexico. It comprised less than 0.1 percent of California acreage in 1994 (California Agricultural Statistics Service). "Joley" was developed by USDA, originating as an open-pollinated seedling from seed imported from Iran. "Joley" trees blossom and bear nuts earlier in the season than "Kerman." Experience with limited plantings of "Joley" indicates that it produces more nuts with split shells and fewer blanks than "Kerman."

<u>Peters</u>

The "Peters" cultivar is used as a pollinator, and accounts for 6 percent of California's 1994 pistachio acreage. It is considered a universal pollinator because it sheds pollen while many female cultivars are receptive.

<u>Gazvin</u>

The "Gazvin" cultivar is a recently-introduced variety from Israel. It may provide more pollen to “Kerman” than does the “Peters” cultivar, because “Gazvin” has an earlier peak-bloom date. Although “Peters” has been an effective pollinator of “Kerman,” its average peak-bloom date occurs before “Kerman” bloom begins. The peak-bloom date of “Gazvin” coincides more closely with the early bloom of “Kerman.”

Propagation and Planting

Pistachio trees are propagated by grafting a bud of a selected cultivar onto a rootstock. The choice of both the cultivar and the rootstock can influence the tree’s resistance to diseases, as well as its cold hardiness, nut yield, the extent of blank nut production, and the tree’s alternate-bearing tendency. There are two dominant pistachio cultivars and two rootstocks that comprise most commercial pistachio orchards in California.

The most common rootstocks used in California pistachio orchards are *Pistacia atlantica* and *Pistacia integerrima* (also known as Pioneer Gold I). During the first decade of commercial plantings, *P. atlantica* and *Pistacia terebinthus* were used exclusively. Both roostocks, however, were found to be susceptible to verticillium wilt, and many pistachio trees in the southern San Joaquin Valley were lost.

Pioneer Gold I was subsequently adopted because it is less susceptible to verticillium wilt, although it is less cold tolerant than *P. atlantica*. A newer hybrid, Pioneer Gold II, combines verticillium resistance and cold hardiness. According to a 1994 survey, Pioneer Gold I rootstock accounts for 48 percent of all pistachio acreage in California, *P. atlantica* accounts for 42 percent, Pioneer Gold II for 3 percent, and *P. terebinthus* for less than 1 percent (California Agricultural Statistics Service).

Rootstock seedlings are grown in containers for approximately one year, until they are large enough to be transplanted to an orchard. Transplanting is usually done in mid-June. A cultivar is budded to the rootstock in the orchard the following April or May, although some rootstock seedlings are ready for budding in the fall. Fall budding is usually done in August.

Seedlings are usually spaced 11 to 12 feet apart within a row, with 22 to 24 feet between rows. The trees are planted close within the row initially to boost production during the early years of the planting, and then are thinned out when crowding occurs. Crowding, however, is usually not a problem for at least ten years because the trees grow slowly.

Mature pistachio trees are usually 20 to 25 feet tall and 25 to 30 feet wide. They begin producing nuts within about 4 to 5 years after budding (or 5 to 6 years after planting), although an economically significant crop is not usually harvested for 7 to 8 years.

Cultivation and Management Practices[4]

Soil

[4] For cost of production budgets, see the appendix.

Although pistachios can adapt to many soil types, they grow best on deep, light, sandy loams that have a high lime content. Well-drained soils are required in order for the trees to flourish and bear well, since the root system will not tolerate prolonged wet conditions. Pistachio trees are more tolerant of alkaline and saline soil conditions than are many other trees.

Temperature

Pistachios thrive in areas with hot, dry summers and moderately cold winters. Optimum temperatures for pistachio production in the United States can be found in California's central valleys at elevations of 500 to 600 feet. Trees should not be planted above elevations of 3,000 feet because cool summer temperatures do not promote good kernel development. Pistachio trees grow well in some areas of southern California, including the desert areas, but produce very few nuts if the winter is too warm. From 700 to 1,000 hours of winter temperatures at or below 45º F are needed for pistachio trees to fruit normally.

Spacing

Mature pistachio trees should be spaced with 20 to 24 feet between rows and 15 to 18 feet between trees for an average of 110 to 145 trees per acre. The ratio of male to female trees is 1:8 in old orchards and 1:14 or 1:24 in newer orchards, with additional male trees in border portions of the orchard.

Pruning

Young pistachio trees require training during their first 4 to 5 years in order for them to develop an open-vase scaffold structure at 1.3 meters. Training begins the second year after the rootstock is planted in the orchard. A strong trunk that extends 36 to 40 inches from the ground to the first scaffold branch is developed to facilitate mechanical harvesting. In each year, new growth should be headed back to 30 inches while the framework of the tree is being established.

Trees are pruned as the orchard matures to keep the tree centers open so that all branches receive sunlight. Trees tend to naturally spread as they develop, and branches will eventually be pulled down by the weight of the foliage and the nuts. Drooping branches tend to sunburn and to shade the branches below. Older wood must occasionally be removed to prevent spreading and to stimulate renewed growth from the scaffold branches. Topping and hedging machines are often used on 3- to 5-year old wood. Pruning is done during the winter.

Pollination

Because pistachio trees are either male or female, male (staminate) and female (pistillate) flowers cannot be produced on the same tree. Wind carries the pollen from the male to female flowers. Female flowers do not produce nectar, nor do they have colorful petals to attract bees. Therefore, bees are not effective pollen carriers.

For maximum fruiting, abundant pollen should be available during the first 2 to 3 days of the female bloom period. The "Kerman" variety has a bloom period of about 11 days, from the first to the third week of April. Since the "Peters" and "Gazvin" varieties bloom from the end of March through mid-April, both can provide adequate pollen to "Kerman" trees. Male pistachio trees tend to be prolific pollen producers, with one male tree providing enough pollen for 10 to 12 female trees.

Fertilization

Nitrogen is one the most likely plant nutrients to be deficient in pistachio orchards, and low levels may affect both leaf production and nut yield potential. The symptoms of nitrogen deficiency include: delayed bud break; short, thin shoots, with reddish bark; and small, pale-green leaves with reddish veins and petioles. In addition, the leaves of the pistachio tree may turn reddish to yellow with time, leaves may drop early from the tree, and yields may be reduced.

Nitrogen is usually applied to the soil of pistachio orchards four times annually, over the March through July period. A recommended application rate is one pound of nitrogen per tree annually, which is about the amount removed by a moderate-sized (1,500 pounds per acre) nut crop.

Boron, zinc, and copper are other nutrients that may be deficient in pistachio orchards. A deficiency of boron is associated with "crinkle leaf," which is characterized by deformed leaves that are twisted, cupped, crinkled, and irregular in shape. Soil applications can be used to correct this deficiency, although repeated applications can result in leaf necrosis, caused by boron toxicity. If boron is applied foliarly, excess boron can cause reduced fruit set.

