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In a Nutshell
Kern County

March 2021

Budbreak, Bloom, and Pollination Events Mark the Start of the Walnut Season

Elizabeth J. Fichtner, UCCE Farm Advisor, Tulare and Kings Counties

Spring leaf out and flowering signals the start of the walnut season, but the processes giving rise to the current year's crop were initiated only weeks after flowering the prior year. As a result, growers and orchard managers are concurrently managing the crop of two seasons for approximately 10 months of the year. Understanding the main botanical and developmental processes occurring throughout the season may aid in better managing two consecutive years of crop. This article will highlight the spring developmental events in California walnut orchards from bud break through bloom and pollination.

Walnut buds. Walnuts are monoecious, meaning they have male and female flowers on the same tree. The male flowers are assembled in structures called catkins (Figure 1), which are borne directly on the prior year's growth (Figure 1). Prior to leaf out, the catkins are visible and easy to identify (Figure 1). Walnuts do not have traditional "simple" female flower buds, but rather a compound bud (Figure 1) that contains the preformed shoot with female flowers at its terminus. At leaf out, the preformed shoot expands and compound leaves begin expanding prior to the appearance of the pistillate (female) flowers (Figure 2). The fact that the female flowers are at the end of the preformed shoot explains why walnut cultivars are characterized by both their leaf out date and bloom date, as well as the date of pollen shedding (anthesis); these occur progressively over time. Generally, the buds on mature trees enclose 4-5 preformed leaves. Often walnut flowers are assembled in pairs; however, it is not uncommon for female flowers to appear singly or in groups of three or four.

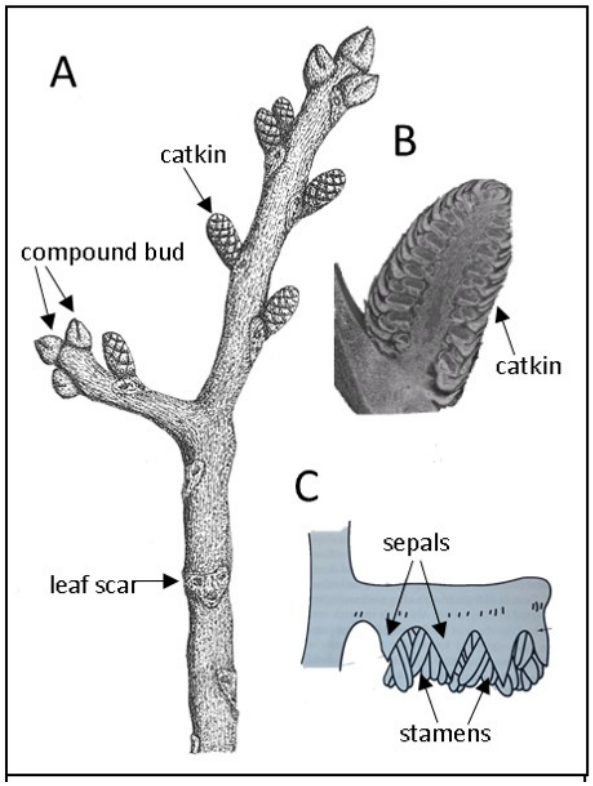


Figure 1.A) A walnut twig bears catkins on the prior year's growth and compound buds contain the current year's shoot and pistillate (female) flower buds. B) A high- resolution computed tomography (HRCT) image of a catkin on a dormant twig. C) Each catkin contains numerous, non-showy, staminate (male) flowers. Illustration credit (A): H. Hartzog; Photo credit (B) B. Pratt; Illustration credit (C): V. Polito.

Successful pollination. At anthesis pollen shed from staminate (male) flowers (Figure 1C) is disseminated by wind, thus eliminating the need for showy flowers adapted to attract insects (as in almonds). Due to its low water content, walnut pollen only remains viable a short time, generally 24-48 hours. Because wind-blown pollen must fall on the stigma of a receptive female flower (Figure 2) by chance, wind-pollinated crops produce copious quantities of pollen, thus facilitating the probability of successful pollination.
Female flowers are only receptive to pollination for a short time. Pollen must be deposited on one of the two stigmas (Figure 2) on a female flower for a nut to develop.

The stigmas are only receptive after they expand and separate. They remain receptive until they part to approximately a 45˚angle (Figure 3). During this receptive phase, an exudate is present on the stigmatic surface, allowing viable pollen grains to stick, hydrate and germinate.