Zinc deficiency can cause "little leaf," which results in the delayed growth of floral and vegetative buds in the spring. The tree tends to produce dwarfed leaves, with leaf tissue values below 7 ppm of zinc, based on foliar analysis in August (Beede, 1994). Copper deficiency causes shoot die-back in late July and August.

Pesticides and Fungicides

Preventive measures are typically used to control insects on pistachio trees. Pistachio trees usually receive two sulfur applications for mite control in July and August. In addition, permethrin insecticides are commonly used after fruit set in mid- to late-April to combat navel orangeworms and other pests.

Fungicides are also used to help control fungal diseases. They may be applied at any time between April and October, whenever conditions make infection by air-borne fungi a problem. Fungicides that are currently registered for use on pistachios include benomyl, which is used at full bloom, and copper hydroxide sprays. Fewer chemical applications tend to be made in August or September because many pesticides and fungicides are prohibited within specific pre-harvest intervals.

Irrigation

Although pistachio trees are relatively drought tolerant, successful commercial production requires adequate soil moisture, particularly during the summer. Insufficient soil moisture reduces tree growth and yields, causes nut production to be lighter and smaller, and increases the number of blanks and non-splits.

Mature pistachio trees with canopies covering about 60 percent of the orchard floor use approximately 40 inches of water during an average summer in the southern San Joaquin Valley. The trees absorb 7 to 10 inches of water per month during June, July, and August. Somewhat less irrigation is required in the Sacramento Valley, where winter rainfall is higher (typically 16 to 20 inches).

Virtually all California pistachio orchards are irrigated. Originally, most of these orchards were irrigated with furrow (flood) irrigation or drag-line sprinkler systems. A higher incidence of fungal infections is associated with those systems, however, and prompted growers to change to low-volume (drip, fan-jet, and microsprinkler) systems (Kallsen). Flood and sprinkler irrigation systems were found to promote fungal infection by raising the relative humidity in the orchards. In addition, the splashing water from high volume sprinklers spreads fungus spores. Nearly all irrigation systems in Kern County orchards are low-volume, but flood irrigation is still used in some areas of Madera County.

Harvesting

California pistachios are harvested mechanically with prune-harvesting equipment, which is composed of two separate, self-propelled units. The shaker, which has a catching frame, and another catching frame (with a conveyor belt and blower), are positioned on opposite sides of the tree. When the tree is shaken, the nuts fall into the canvas aprons of the catching frames and roll onto the conveyor belt. Two experienced workers can harvest about one acre of pistachio trees per hour (Crane and Maranto).

Production Perils

Major production perils affecting pistachio trees include excessive rain, late frosts and hard freezes, and various diseases.

<u>Excessive Rain</u>

Excessive rain can damage the pistachio tree in several ways. Continually saturated conditions deprive the roots of oxygen and can make the tree unproductive. Also, the saturated soil makes it harder for the roots to hold anchor in the soil. If rains are accompanied by heavy winds, especially when the tree is full of nuts, the wet conditions could cause the tree to topple. Continual rainy conditions also provide a perfect environment for fungal diseases to thrive.

<u>Frosts and Freezes</u>

Pistachio trees can generally tolerate relatively low winter temperatures, with some having survived temperatures as low as 6º F without injury. One of the few winter-related setbacks to pistachio production occurred in December, 1990, when a “100-year freeze” caused widespread damage to most fruit and nut trees in southern California. Pistachio trees were killed in Kern and Madera counties.

Cold damage can be minimized by choosing an orchard site that has good air flow and by planting trees with cold-hardy rootstock. *Pistacia atlantica* is the most cold-tolerant rootstock, followed by Pioneer Gold II and Pioneer Gold I.

<u>Diseases</u>

Major diseases affecting pistachio trees include the fungal diseases Verticillium wilt, crown and root rot, and bacterial diseases such as canker.

<u>Verticillium Wilt</u>

Verticillium wilt is caused by the soil-born fungus *Verticillium dahliae*, and is the most serious disease affecting pistachio trees in California, particularly in the southern San Joaquin Valley (Ferguson). The verticillium fungus can live in the soil for many years. It invades the plant through the roots, and moves up the trunk and limbs through water-conducting tissues. When the tree is infected, the leaves wilt, turning yellow and then brown. Eventually, the tree dies. Pre-plant soil fumigation with methyl bromide and chloropicrin is recommended, although planting with resistant rootstock is the best way to control this disease.

The two most common rootstocks used in early California pistachio orchards, *Pistacia atlantica* and *Pistacia terebinthus*, were found to be susceptible to verticillium wilt. During the late 1970's and early 1980's, many pistachio orchards in the southern San Joaquin Valley were planted where cotton had been grown and the soil was infected with verticillium. Thousands of pistachio trees planted in Kern County died and were replaced with trees having new rootstock. *Pistacia integerrima* (Pioneer Gold I) rootstock is tolerant of the disease, and has been used successfully in infected areas.

<u>Crown and Root Rot</u>

Crown and root rot is due to infection by several species of Phytophthora, a soil-borne fungus. Pistachio trees in poorly-drained areas are the most likely to be infected. The fungus, however, is widespread. Symptoms of Phytophthora rot are similar to verticillium wilt. Less vigorous trees are the most likely to succumb to Phytophthora infection and to die quickly. The incidence of crown and root rot is expected to increase as pistachio trees increase in age and decline in vigor.

<u>Trunk and Branch Canker</u>

Three species of Phytophthora, *P. parasitica*, *P. cryptogea*, and *P. capsici*, have been associated with trunk and branch cankers (MacDonald, et al.). Symptoms of the disease include the development of dark, sunken areas of bark from which resin exudes. These cankers can enlarge over time, girdling and eventually killing entire branches or trees.

Fungicides are not an effective treatment for control of trunk and branch cankers. The best control is to minimize tree injury during the growing season, because spores enter through wounds such as those from pruning cuts or limb breakage. Using irrigation systems that do not splash water onto branches or trunks also reduces the likelihood of infection, as surface waters may be contaminated with pathogenic species of Phytophthora.

Walnuts

California accounts for 99 percent of U.S. walnut production. Production is concentrated in the Central Valley, although walnut acreage is scattered throughout much of the state. The top five walnut producing counties in 1994 were San Joaquin, Tulare, Stanislaus, Butte, and Sutter. In 1995, there were about 170,000 bearing acres of walnuts in the state, and walnuts were second in nut acreage only to almonds. In 1995, walnut production ranked 9th in revenue among all fruit and tree nut output in California, and 10th in export value among all of California's agricultural commodities (California Agricultural Facts).

Walnut Tree Characteristics

The walnut tree is deciduous, shedding its leaves in the fall. The tree is monoecious in that a single tree has both pistillate and staminate (female and male) flowers and is able to self pollinate. For many varieties, however, adequate pollination requires that a second variety be planted that will shed pollen at the time of pistillate receptivity for the first variety. The flower is wind pollinated. Between two and seven years are required before a walnut tree begins producing nuts.