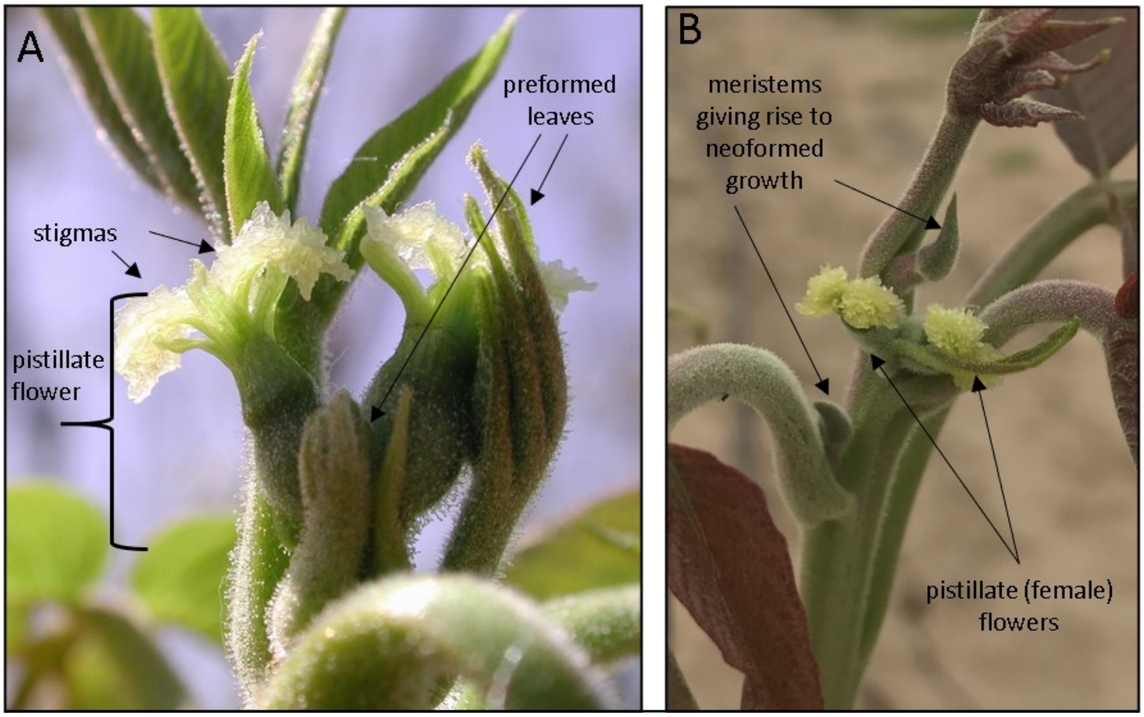
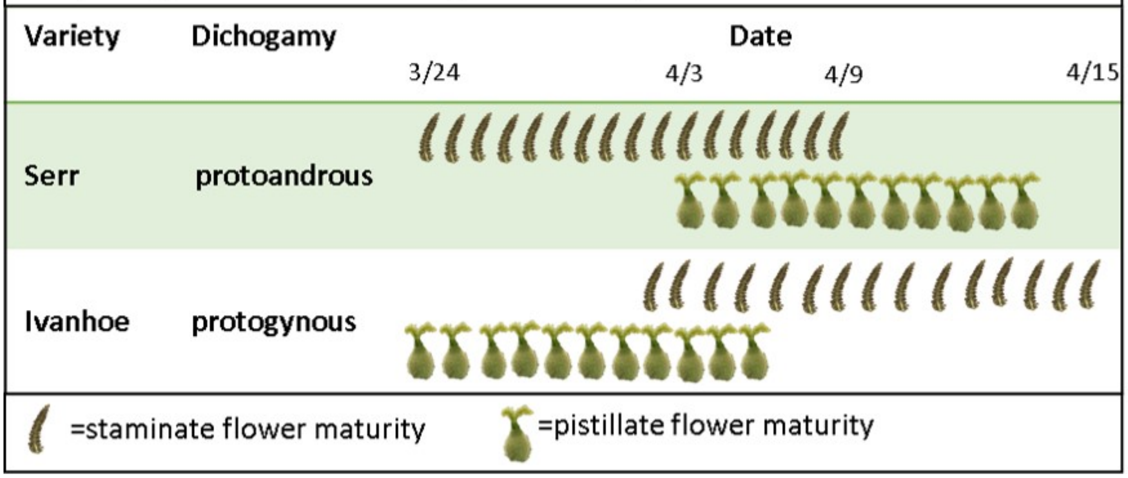


Figure 2. In A, two pistillate flowers have emerged at the end of a preformed shoot. New meristems emerge in B, giving rise to neoformed (in-season) growth. Photo credit (A): V. Polito.

Self-compatibility and cross pollination. Walnut is self-compatible, meaning that the pollen shed by catkins on one tree is capable of pollinating pistillate flowers on the same tree - or other trees, regardless of variety. However, walnuts have adapted a mechanism called dichogamy to reduce the degree of inbreeding. In dichogamous plants, pollen shedding and pistillate bloom occur at different times, increasing the likelihood of outcrossing with other individuals. Walnuts are heterodichogamous meaning that the female bloom may either precede or succeed the male bloom. Most commercial walnut varieties (ie. 'Tulare', 'Chandler', 'Howard', 'Serr') are *protandrous*, meaning that the male flowers mature and pollen shedding occurs before female bloom begins. 'Ivanhoe', 'Gillet', and 'Forde' are *protogynous*, meaning that the female flower begin opening prior to the pollen shedding. Using 'Ivanhoe' as an example, the female flowers begin becoming receptive at about the same time that 'Serr' is shedding pollen, thus 'Serr' may be a large contributor to 'Ivanhoe' pollination (Table 1). Dichogamy is the reason that including pollenizers in orchards is recommended for some varieties and situations, for example with main varieties that do not have good male-female overlap or in isolated walnut blocks that might not have sufficient local pollen to set a crop. In most walnut-growing regions, however, there tends to be sufficient pollen movement among orchards to set good crops. For more information on appropriate pollenizers for commercial walnut varieties, visit: http://fruitandnuteducation.ucdavis.edu/fruitnutproduction/Walnut/Walnut_Cultivar_Table/.