There are two major commercial species of walnuts. The first type is the English walnut, which is native to a wide-ranging area from eastern Europe to the Himalayas, and is also called the Persian walnut. The second type is the black walnut, which is native to the United States. Almost all walnuts sold commercially in the U.S. are the English variety. Black walnuts have a hard shell and poor hulling characteristics, making them less desirable for commercial use (Walnut Marketing Board).

Varieties

Walnut trees are part of the genus *Juglans*, and in the same family as pecan and hickory (Walnut Fact Sheet, U.C. Davis). The most important commercial species include English or Persian walnut (for nut production), *Juglans regia*; Eastern black walnut (for timber production), *Juglans nigra;* Northern California black walnut (for rootstock), *Juglans hindsii;* and "Paradox," (for rootstock) a cross between the English walnut and the Northern California black walnut (Walnut Fact Sheet, U.C. Davis).

The major walnut tree varieties are "Franquette," "Hartley," "Payne," "Vina," "Chico," "Serr," "Eureka," "Tehama," "Sunland," "Ashley," "Amigo," "Howard," "Pedro," "Chandler," and "Tulare" (a new variety). The most common variety currently in production is "Hartley," although "Chandler" is the most popular variety for new plantings. Certain varieties are preferred for planting in different areas based on the timing of their leafing. Varieties that leaf later in the season, for example, potentially have fewer problems with late spring frosts and rains, and are preferred in foothill counties that are prone to spring frosts. The information on tree varieties that follows is from *Walnut Orchard Management*.

Payne

"Payne" originated in 1898 as a seedling and is a standard in many California producing areas. The "Payne" tree is moderately sized with a rounded shape and good vigor, and its yield potential is high to very high. Moderate to heavy pruning is required when the trees are young to avoid overbearing. "Payne" is susceptible to codling moth and blight. Walnuts from "Payne" trees are harvested early in the season, as the nuts mature in early September. The nut size is medium to small.

Approximately 80 to 90 percent of the lateral buds on "Payne" shoots are fruitful. The tree begins to leaf in mid- to late-March in the Central Valley, and is the standard by which other varieties are compared. The pollen shedding period on "Payne" coincides well with the period of pistillate flower receptivity, and solid blocks of "Payne" trees are often very productive. "Payne" walnuts dominate the west side of Stanislaus and Merced Counties, as well as San Benito County.

Hartley

"Hartley" is the most widely planted variety of walnut, and its yield potential is moderately high to high. Its popularity stems from its light kernel color, lack of problems with codling moth and blight, and its good yields. It is, however, susceptible to deep bark canker. With moisture stress or poor soil conditions, deep bark canker can be a limiting factor in production. "Hartley" trees prefer fertile, deep, well-drained soil, and an adequate water supply. It is a moderately-sized tree, moderately spreading, with good vigor on fertile soil. "Hartley" is the dominant variety in the Sacramento and San Joaquin Valleys and in San Luis Obispo County.

Up to 10 percent of the lateral buds are fruitful on "Hartley." They are somewhat slow to come into bearing, but yield good crops at maturity. "Hartley" trees begin to leaf about 16 days after "Payne." Acceptable pollinators are the late-blooming "Franquette" and several University of California selections. "Hartley" is harvested mid-season. The nut has a broad, flat base and a pointed tip, and the nuts are large and well sealed. "Hartley" is the primary bleaching variety sold in-shell.

Franquette

"Franquette" is an old French variety that is planted to a limited extent, and mainly in the foothill counties and areas with a tendency toward late spring frosts. The "Scharsch-Franquette" selection is considered one of the best pollinators for medium- to late-blooming varieties such as "Hartley." The "Scharsch-Franquette" variety begins to leaf about 31 days after "Payne." Only terminal buds are fruitful on the "Franquette." Harvest-time is late in the season, and the nut size is small. "Scharsch-

Franquette" trees are large with an upright shape, and they are moderately to highly vigorous. "Franquette" is the major variety grown in Lake County.

Serr (UC59-129)

"Serr" is a University of California selection that is a cross between the "Payne" and "Pl-159568" varieties. It produces a low to moderately heavy yield, depending on the location and orchard conditions. In addition, this variety tends to drop its flowers more than other varieties. As a result, "Serr" has become less popular over time. Between 30-50 percent of its lateral buds are fruitful, and it leafs about one day ahead of "Payne." Suitable pollinator varieties include "Chico," "Tehama," and other varieties that shed their pollen in mid-bloom. Harvesting is early to mid-season, and the nut tends to be large in size. The tree is large and moderately spreading with good to excessive vigor. It bears earlier and more consistently on less fertile soil than other varieties. Serr is susceptible to codling moth and blight. It is the major variety in Kern County.

Ashley

"Ashley" is a well established, highly fruitful variety with 80 to 90 percent fruitful lateral buds. The tree leafs about the same time as does "Payne." Many other characteristics are also similar to "Payne," including its susceptibility to codling moth and blight. "Ashley" requires consistent, heavy pruning in order to remain vigorous.

Sunland (UC66-4)

"Sunland" is a University of California variety, developed as a cross between "Lompox" and "Pl-159568." Although not well established, this variety has the potential to produce high to very high yields. It leafs two days after "Payne," and "Chico" and "Tehama" can serve as pollinators. "Sunland" has 80 to 90 percent lateral bud fruitfulness. This variety produces a very large nut, and harvesting is in mid- to late-season. Young trees are very vigorous, with tree size similar to the "Payne" variety. "Sunland" should not be planted in areas where late spring frost or blight are problems.

Chico (UC56-206)

"Chico" is a cross between the "Sharkey" and "Marchetti" varieties, and 80 to 90 percent of its lateral buds are fruitful. "Chico" leafs two days after "Payne." Because "Chico" blooms early and sheds pollen late in the season, it crosses very well with early bloomers such as "Payne" and "Serr." It is planted mostly as a pollinator for early leafing varieties, but can also be a very good main variety in most areas of California. "Chico" produces a small nut, and heavy pruning is necessary to maintain nut size. The tree is small and shaped similarly to "Payne," but is upright. "Chico" is well adapted to a hedgerow planting or to a closely spaced planting.

Vina (UC49-49)

"Vina" is a cross between the "Franquette" and "Payne" varieties. It has 80 to 90 percent lateral bud fruitfulness, and leafs 7 days after "Payne." Acceptable pollinators include varieties that shed pollen in mid-season such as "Chico," "Tehama," "Howard," and "Chandler." Harvest is early to mid-season. "Vina" trees are small-to-medium in size, and shaped similarly to "Payne." The tree's vigor is moderate to good, and pruning is necessary to maintain its vigor and nut size. Although "Vina" exhibits fewer blight problems than "Payne" or "Ashley," under poor conditions this disease can be a problem. "Vina" is a popular variety in many walnut-producing areas in California.