Dissimilarity between nuts. The developing nut crop on a tree may have multiple male parents, with the male parentage of each nut determined by the pollen source available at the time it was receptive. The timing of individual pistillate flower receptivity can also affect nut size. Studies have shown that the later blooming flowers give rise to smaller nuts than earlier blooming ones. Climate conditions during bud break and bloom and lack of adequate winter chilling may also impact male and pistillate bloom timing, pollination and, as a result, nut set and size.

Table 1. The male bloom on the protoandrous 'Serr' overlaps the female bloom on the protogynous 'Ivanhoe' making it a suitable pollenizer for 'Ivanhoe.'



Pistillate Flower Abortion. In some varieties, too much pollen may result in pistillate flower abortion (PFA). In California, this phenomenon was first characterized in 'Serr' blocks (termed 'Serr' drop) where nut set was notably higher as distance from 'Tehama' or other pollenizers increased. PFA does occur in other cultivars, mainly 'Tulare', but to a lesser extent. Excessive pollen on pistillate flowers has been determined to be the cause of PFA. Management of PFA may be achieved by reducing pollen load in 'Serr' blocks by removing pollenizer trees or mechanically shaking the catkins from pollenizer trees. If the male and female bloom in a 'Serr' block are expected to overlap significantly, some growers may opt to also shake catkins from the 'Serr' trees. Rain events during bloom remove pollen from the air and may significantly mitigate PFA. PFA risk is greatest in the years when Serr blocks produce abundant catkins, there is large overlap of male and female bloom and when rain does not occur during bloom. The ethylene biosynthesis inhibitor, Retain® (Valent BioSciences), applied at 5-30% female bloom, has long been shown effective in reducing PFA in susceptible varieties, but the economic cost-return balance (cost of treatment vs expected increase in yield) must be weighed carefully in every situation.

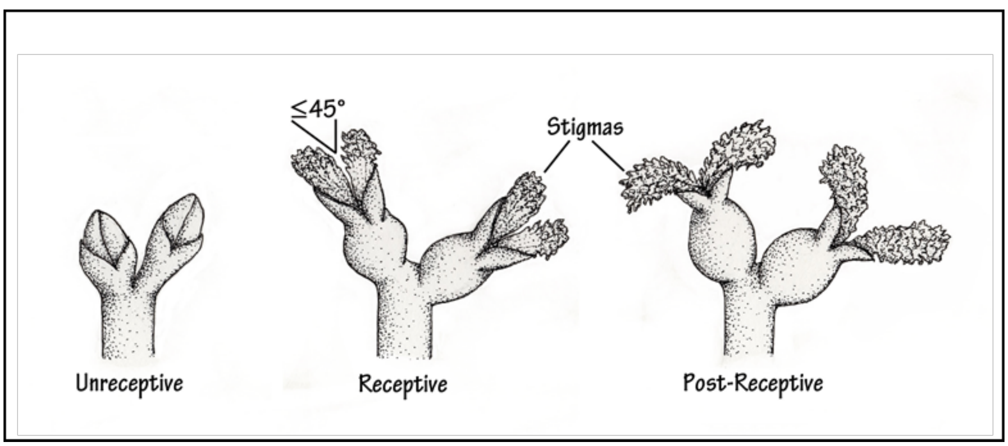


Figure 3. Female flowers are receptive until they have emerged to approximately a 45° angle. Illustration: H. Hartzog.

Conclusion. The timing of spring leaf out and female flower emergence and maturation varies widely between cultivars and is heavily influenced by the weather. In years where temperatures drop substantially after the early varieties have leafed out (mid-March), late varieties such as 'Chandler' may be a full month later than their early counterparts. Only 8-10 weeks past bloom, the compound buds housing the pistillate flowers for the following year's crop begin forming, and the process continues.

Acknowledgment: The editorial review of P. Brown, B. Lampinen, and J. Grant are appreciated.

Online Resource for Information on Whole Orchard Recycling (WOR)

Mae Culumber, Farm Advisor, UCCE Fresno County

Whole-orchard recycling (WOR) involves grinding whole trees into wood chips, spreading them evenly on the soil surface, then incorporating them into the soil before replanting. Almond Orchard 2025 goals (https://www.almonds.com/almond-industry/2025-goals) promote the use of innovative, responsible, and sustainable growing practices by finding high-value uses for orchard waste, including wood chips. The WOR approach may offer a sustainable method of tree removal that could enhance both air and soil quality without compromising tree health, yield, and economic benefits to growers. There are over 1.2 million acres of bearing almonds in California. Of these, over 88,000 acres are over 20 years old and soon to be removed and require disposal. A majority of these acres will be replanted to almonds in the coming years. Restrictions on agricultural burning has decreased the number of permissive burn days, and most cogeneration plants are no longer accepting orchard waste. Tree fruit, nut, and vine growers, who wish to remove dead trees and unproductive old orchards, need alternative methods of orchard removal. A majority of these acres will be replanted to almonds in the coming years. Follow this link or access the article at https://ucanr.edu/sites/Nut_Crops/ to find more information about the WOR process from termination of the previous orchard to replanting and caring for young almond trees.

Phytophthora-Not Just a Root and Crown Disease in Almond

Mohammad Yaghmour, Farm Advisor, UCCE Kern County, Greg Browne, Research Plant Pathologist, USDA ARS, Brent Holtz, Farm Advisor, UCCE San Joaquin County

Phytophthora continues to cause serious losses in California almond orchards. These pathogens affect almond trees of all ages, causing decline and death in both young and mature orchards. The diseases caused by *Phytophthora* are commonly named after the plant part(s) affected. For example, *Phytophthora* causes root rot, crown rot, trunk and scaffold cankers, and pruning wound cankers. At least 10 different species of *Phytophthora* infect almond; however, the species vary in the tree parts affected as well as their general aggressiveness in causing disease.

Phytophthora spp. are not fungi, and therefore cannot be managed with fungicides that target fungal pathogens such as members of the Botryosphaeriaceae family. *Phytophthora* species are classified as oomycetes and are often referred to as “water molds’ because they thrive in wet conditions. In wet conditions they produce infective, swimming zoospores. In dry conditions they can produce thick-walled spores adapted for long-term survival. Soil fumigation can reduce, but not eliminate, populations of *Phytophthora*. Wounds may facilitate but are not necessary for infection by *Phytophthora*.

In California almond orchards, *Phytophthora* has most often been associated with root and crown rot (Figure 1A and B); however, it has also been associated with aboveground disease in almond (Figure 1C). Inoculum causing root and crown rot may be introduced to orchards in surface water such as canal, river, and reservoir water. It also may be introduced in asymptomatic infections on planting stock. Periods of soil saturation are conducive to *Phytophthora* infection. In recent years, numerous farm calls in the southern San Joaquin Valley

Figure 1. Phytophthora root and crown rot may result in gummosis on the trunk and scaffolds of both mature (A) and young (B) almond trees. Perennial Phytophthora canker (PPC) more often forms in pockets containing the debris deposited at harvest (C). To diagnose diseases caused by Phytophthora, the canker must be exposed with a hatchet (D and E). Tissue should be sampled from the margin of the canker (D, arrow).

(SSJV), as well in almond-growing areas to the north, have involved Phytophthora crown and root rot on newly planted almond orchards, up to a few years old. Aboveground *Phytophthora* infections were documented in the late 1990s and early 2000s. These aboveground infections resulted in a disease called Perennial Phytophthora Canker (PPC). Following intense late-spring rains in 2019, a resurgence of PPC was observed in several Kern County almond orchards (Figure 1C), resulting in tree losses in the thousands. Although PPC has a high documented incidence in Kern County, it has occurred in most other almond growing regions in California's Central Valley.

Insights on Perennial Phytophthora Canker. PPC is lesser-known and more sporadic than Phytophthora crown and root rots, yet it affects mature, bearing trees. The most common infection site in mature trees is in "pockets" that form naturally where several scaffold branches join the trunk (Figure 1C). Less commonly, infections are centered near joints of two scaffold branches. At these junctures, growth cracks may form in the bark due to opposing pressure. During harvest operations, debris composed of leaves, soil, and twigs can accumulate in these pockets or cracks. This debris has been found to harbor *Phytophthora*, including *Phytophthora citricola*, the main species associated with PPC. The winter and spring rainy season may allow water to accumulate in these pockets and cracks, thus facilitating sporulation and infection. Although less common, PPC has been observed to develop from root and crown infections that proceed to colonize up the main trunk and into the scaffold. In previous surveys with Farm Advisor Mario Viveros (retired UCCE Farm Advisor), *P. citricola* was the predominant species causing PPC cankers of aerial origin, and *P. cactorum* was more commonly associated with cankers that developed below the soil or at the crown. Recent surveys conducted in Kern County in 2019 corroborated the associations of these pathogens with infections initiating at the root/crown and infections initiating in pockets.

Symptoms and Diagnosis of PPC. Regardless of the location of the initial infection, PPC causes profuse yellow to amber gumming. Removing the bark with an axe (Figure 1D) reveals the perennial canker (Figure 1E) that can expand rapidly over time leading to main scaffold decline. Trees exhibiting PPC tend to defoliate earlier in the fall than healthy trees, and may also exhibit Foamy canker, (Figure 2), a secondary issue that is not the main cause of tree decline and mortality. The symptoms can be confused with those caused by other pathogens, especially fungi; therefore, it is important to conduct lab tests to confirm whether a *Phytophthora* sp. is involved. Fungicides targeting true fungi will be ineffective at managing PPC.

The best time to isolate and diagnose PPC is when the cankers are active and expanding. In Kern County, the pathogen has been isolated from mid-January to April, as well as later in the season when the cankers were active and exuding fresh gumming. Optimal samples are collected by exposing the edges of the cankers, at the boundary between necrotic and healthy tissue (Figure 1E). Samples should be kept cool (not frozen) and sent to a laboratory for isolation and identification. A positive diagnosis of PPC enables the implementation of cultural and chemical methods to manage the disease on already infected trees, and to prevent disease spread in the orchard.

Cultural and genetic management of Phytophthora. For the suite of *Phytophthora* diseases on almond, several early orchard design decisions can profoundly impact disease management. Examples of operations influencing disease development include: rootstock choice, land preparation and drainage, irrigation system design and operation, timing and depth of tree planting, and tree training.

Figure 2. Foamy canker may form on trees already in decline due to PPC. In these situations, foamy canker is a secondary symptom, but not a main cause of tree decline.