Tehama (UC58-11)

"Tehama" is a cross between "Waterloo" and "Payne," with 70 to 80 percent of its lateral buds bearing fruit. This variety leafs 11 days after "Payne," and is harvested in mid-season. Its trees are large, upright, and have good vigor. "Tehama" was primarily planted in the past as a pollinator, and few acres presently are planted to this variety.

Amigo (UC56-226)

"Amigo" is a cross between "Sharkey" and "Marchetti," and is very fruitful, with 80 to 90 percent of its lateral buds bearing fruit. "Amigo" leafs 12 days after "Payne." Its harvest is early to mid-season. "Amigo" has been planted as a pollinator to "Hartley," although few trees have been planted in recent years.

Howard (UC64-182)

"Howard" is a cross between "Pedro" and "UC56-224." It has the potential to be very productive, and 80 to 90 percent of its lateral buds are typically fruitful. The tree leafs 15 days after "Payne." Possible pollinators include "Scharsch-Franquette" and "UC66-178." Harvest is mid-season, slightly ahead of "Hartley," and tree size is small to medium and semi-upright with moderate vigor. "Howard" is smaller than "Vina" and "Chandler," and may be used in hedgerow plantings. Because it is late leafing, "Howard" exhibits fewer blight problems than other varieties.

Pedro (UC53-113)

"Pedro" is a cross between "Conway Mayette" and "Payne." It blooms early in the season and was introduced primarily as a pollinator. "Pedro" leafs 18 days after "Payne," and is highly fruitful, with 80 percent of its lateral buds bearing fruit. Harvest is mid- to late-season. When high temperatures occur, shell and kernel quality may be inferior to other varieties.

Chandler (UC64-172)

"Chandler" is a cross between "Pedro" and "UC56-224." "Chandler" leafs 18 days after "Payne," and 80-90 percent of its lateral buds are fruitful. Possible pollinators for "Chandler" include "Scharsch-Franquette" and "UC66-178." Harvest is mid-season. The tree size is larger than "Howard," and it is moderately vigorous and semi-upright. "Chandler" may experience fewer blight problems than other varieties because it is late leafing. "Chandler" has become a popular variety because it has high nut quality and minimal insect and disease problems. It also produces large, light kernels, making it an excellent shelling variety that cracks into halves easily. A drawback, however, is its tendency towards tip shrivel on the kernel.

Rootstock

Most of the walnut trees planted in San Joaquin County, and about one-half of the trees in Kings and Fresno counties, are on "Paradox" rootstock, which is highly recommended because of its vigor. "Paradox" is nematode tolerant and phytophthora resistant. In some areas, however, "Paradox" may lead to early crowding, and may require tree removal before costs are recovered. The trend in the early nineties has been to plant "Chandler" on "Paradox" rootstock throughout most of California.

Despite this trend, northern California black walnut is the most common rootstock used in existing orchards. It produces a smaller tree than "Paradox," and is recommended in situations where blackline disease is epidemic. Some growers intersperse northern California black walnut stock in between their "Paradox" plantings because they know the black walnut tree will grow more slowly. As a result, they can keep it in their orchard longer before it becomes necessary to remove it for thinning (University of California, Agricultural Issues Center).

Propagation and Planting

The most common propagation method for walnut trees is grafting or budding on seedling rootstock. Presently, researchers are experimenting with the rooting of cuttings to produce clonal rootstock and own-rooted cultivars.

Standard tree planting distances are about 30 feet apart both within a row and between the rows, resulting in about 48 trees per acre. High density planting involve the spacing of trees 24 feet apart, resulting in about 76 trees per acre. Hedgerow plantings space trees about 11 feet apart within a row, and 22 feet apart between rows, resulting in about 180 trees per acre.

After planting, tree trunks are treated with white, water-based paint to protect the trees from sunburn. In addition, new trees are topped soon after planting in order to encourage trunk development. Regular pruning begins during the winter months of the tree's second year. The trees are trained to grow with a modified central leader. In the second year, about 2 trees per acre under standard planting conditions will need to be replaced. In the third year, one tree per acre is typically replaced (Ramos).

Cultivation and Management Practices[5]

Walnut trees need, deep, well drained, fertile soil, and produce the highest yields in warm, temperate climates. The trees have the greatest vigor when rain is minimal during the growing season because of their susceptibility to blight. Under such conditions, however, irrigation is a necessity.

Climate

California's long, warm, dry summers and mild winters are similar to the native habitat of the English walnut. Consequently, the Mediterranean strains easily adapt to California growing conditions. Varieties grown in California are able to withstand winter temperatures as low as 12-15^{o} F without serious injury. Indeed, the walnut-growing areas of California are limited more by insufficient winter chilling than by cold tolerance.

Chilling requirements vary by variety. The commercial varieties that dominated the former industry in southern California, for example, had low chilling requirements and were adaptable to mild winters. In contrast, the walnut varieties imported from France into northern California, the major varieties planted today, have a relatively high winter chilling requirement. If the sufficient number of chilling hours are not met, bud opening can be seriously delayed and blooming will be uneven, resulting in a poor crop and branch dieback (University of California, Agricultural Issues Center).

Fertilization

For optimal growth, walnut trees need sufficient amounts of various nutrients, including: nitrogen, zinc, boron, chloride, potassium, manganese, iron, magnesium, phosphorus, and copper. Deficiencies in any of these nutrients usually affect growth of the leaves and nut production. In severe cases of deficiency, however, the trees' health can be harmed (Ramos). The following paragraphs discussion deficiencies by type of nutrient:

C Nitrogen--Nitrogen is the major nutrient required for proper tree growth and optimum nut yields. Application of nitrogen in orchards is widely practiced, and deficiency symptoms are rarely found.

C Zinc--Zinc deficiency is prevalent in the sandy soils of the San Joaquin, Sacramento, and southern California interior valleys. Deficiency symptoms appear early in the season, especially if severe. The first evidence of zinc deficiency is delayed bud opening, which can be retarded by up to a month along the distal ends of the shoots. When the buds do open, the leaves are small, chlorotic, and appear in tufts, giving them the term "little leaf." In severe cases, dieback can occur.

[5] For cost of production budgets, see the appendix.

- Boron--Boron deficiency tends to be found in the Sierra Nevada foothills and sometimes in Lake and Mendocino counties. Boron deficiency results in stunted trees that have weak shoot growth, and the tree tends to have a bushy appearance. Leaves often are chlorotic and misshapened, and are sometimes reduced to small, bractlike forms. In severe cases, terminal dieback occurs. Boron toxicity, on the other hand, is becoming more common. Symptoms appear in mid- to late-summer, after enough boron has been accumulated in the leaves to cause injury. First, the tips and then the margins of leaflets become necrotic. In severe cases, the necrotic tissue progresses into the intervenial areas, and the margins of the leaflets curl upward. Every leaf on the tree can be so severely scorched that the tree appears as if it has been injured by fire.