For management of PPC, tree training practices should reduce the likelihood of future pocket formation by selecting scaffolds that join the main trunk at multiple lateral positions. This practice may also help in reducing the incidence of other fungal canker diseases. Rootstock selection should be based on the soil environment, but growers should be aware that peach-almond hybrids (e.g. Hansen 536) are relatively susceptible to Phytophthora root and crown rots, particularly in their first few years after planting. Regardless of rootstock, the graft union should remain above ground at planting to prevent soil contact with the scion material that is susceptible to *Phytophthora*. Growers should avoid planting trees in very late spring or summer (as is sometimes done for potted trees on dual drip lines), because the irrigation strategy required to meet the demands of the underdeveloped root system is conducive to *Phytophthora* infection. When potted trees are planted in the summer, the drip lines are aligned above the root crown where water saturation can lead to infection by *Phytophthora.* Additional cultural practices for managing *Phytophthora* include planting on berms and improving water infiltration. Although all almond varieties are highly susceptible to *Phytophthora*, marked differences in genetic resistance are known among almond rootstocks. Generally, peach-almond hybrids are more susceptible to *Phytophthora* than peach rootstocks. Some plum hybrid rootstocks can offer an additional increment of resistance to some species of *Phytophthora*, in comparison to peach. The Almond Board of California (ABC) is supporting long-term research to develop rootstocks with improved resistance to *Phytophthora* and other soilborne pathogens. We are monitoring the prevalence and aggressiveness of different *Phytophthora* species on almond to ensure that our rootstock screens for resistance adequately represent *Phytophthora* challenges in orchards.

Chemical management of *Phytophthora.* Systemic compounds for oomycete management, including mefenoxam and phosphites, have been used for control of Phytophthora crown and root rots on almond. Best results for phosphite use were obtained from foliar applications during summer or fall, before leaf senescence. Phosphites move systematically from source to sink inside the tree and can suppress canker development and infection for up to five months after application. Additionally, we are cooperating with Dr. Jim Adaskaveg (UC Riverside) on an ABC-funded project focused on evaluating new compounds for management of *Phytophthora* in almond.

Concluding comments. As we have suggested, staying ahead of problems with Phytophthora can require judicious orchard design and planning; timely, precise execution of orchard tasks; early awareness of potential Phytophthora problems as indicated by visual orchard scouting; and accurate diagnosis of Phytophthora diseases. Even after planting, early identification of a Phytophthora problem can facilitate integrated and timely corrective actions that will help to mitigate further loss. It is expected that continued teamwork among growers, advisors, and researchers will facilitate additional improvements in cultural, genetic, and chemical control strategies for *Phytophthora* on almond.

References: (1) Browne, G. T., Viveros, M. A. Plant Disease, 2005; (2) Browne, G. T., Viveros, M. A. Plant Disease, 1999.

Implementing Best Management Practices for Nitrogen Fertilization in Almonds

Douglas Amaral, Farm Advisor, UC ANR, Kings and Tulare Counties, Patrick Brown, Professor, UC Davis

From full leaf out until early post-harvest, nitrogen management is critical. This is the time where correct timing and rates have the biggest impact!

Efficient nitrogen use in almond benefits orchard health, productivity, and environmental and economic sustainability. Photo: Douglas Amaral.

With growing season upon us, an understanding of the seasonal uptake of nitrogen (N) is essential to time fertilizer applications. Nitrogen fertilizers are the most important chemical input in modern agriculture. Among all essential nutrients for higher plants, N is required in the largest quantity. It is estimated that over 100 million tons of N fertilizers are applied globally. However, this number could be much lower if our farming systems used N more efficiently. Typically, less than half of the applied N is utilized by the crops while the rest is lost to air and water by run-off, leaching, denitrification and volatilization.

Due to excessive use of N in California, the Irrigated Lands Regulatory Program (ILRP) implemented new regulations to prevent agricultural runoff from impairing surface waters, requiring every grower to implement a N management plan. As a result, there is a growing pressure for all Ag to ‘tighten’ the efficiency of N use and it requires an improved understanding of N demand to grow Almonds.

Nitrogen in Plants

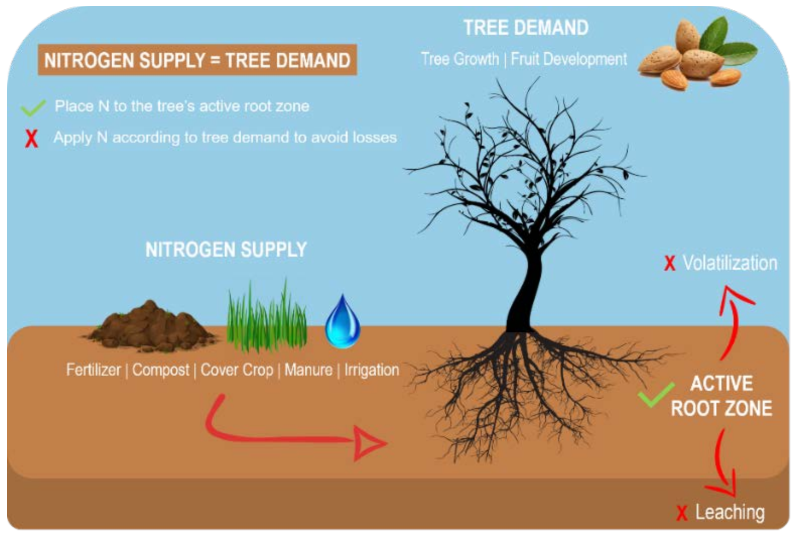
Nitrogen is essential for a wide range of processes in plant production. It is the major element found in the chlorophyll, which is needed for photosynthesis, the most important of all the plant processes – converting the sun's energy into carbohydrates. It is also needed for the formation of amino acids (the building blocks of proteins, major component of the almond kernel) as well as DNA and RNA, which are the genetic materials that allow cells (and eventually, plants) to regulate growth, development, and reproduction.