- Chloride--Although chloride deficiency is not found in the field, excess chloride appears as an occasional problem. Excess chloride results in terminal and marginal necrosis of the leaflets, with symptoms appearing in mid-summer and progressively becoming worse with time. Chloride toxicity is difficult to distinguish from boron toxicity, since both produce a similar scorched pattern. Many trees observed with high chloride have also contained high levels of boron. Leaf analysis can determine which element is in excess, while irrigation water should be tested if an excess of either nutrient is suspected.

- Potassium--Potassium deficiency is present in many growing areas, including the Chico area, the southwestern part of the Santa Clara Valley, some sandy soils in the San Joaquin Valley, and some soils in Santa Barbara County. When potassium is deficient, the leaves begin to show symptoms in early- to mid-summer, becoming pale, with the edges folding upward and curling inward. Nut size will also be reduced.

- Manganese--Manganese deficiency tends to be found in the coastal and semi-coastal areas of Ventura, Santa Barbara, and southern San Luis Obispo counties, with scattered cases elsewhere. Symptoms begin appearing early- to mid-summer, including chlorosis, which develops between the main lateral veins and extends from the mid-rib to the margin. The chlorotic pattern produces a “herringbone” effect. Only in severe cases will the leaf size be smaller and nut yields reduced.

- Iron--Iron chlorosis occurs in the coastal regions of Ventura, Santa Barbara, and San Luis Obispo counties, with scattered cases elsewhere. When excess iron is present, the leaves become chlorotic early in the season, with the entire leaf assuming a uniform yellow color. Terminal leaves tend to be affected more than basal leaves. In severe situations, chlorotic leaves may develop scorch and abscise from the tree. Iron chlorosis symptoms frequently are associated with calcareous soils (lime-induced chlorosis) or with heavy, poorly-drained soils.

- Magnesium--Magnesium deficiency is often associated with low pH soils, such as those along the Sierra foothills or in the north coastal areas. Symptoms appear in mid- to late- summer, after considerable shoot growth. Basal leaves, especially those on vigorous shoots, begin to show a distinct chlorotic region at the apical and lateral margins of the leaflets, eventually leaving an inverted "V"-shaped area along the basal part of the mid-rib. As the season progresses, the chlorotic areas along the margin become necrotic and dark brown in color.

- Phosphorus--Phosphorus deficiency is mostly found in rocky, volcanic soils in a restricted area near Clear Lake (in Lake County). When this deficiency is present, the trees usually show very weak growth and have sparse foliage with smaller-than-normal leaves. Leaves are yellow and develop necrosis in irregular areas, followed by early defoliation.

- Copper--Copper deficiency has been found in scattered areas. Symptoms tend to appear in mid-summer, with scorch developing on the leaves near the tips of shoots. Defoliation tends to occur later in the season, along with a slight shriveling of the shoots. Small dark brown spots appear on the shoot near the tip, and terminal dieback then occurs in late summer. When copper deficiency is present, the nut kernels are often badly shriveled.

Irrigation

California walnut orchards are irrigated for optimum nut yields. Walnut trees are planted on a wide range of soil types, and have the capacity to store and supply anywhere from 15 to 50 percent of seasonal water demand. Irrigation water is necessary to supplement this water, as well as to maintain a favorable salt balance. Irrigation is also used for frost protection.

Several methods of irrigation are used in walnut production. Flood (or border) irrigation requires level ground (with not more than 1 percent slope), where relatively large flows of water are available. Furrow irrigation is another form of gravity irrigation, and is used on lands with no more than a 2 percent slope. Sprinkler irrigation and drip irrigation are also used (Ramos).

Harvesting

Walnut harvesting occurs between early September and mid-November, when the rubbery green hulls of the nut begin to split. Nuts are harvested by machines that shake them from the trees. Once harvested, walnuts are typically taken to collecting stations where they are hulled, washed, and dried. They are then delivered to the final handler, where they are weighed, sized, inspected, and processed further. Quality standards for the harvested nuts are determined by the Walnut Marketing Board. About 50 percent of the California crop is handled through Diamond Walnut Growers, with the other 50 percent handled through many independent handlers.

Production Perils

Several production perils affect walnut trees, and are similar to those affecting other nut trees.

Excessive cold can be a problem, as can late spring rains. Also, walnut trees can be plagued by fungal and bacterial diseases.

Excessive Cold

In early spring, when walnut trees begin their growth, leaves, shoots, blossoms, and nuts can be easily killed by temperatures that drop below freezing. This danger is usually restricted to mountainous and localized low-lying areas, and can be mitigated by choosing varieties that are late leafing, such as "Hartley" and "Franquette." Because of the climate, however, spring frosts are one of the limiting factors to walnut production in areas such as the Sierra foothills and Lake County. Autumn frosts also limit the range of walnut production areas (University of California, Agricultural Issues Center).

Late Spring Rains

Late spring rains encourage the development of walnut blight. Early leafing varieties are prone to damage, particularly when grown in the higher rainfall areas of northern California, and especially in years that also have late spring rains. Because of this problem, many early leafing varieties in the Sacramento Valley have been replaced with later varieties that tend to escape infection (University of California, Agricultural Issues Center).

Apoplexy

The cause of apoplexy is unknown, although it is associated with the combined effects of hot weather, irrigation, and nitrogen fertilization. Apoplexy kills both large and small trees, and tends to quickly cause the decline and death of trees once they are affected. Apoplexy appeared more frequently in the 1980's than it does today.

Diseases

Diseases that affect the life or the vigor of a walnut tree include: viral diseases, such as blackline; fungal diseases, such as Armillaria root and crown rot, and Phytophthora root and crown rot; and bacterial diseases, such as deep bark canker.[6]

Blackline Disease

Blackline disease is a serious, infectious viral disease of English walnut trees propagated on northern California or "Paradox" rootstock in California's commercial orchards. The disease appears

[6] The following discussion of diseases is based on discussions with Ramos, and publications from the University of California, Agricultural Issues Center.

as far north as Tehama County and as far south as Tulare County. The highest incidence and most serious damage occurs in coastal walnut growing areas and in the lower Sacramento and upper San Joaquin valleys.

The above-ground symptoms of blackline disease are similar to those caused by other soil pathogens, nutrient deficiencies, and improper cultural practices. The first symptoms to appear are poor terminal growth, followed by yellowing and drooping leaves, then premature defoliation, particularly in the top part of the tree. As the disease progresses, the trees exhibit various degrees of dieback and general decline. Profuse development of sucker shoots from the rootstock is a good indication that a walnut tree may be affected by blackline, although sprouting alone is not an infallible diagnosis.

Positive diagnosis of blackline disease requires careful examination of the graft union, with infected trees showing small cracks in the bark at the union. Removing a small patch of bark may reveal a narrow strip of darkened cambium and phloem tissue, and a blackline (hence the name) at the junction of the rootstock and the scion. In its early stages, this blackline is not continuous and several patches may need to be removed to find the line. Eventually, blackline extends around the union and girdles the tree completely, resulting in the death of the scion top, usually 2 to 6 years after the girdle is completed.