Matching Supply with Tree Demand

Managing N in almond orchards is a balancing act of supply versus tree demand. When making fertilization decisions, growers need to consider the different supplies of N, as well as the demand for N due to tree growth and kernel production requirements. An understanding of all different N (re)sources (fertilizer, compost, cover crop, manure, irrigation water) and how N can be "lost" (volatilization, leaching) in the orchard will help growers better make management decisions.

Understanding Tree Demand

As previously stated, N is essential for a wide range of processes in tree production such as growth of all annual (flowers, leaves, and kernel) and perennial organs (branches, trunk, and roots). However, the primary factor impacting N demand in trees four years and older is kernel yield. Based on a study developed by UC-Davis professor Dr. Patrick Brown and team, it is estimated that with every 1,000 lbs. of almond kernels produced, 68 lbs. of N are exported from the field and an additional amount of N is required to satisfy the trees' annual growth demand. Thus, potential yield estimation early in the season can have a significant impact on N management decisions. Growers can normally make these estimations based on their orchard productivity over the past years, combined with the expected productivity of similar orchards in their growing region, environmental conditions of the prior year, winter chill and spring flowering conditions.



The nitrogen cycle: a balancing act with the goal of applying adequate N to supply tree demand for growth and fruit production, and to avoid nitrogen losses to the environment. Adapted from: ABC N-BMP 2020 guidance.

Approaches to Improve Nitrogen Management

In order to achieve maximum productivity and to reduce N losses to the environment, a close attention to the four R's – Right Amount, Right Time, Right Place, and Right (re)Sources – is needed in all orchard fertility programs. Remember, you need to **TRAP** the N in the soil:

- **TIME** nitrogen application according to tree uptake patterns,
- Identify and understand available nitrogen **RESOURCES** (fertilizers, composts, manure, cover crops, irrigation water),
- Apply the **AMOUNT** needed according to tree demand, and;
- **PLACE** nitrogen to the tree's active root zone.

Following the 4 R's principle can be viewed as a balancing act with the goal of applying adequate N to supply tree demand for growth and fruit production.

Timeline of Nitrogen Uptake in Almonds

Proper rates and timing of N fertilizer are important for managing the delicate balance between vegetative and reproductive growth, while avoiding losses to the environment. Therefore, using small and frequent fertilizer applications during the season will have a significant impact on tree production and reduction of N losses by adjusting application according to the trees' needs.

It is important to note that N reserves that are built up in the previous season are used to support early growth the following spring. It means that perennial organs – branches, trunk, and roots – are an important additional sink of N during winter. The remobilization of internal N reserves is therefore crucial for optimal shoot growth, flowering, and fruit set since bud break occurs when conditions (end of winter) are not optimal for root N uptake. Thus, maintaining your trees healthy throughout the season is essential.

In summary, as described in the table below, N uptake from the soil closely follows the development of fruits and shoots, increasing in March after stored tree nitrogen is depleted (70% leaf out) and slowing dramatically after hull split.

Tree Phenology (Tree Growth Stage)	Key Nitrogen Dynamics
Dormancy	Nitrogen remains stored in the perennial wood
Bloom Time	Nitrogen demand is supported by remobilization of stored nitrogen
70% Leaf Out	Nitrogen uptake from the soil begins and stored nitrogen is depleted
100% Hull Growth	30% nitrogen uptake from soil has taken place by 100% hull growth
Kernel Fill	55% nitrogen uptake from soil has taken place by the end of kernel filling
Kernel Weight Accumulation Complete	85% nitrogen uptake from soil has taken place by the end of kernel weight accumulation
Beginning of Hull Split to 3 Weeks Post-Shake	100% nitrogen uptake from the soil has taken place*
Early Leaf Senescence to Leaf Fall	No nitrogen uptake from the soil

*For late-harvest cultivars, cold temperatures or harvest stress can limit post-shaking nitrogen uptake.
Source: *ABC N-BMP 2020 guidance*.

Excessive Use of Nitrogen: Too Much of a Good Thing

While it is always important to ensure sufficient N supply for optimum growth and yield, it is equally important that we do not assume that more is better. Nitrogen is the nutrient most often abused in terms of this 'more-on' approach. Excess N can cause several problems.

When nitrogen is overapplied, it negatively affects the uptake of other nutrients. Overapplication of nitrogen is associated with higher incidence and severity of hull rot, which may affect nut quality and food safety. Excess N can also cause excessive vegetative growth in the current season, thus compromising the production of next year's flower buds and subsequent production of next year's crop.

Excessive vegetative growth (no production) due to excess N in the soil. Photo: Elizabeth Fichtner.

Additionally, plants cannot absorb all the excess nitrogen in the soil and extra N levels will leach out of the soil. As a result, groundwater and drinking water become contaminated from the nitrate levels.