The blackline virus infects the English scion, but not the northern California or "Paradox" rootstock of a tree infected with blackline. The virus can be present in the English walnuts' bark, leaves, nuts, catkins, and pollen. It spreads through the scion relatively slowly, depending on the cultivar, climatic conditions, and physiological state of the tree. It can be spread from tree to tree through pollination, as well as by grafting or budding.

The most effective control for blackline disease involves using graft- or bud- wood only from healthy trees, and blackline virus-free English walnut trees should be used for propagation. The problem, however, is that infected trees are often symptomless. As a result, graft- or bud-wood that might appear to be healthy may already be infected.

Armillaria Root and Crown Rot

Armillaria root and crown rot (*Armillaria mellea*) also is called "oak root fungus disease," "shoestring root rot," and "mushroom root rot." It is caused by a soilborne fungus and affects many nut and fruit crops, forest trees, shrubs, vines, and herbaceous plants. The fungus infects the roots, crown, and basal trunk of walnut trees. Early symptoms include poor terminal growth, small chlorotic leaves, premature leaf drop, and dieback of terminal shoots. Commonly, only one side of the tree corresponding to the infected side of the root system or crown may show these symptoms. Eventually, the disease destroys the entire root system and/or may completely girdle the lower trunk, killing the tree. Infected walnut trees may show decline for 2 to 5 years before death. In a newly infected orchard, a single tree may be infected or there may be several sites of infection. The disease then spreads in a circular manner, infecting adjacent trees.

If the fungus is present in an orchard, losses from Armillaria root and crown rot can be minimized through soil fumigation prior to planting and the use of resistant rootstock, such as northern

California black walnut.

Phytophthora Root and Crown Rot

At least 14 different species of Phytophthora, a soilborne fungus causing root and crown rot, are known to infect California walnut trees. In the early stages of infection, the tree exhibits poor terminal growth, accompanied by small, chlorotic, and drooping leaves. As it progresses, the disease causes the tree to show sparse foliage and dieback of terminal shoots. Infected trees may decline slowly over several years or may collapse and die in the same growing season as the first foliage symptoms appear. The rate at which a tree succumbs to Phytophthora depends on the species of Phytophthora, the soil type, the climatic conditions following infection, and the age of the infected tree. The tree dies when massive infection and destruction of the entire root system occur, or when the crown is completely girdled. Generally, a tree affected with crown and root rot dies faster than one infected with only root rot.

To control Phytophthora, soils should be fumigated with methyl bromide before planting a walnut orchard. Fumigants, however, cannot eradicate Phytophthora from heavily infected soil, and fumigated sites can become reinfected. The use of "Paradox" as a rootstock is suggested in Phytophthora-infected areas because it is the most resistant among the walnut rootstocks. Careful soil-water management also helps control the spread of the disease.

Deep Bark Canker

Deep bark canker is caused by the *Erwinia rubrifaciens* bacteria, and belongs to the same taxonomic group as the fire blight organism. This canker causes large, longitudinal cracks in the bark of the trunk and in scaffold branches. These cracks are many times longer than they are wide because the bacteria advance more rapidly vertically than horizontally. During late spring through early fall, a reddish-brown to dark brown plant sap oozes from these cracks, giving the cankers a bleeding appearance.

Walnuts are highly susceptible to deep bark canker infection from April through October, and are almost resistant to infection during the winter. During fall harvest, the shaking machinery can cause wounds that serve as entry sites for the pathogen. The wounds may remain susceptible to infection for up to 10 days after harvest.

The canker is mainly a problem in the San Joaquin and Sacramento valleys. The "Hartley" variety is the most susceptible walnut cultivar, but "Payne," "Ashley," "Eureka," "Franquette," and other varieties are also infected occasionally. The disease does not kill walnut trees. In combination with diseases such as root rot or crown gall, however, it may contribute to gradual decline of the tree and eventual death.

There are no chemicals that have been found to control deep bark canker. Good cultural practices, such as water management to improve the vigor of the tree, are important for reducing spread of the disease and improving the chances of recovery once the tree is infected.

Crown Gall

Crown gall is caused by the *Agrobacterium tumefaciens* bacteria, and affects many species of plants including walnut trees. The "Paradox" hybrid appears exceptionally susceptible. When this disease is present, the most obvious symptoms are gall formations, which range in size from minute to several inches in diameter. The galls are undifferentiated, disorganized, and spongy in texture, and develop on the crowns and roots. Eventually, the central portions of the galls die, leaving a cavity inhabited by wood-rotting fungi and other decay organisms. Those trees that are severely girdled by crown gall often become stunted. Girdling is a serious problem only when the infection occurs early in the tree's life and affects most of the crown area. Research suggests that the tree's productivity as well as its growth are reduced once most of the crown region is girdled.

The crown gall bacteria enters the plant through wounds. Disease inception often occurs in nurseries where there are numerous opportunities for infection to occur. Preventing injury is the best way to prevent the disease. The benefits of chemical pesticides in controlling crown gall are questionable.

Branch Wilt

Branch wilt is caused by the fungus *Hendersonula toruloidea,* and can infect all walnut cultivars. "Franquette" and "Mayette" are the most susceptible. Symptoms first occur in mid-summer, when leaves on infected branches suddenly wilt, die, and remain attached to the tree. By the end of summer, one or more dead branches with attached leaves are intermingled with healthy branches on a tree. Large scaffolds sometimes are killed, and the dead wood and bark of the branch turn dark brown to black. The outer corky layer of tissue cracks and peels away, revealing patches of sooty black substance.

The branch wilt fungus developed most rapidly at high temperatures, and must enter the host tree through a wound. When temperatures fluctuate (do not stay constantly high, as in most fields), sunburn on the tree is necessary for the fungus to infect the tree. As a result, the disease is most prevalent in locations providing the greatest opportunity for sunburn, such as the southwest side of a tree, and on trees on the orchard's south or west edges. Because there are no chemical treatments for this disease, only good cultural practices can prevent or reduce its incidence.

State Analyses and Demand for Insurance

California

California is the major nut-producing state, producing virtually all the almonds, pistachios, and walnuts produced in the United States. While production takes place throughout the state, orchards are mostly located in the central valley area.

Production Perils

Irrigation is used in all major commercial orchards in California, which helps alleviate the damage that the trees might otherwise incur due to drought, excessive heat, and frost. There have been, however, instances where weather has caused severe damage or death to trees, and various diseases and disorders also can pose significant perils.

As an example, almond trees can suffer from bud failure or "crazy top," particularly in very hot summers. When a tree experiences bud failure, buds will not develop the following year. While bud failure does not kill the tree, it renders the tree unproductive in future years. The cause of bud failure is unknown, and it only randomly affects trees in an orchard (Freeman).

Flooding has been a problem for nut growers in recent years. Depending on the time of year and the specific conditions, flooding affects trees differently. In extreme cases, flooding can prompt tree death due to several factors. If the tree becomes waterlogged, the roots cannot get enough oxygen and suffocate. Fungal diseases, such as Phytophthora, are favored by wet weather and, in combination with stress caused by flooding, can result in the death of the tree. Also, heavy winds can more easily blow the tree over because root systems are not well anchored in saturated soils. In general, if the trees are dormant, they can withstand flooding for longer periods of time than during the growing season.

Because they are shallow rooted, almond trees are particularly susceptible to saturated soil conditions, especially if the tree is loaded with nuts and high winds are present (Freeman; Sibbett; McGranahan). Other types of nut trees are also susceptible. In 1996, extreme flooding affected walnut trees in the flood plains around Yuba and Sutter counties. Levies broke and many trees were uprooted. For the remaining trees, the effects of flooding took several years to appear, with the trees remaining productive in the interim. Walnut trees are slow to react, and can take 2 to 3 years before the actual effects of flooding become apparent (Hasey).

Freezing weather can also be a problem in California. Freezing temperatures that occur early in the season, before the trees acclimate to cold temperatures, can retard the growth of nut trees. In addition, winter temperatures below certain critical temperature (varying with the type of tree), can kill the tree.

Several diseases exist that can kill nut trees in California. Because resistant varieties are available, almond producers do not experience great losses due to diseases. In contrast, pistachio growers south of Bakersfield must be careful not to plant where Verticillium wilt is present in the soil, because tree death may result. Although some varieties have greater resistance than others, none are totally resistant to this disease. Verticillium has been the major source of mortality in pistachio trees (Ferguson). For walnut trees, blackline and crown gall can be a problem. Crown gall is a problem for trees until they are about seven years old. Growers are not always aware of the presence of crown gall because it may take several years for the disease to appear. While the disease is likely to be present in seedlings, not all nurseries are willing to replace infected trees.

Demand for Crop Insurance

Several farm advisors in California felt there would be interest in crop insurance for nut trees, especially in areas where flooding and strong winds are likely to occur. Growers may also be interested because of the number of diseases that can affect different trees. Many years are often required before a disease becomes apparent and, in many cases, there are no rootstock that are totally tolerant to a disease. Growers may also want crop insurance for their trees because they may already have coverage for the crop and want to cover their investment in the tree as well.

While farm advisors indicated interest in crop insurance for nut trees, their enthusiasm was much greater for crop coverage. They indicated that cost would be a key factor in determining whether or not a grower would purchase crop insurance for a tree (versus the nut crop), since the incidence of losses are less frequent for trees.

The Farm Service Agency (FSA) administers the Tree Assistance Program (TAP), which provides growers with financial assistance for the replacement, removal, or uprighting of damaged trees. Few TAP payments have been made in California. In Sutter and Yuba counties, flooding has caused walnut tree losses, for which qualifying growers received TAP payments. Excessive rains in the mid-1990's in Fresno County resulted in TAP payments in six situations, which helped cover the costs of tree removal, site preparation, and replanting costs for seedlings. Among those payments, assistance was provided for the replacement of entire orchards along the San Joaquin River (Schoonhoven). In Sutter and Yuba counties, TAP provided financial assistance for tree removal and replacement due to flooding and excessive rains in 1993 and 1994 (Navdeep).

FSA officials indicated that there would likely be demand for crop insurance coverage for nut trees. While instances like the 100-year flood that occurred in the early 1990's is unlikely to occur soon, other severe weather-related perils--such as a hard freeze--may arise that necessitate assistance. In addition, it is difficult for growers to qualify for TAP (Schoonhoven).

Georgia and Other Southern States

Georgia is one of the major pecan-producing states, accounting for one-quarter to one-half of the nation's pecan crop. Most of the production is from improved varieties, although Georgia also accounts for the largest share of native (seedling) pecans. Most of Georgia's acreage is concentrated around Albany, where pecan production has replaced cotton, and in Dougherty, Mitchell, and Lee counties.

Production Perils

Scab is perhaps the most important disease affecting pecans. It is particularly difficult to address, as older cultivars lose their resistance over time, and new cultivars must be introduced. This is a lengthy process, as breeding new varieties requires about 25 years. The creation of new varieties, however, is the only way to perpetuate pecan production east of the Mississippi River. In addition to scab, other diseases also affect nut trees in the South. In particular, the humid Southern climate provides the perfect environment for fungal diseases, such as shuck decline, which can kill nut trees.

Weather factors also affect pecan production in the South. Pecans in Georgia, northern Mississippi, and Alabama are likely to experience freezing temperatures that can kill trees if occurring early in the fall. In addition, ice storms in these areas can break the limbs of nut trees, and possibly destroy the tree's canopy. When severe damage occurs, the tree may be rendered unproductive and removal may be required. Ice storms are one of the few weather-related perils that have destroyed entire pecan orchards.

Hurricanes are also a problem throughout the South, particularly for orchards within 150 to 200 miles of the Gulf Coast. The peak hurricane season is in August and September, when the crop is heaviest on the trees and, thus, when high winds are likely to cause the greatest damage. Hurricanes, like ice storms, can destroy an entire orchard, although such severe situations are fairly uncommon (Wood). Tornados and thunderstorms, which are common in the South, are often accompanied by heavy winds and lightning. Older trees are often very tall, and are more likely to be hit by lightning than smaller trees. The damage from thunderstorms is more likely to occur around the borders of an orchard, and not affect all trees in the orchard to the same extent.

Demand for Crop Insurance

Pecan growers in Georgia, northern Mississippi, and Alabama are believed to have a fairly high demand for crop insurance to cover their nut trees. The demand for nut tree insurance is, however, thought to be less than the demand for insurance of the nut crop. Many orchards that are producing commercial pecan crops were planted in the 1800's, and some native trees are much older.

Weather can play a major factor in pecan production, and the effects of poor weather can cause a tree to become nonproductive for many years, especially if the tree's canopy is damaged. In some cases, the tree may be rendered useless because a new tree could be planted and become productive by the time the damaged tree again becomes productive. This situation might create a special case for crop insurance covering pecan trees. The tree may still be alive but not produce a commercial nut crop. Growers might be interested in special provisions that would cover the tree for several years until the tree returns to its former productive capacity.

FSA agents in Georgia's major pecan-producing counties, and in Mobile, Alabama do not recall TAP payments for loss of pecan trees. In Dougherty County, the agent recalled only one TAP payment, which provided assistance for uprighting and stabilizing trees in a pecan orchard (Palmer).

Texas

Texas is the second largest pecan-producing state. Most of its pecan trees are improved varieties, with about one-quarter to one-third of the crop (depending on the year) originating from native varieties (USDA, NASS). Production is concentrated in central to southeastern Texas and in the El Paso area. The heavy concentration of orchards in these areas dates to the 1960's and 1970's, and was stimulated by tax opportunities. Once the tax laws were changed in the 1980s, the rate of plantings declined (Pena). Most of Texas' pecan production is irrigated.