Improving Nitrogen Use Efficiency

Nitrogen management plays an important role in determining your bottom line, so ensure you manage this nutrient well in order to keep tree performance, production and nut quality up as well as costs down. Some approaches that can be adopted to minimize risks and optimize N use include applying N to meet tree demand and according to tree uptake patterns. For this, an efficient irrigation system is essential – fertilizers must be present in the root system where they are most likely to be used by the tree.

In summary, adopting the 4R's principle will help growers to improve N management, sometimes achieving over 80% efficiency under optimal conditions. However, every individual orchard must have a specific N management plan – there is no "one-size-fits-all" approach – and grower judgment remains critical. A complete N management guide for Almonds (*ABC N-BMP 2020 guidance*) has been recently developed by the Almond Board of California in cooperation with UC researchers and can be accessed by clicking here.

2021 Virtual UCCE Statewide Walnut Series Presentations Available Online

Presentations from the two-day 2021Virtual UCCE Statewide Walnut Series held on February 16 and 17 are now available to view on YouTube.

February 16, 2021: https://www.youtube.com/watch?v=G1TI68kINmQ&t=3s

February 17, 2021: https://www.youtube.com/watch?v=Irxdb9fuLMU&t=2s

Pest Management Webinars

Virtual Webinars

The Vertebrate Pest Council is hosting a virtual seminar series to provide updates and information on managing vertebrate pests. Each seminar is two hours long and will cover a different topic. Webinar presenters include pest management professionals from both the University of California Division of Agriculture and Natural Resources and county government. CE Credits (DPR, SPCB, CDPH) have been applied for.

The seminars will be held over three days, with a 2-hour webinar offered each day. Attendees may choose to register for individual days or the whole three-day series. A summary of agenda topics includes:

March 30, 2021 (8am-10 am): Field rodents including ground squirrels, gophers, and voles.
March 31, 2021 (8am-10am): Rodenticide mode of action and regulation, and exposure to wildlife
April 1, 2021 (8am-10am): Managing commensal rodents

For more information, please go to this website: http://www.vpconference.org/
Please email trainingsupport@target-specialty.com with any questions.

Zinc Fertilization in California Orchard Crops

Phoebe Gordon, UCCE Madera and Merced Counties

Zinc is the micronutrient that is most commonly deficient across the state of California. This is primarily due to its low availability in Central Valley soils due to the high pH and sometimes presence of carbonates, which zinc will adsorb to at high pH. Just a 1 unit increase in pH will decrease zinc availability 100-fold.

Symptoms of zinc deficiency differ from crop to crop, but there are some symptoms that are common across species. Reduced yields are the primary symptom and the one we care most about, but that can be difficult to diagnose if there are no zinc sufficient trees in your orchard to compare. A classic symptom is new growth exhibiting small leaves and extremely short internodes that result in a rosetting effect. In almonds and other *Prunus* species (Figure 1), these new leaves can look lance-like. Walnuts and pistachios (Fig. 1) can exhibit interveinal chlorosis in addition to smaller leaves with short internodes, and pecans (Fig. 2) will also exhibit necrotic margins or spotting. However, it is important to remember that once you see deficiency symptoms, your orchard is already losing yield.

The most ideal way to remediate any nutritional deficiency is with a soil application, however soil conditions in California orchards necessitate foliar applications to fix zinc deficiencies. This is because zinc is basically immobile in soils, and while it can be banded, the required rates can be so high that it can be uneconomical or even possibly cause phytotoxicity. This also doesn't take into account that any factor that makes zinc unavailable in soils. High pH and the presence of carbonates will eventually make any applied zinc unavailable as well. Chelated forms of zinc are more mobile in soils, but they can be expensive. All these add up to foliar zinc being the most practical way to remediate zinc deficiencies in California orchards.
Zinc has limited mobility within plants, though the degree to which it is mobile differs depending on the crop plant and the study. Two studies examined the absorption amount and fate of foliar applied zinc in California orchard trees. Zhang and Brown (1999) examined walnut and pistachio leaves in laboratory experiments and found only 3.5 and 6.5% was actually absorbed into plant tissues and moved away from the site of application, respectively. Sanchez et al (2006) painted zinc sulfate on the top surface of all leaves of one year old peach trees to simulate a foliar spray and found that 7% of foliar applied zinc was recovered the next spring during leaf break, indicating a small fraction of zinc that was taken up (which was not tested) was remobilized and

reused the following season. This study also included nitrogen in the foliar application; nitrogen has been shown to increase absorption of zinc in some species.

The lab work done by Zheng and Brown also showed that in walnuts and pistachios, zinc is absorbed more readily in young pistachio leaves than older ones, but absorption did not differ in walnut leaves based on leaf age. However, looking at the paired research trials which included Bob Beede in pistachios and Joe Grant in walnuts, both showed that foliar sprays were best applied during early spring flush in pistachios and late spring flush for walnuts. The difference in timing is due to the reduced ability of mature pistachio leaves to absorb zinc. Because mature walnut leaves absorb as much as young leaves, the late spring flush period results in increased surface area and therefore better absorption. This work also showed that the combination of zinc and nitrate resulted in phytotoxicity in pistachios and walnuts, and this combination is not recommended.