Production Perils

The arid climate in central and western Texas, as well as in New Mexico, Arizona, and California, requires that pecan growers irrigate their orchards. The soils in these areas tend to be high in boron and sodium, however, and irrigation tends to increase the levels of these chemicals. In high doses, boron and sodium are poisonous to the pecan's root system and can kill the roots.

In addition, fungal diseases, severe freezes, and severe storms can also be problems for pecan growers. Pecan trees in the western states are susceptible to cotton root rot fungus, for example, particularly in areas where orchards were planted in former cotton fields. Severe freezes can also kill pecan trees, especially if they occur after mild weather. Heavy storms have been known to cause limb loss, affecting the productivity of the tree (Pena).

Demand for Crop Insurance

The lack of major perils affecting pecan trees in western production areas would probably limit the demand for crop insurance among growers. Those growers, however, located in areas where heavy storms are likely to occur would likely have the greatest interest, since these storms can destroy entire orchards. According to FSA agents in Gonzales, Guadalupe, and El Paso counties in Texas, TAP payments have not been made for losses to pecan trees.

Oregon

Oregon is the major hazelnut producing state in the U.S. Almost all of the state's acreage is concentrated in the Willamette Valley, where mild temperatures provide an ideal environment for the hazelnut tree.

Production Perils

Eastern Filbert Blight (EFB) is the major problem affecting the health of the hazelnut tree. This fungus creates the most serious damage in the northern third of the Willamette Valley. It is a perennial canker that girdles the branches and then the trunk of the tree, and orchards infected with this disease can die off in 7 to 10 years. While good management practices can often control the disease, such practices tend to be very costly and uneconomical. Usually, EFB infestation results in abandonment of the orchard. Other diseases and insects are relatively easy to control and do not pose a serious threat to hazelnut orchards.

Adverse weather is not generally a serious peril for hazelnut growers. Flooding is usually not serious, and typically occurs when the trees are dormant, producing only minimal damage. In addition, orchards are often planted on high ground, where flooding is less likely to occur. Cold snaps that have hit the area have produced damage and, when such conditions occur, about half of the trees were able to recover. Affected trees have, however, shown a greater tendency toward alternate-bearing. Ice storms occasionally break branches on the trees, although the damage is typically not so serious as to require tree replacement (Mehlenbacher, 1997b).

Demand for Crop Insurance

The hazelnut extension specialist in Oregon did not believe that demand for crop insurance for hazelnut trees would be significant. The greatest demand would likely emerge from growers most concerned about Eastern Filbert Blight, since the disease can kill an entire orchard in 7 to 10 years. Hazelnuts are hardy and are grown in a mild environment, and many growers are believed not to be very interested in obtaining insurance only for the trees (Mehlenbacher, 1997b).

There have been few requests from hazelnut growers for TAP assistance in Oregon. In Josephine County in southern Oregon (which is not one of the major hazelnut counties), one grower requested assistance due to flooding of hazelnut trees in an area near the Rogue River.

Nut Tree Crop Insurance Implementation Issues

Adverse Selection

Adverse selection should not arise as a major issue in developing insurance programs for tree nut growers. Growers would be unlikely, for example, to select a rootstock non-resistant to diseases for several reasons. First, several years are required for a nut tree to produce a crop and for the grower to receive a return on his or her investment. Second, in most cases, tree losses due to disease can take years to occur, and it would be costly to growers to purchase and maintain the land until that time.

Adverse selection based on location site could, however, be an insurance issue if premium rates are not estimated accurately. Planting an orchard in a soil type unsuitable for the crop, such as planting pecans in shallow soil with low water retention, could have adverse affects on the orchard during a drought year. Also, planting pistachios on land that is known to have verticillium wilt could also been an instance of adverse selection. Nut tree plantings in areas where hurricanes are more likely, such as along the Gulf Coast, may also be encouraged if growers knew they would have insurance to reimburse them for losses. In the case of site selection, it may take several years before tree damage occurs. In the meantime, growers could receive output from their trees and, under adverse conditions, also receive insurance payments for losses.

Setting Reference Prices

The replacement cost for lost trees would need to be estimated based on the trees' age, location, and variety. The tree's value increases as the tree reaches full productivity, and in some cases may decline overtime. Value also increases for certain varieties of a specific nut which may have a higher value in the marketplace than other varieties. Also, location may affect a tree’s productivity and therefore, may need to be taken into account when setting a reference price for tree replacement.

Estimating “Appraised Production”

Estimating appraised production may not be that difficult for nut trees except native variety pecans. The centralized location of most nut production and the dominance of certain varieties helps establish a tree’s potential productive capacity. Pecans, however, vary by location and variety. Improved variety trees are more uniform and the estimation of value per tree or acre is easier to establish than for native (seedling) varieties. With native varieties, plantings are more varied and each individual tree is slightly different from the other.

An issue with estimating "appraised production" is whether a tree is salvageable or unproductive from an economic standpoint. With different management techniques, some growers may be more willing to salvage damaged or windblown trees than other growers who may not find it economically viable to do so. This situation makes it difficult to determine when a grower should receive an indemnity for temporary damage or a total loss.

Moral Hazard

Moral hazard may become an issue in the presence of tree diseases. Diseases usually take several years to become apparent, and even longer to kill a tree or render it unproductive. A grower who knows that his or her orchard has diseased trees might be interested in obtaining crop insurance once the disease has been diagnosed, even though no previous interest in insurance was expressed and the trees are as of that time still symptomless.

The type of irrigation system creates another moral hazard potential. Orchards with sprinkler or flood irrigation systems have a higher incidence of fungal infection than those with a low-angle or drip system because sprinkler water that comes into contact with the tree initiates production of blight spores. It may be desirable to limit coverage to resistant rootstock and fields with low-volume irrigation systems to avoid insuring orchards prone to fungal diseases.

Other Implementation Issues

The Risk Management Agency might consider requiring mandatory inspection of tree nut orchards before participation in an insurance policy, in order to ensure that no serious insect or disease problems exist. This would benefit the agency because, at present, most serious losses due to insects and disease can be managed.

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Contacts

Almonds

Mark Freeman, Farm Advisor
Fresno County, California
(209) 456-7285

Steve Sibbett, Farm Advisor
Tulare County, California
(209) 733-6486

Hazelnuts

Shawn Mehlenbacher, Professor
Department of Horticulture
Oregon State University
Corvallis, OR 97331
(541) 737-5467

Pecans

Jose Pena, Extension
Texas A&M University
(830) 278-9151

Tommy Thompson, Research Geneticist
USDA, ARS
(409) 272-1402

Bruce Wood, Research Horticulturist
USDA, ARS
(912) 956-5656

Pistachios

Louise Ferguson, Extension Pomologist
Kearney Agricultural Center
(916) 752-0507

Walnuts

Gale McGranahan, Pomologist
University of California, Davis
(916) 752-0113

Janet Hasey, Farm Advisor
Sutter/Yuba Counties
(916) 822-7515