Figure 1: Zinc deficient walnut (top left, source K. Uriu), zinc deficient almond (top right, source W. Asai), zinc deficient pistachio (bottom, source: B. Beede)

Figure 2: Zinc deficient pecan (source: R. Heerema)

In almonds and peaches, fall sprays with zinc are adequate for addressing zinc deficiency as well as spring sprays. Work done by Franz Niederholzer has shown that low rates of foliar applied zinc in October (5 lbs of Zn sulfate per acre) are as effective as much higher rates applied in November (20 lbs of Zn sulfate per acre). In the past it was suggested that these heavy, late applications, which defoliate the trees, may have the side benefit of reducing rust inoculum in an orchard. However, work done by Macej Zweinecki at the Carbohydrate Observatory at UC Davis has recently shown how important carbohydrates are to tree health, and we now recommend that growers and PCAs do not do this. Spring applications, applied once leaves reach nearly full size, of zinc on *Prunus* species may result in phytotoxicity symptoms, so it is best to use products that are safe for this application. However, if rains follow these applications, shot-hole symptoms may occur. I visited several orchards in the spring of 2020 with this issue. The trees retained the leaves and I didn't hear back about any further issues (and in my world, no follow-up news is typically good news!)

Crop	Deficient	Sufficiency range
Almonds	< 15 ppm	
Pecans	< 30 ppm	30 – 100 ppm
Pistachio	< 7 ppm	10 – 15 ppm
Prune	< 18 ppm	
Walnut	< 18 ppm	

Table 1: Leaf critical values for some major orchard crops grown in the Central Valley

In pecans, the story is a bit different. Pecans are regarded to be extremely zinc hungry plants, and their leaf sufficiency values are much higher than other tree species (Table 1). In areas with low soil availability, sprays should start at bud break and continue until growth stops. In mature trees, this will likely be 3-5 sprays, but in young rapidly growing trees, you may need to spray weekly for several months. It has been found that nitrate or the inclusion of UAN32 increases the absorption of zinc in pecans and applying zinc as a sulfate has been found to be as effective as a chelated form. Because of the need for continual and frequent foliar applications, Walworth et al. (2017) examined soil applications of chelated zinc at either 2 or 4 lbs an acre, split up over the year in a young pecan orchard in a calcareous soil. They found that soil applied zinc raised tissue levels in all parts of the plant, in contrast to foliar applications, which only raised leaf levels. The soil applications were unable to raise leaf zinc values to the 40 ppm that was previously recommended pecan leaf sufficiency values, however, all visual symptoms of zinc deficiency were eliminated. In a paired study looking at photosynthetic rates in this trial, leaf photosynthesis was maximized at 15 ppm of leaf zinc. Because of this, suggested sufficiency values were decreased to 30 ppm. An additional study examined applying 70 mL of ZnEDTA directly in planting holes at planting, which was found to mostly eliminate zinc deficiency symptoms for three years with no additional foliar applications. While these studies were performed in Arizona, it is reasonable to assume, due to the similar climactic conditions and high pH soils, that sufficiency standards would be similar in California.

As with other foliar applications (insecticides, fungicides), adequate spray coverage is essential, since a tiny fraction of applied zinc will be remobilized into other tissues, if at all. The same rules that you should use for good spray coverage for pesticides apply for nutrient sprays; drive slowly (2 mph or less), don't apply during a windy day, and make sure the spray distribution reflects the size of your trees. Additionally, it is helpful to spray when humidity is high so that droplets do not evaporate before the zinc has time to be absorbed into leaf tissues; in our arid climate this can be at night or early in the morning.

Leaf critical values for some major orchard crops are provided in table 1. Something I would like to note: it can be tempting to think that your trees' zinc levels have increased drastically after a zinc spray. This is because foliar applied zinc binds very readily to the leaf cuticle, or the layer of wax that protects a leaf. Unless the zinc is washed off with a dilute acid, that excess will remain and be included in leaf tissue values. So, if you do a spring zinc spray in an orchard, you should not view your leaf tissue zinc levels from that orchard as an adequate measure of the trees zinc status. Bag some leaves before a spray and mark the branches or spurs that you protect. Remove the bags immediately after the sprays so the leaves don't die and fall off, and come back and sample those leaves later for your July leaf tissue analyses to get a more accurate assessment of your orchard's zinc levels.

One last thing about zinc: high soil phosphorus levels in soil reduce zinc availability. While we do not heavily rely on phosphorus fertilizer in orchard agriculture because, to the best of our knowledge, phosphorus is not needed in large quantities in orchard crops and is abundantly available in soils, this can be seen in orchards that are established in old dairy corrals.

Literature used to write this article:

Brown, P., Zhang, Q. and Beede, B., 1993. Effect of foliar fertilization on zinc nutritional status of pistachio trees. *California Pistachio Industry. Annual Report*.

Brown, P., Zhang, Q. and Grant, J., 1995, IMPROVING WALNUT ZINC NUTRITIONAL STATUS BY FOLIAR SPRAYS. *1995 Walnut Research Reports.*

Heerema, R.J., VanLeeuwen, D., Thompson, M.Y., Sherman, J.D., Comeau, M.J. and Walworth, J.L., 2017. Soil-application of Zinc-EDTA increases leaf photosynthesis of immature 'Wichita'pecan trees. *Journal of the American Society for Horticultural Science*, *142*(1), pp.27-35.

Sanchez, E.E., Weinbaum, S.A. and Johnson, R.S., 2006. Comparative movement of labelled nitrogen and zinc in 1-year-old peach [Prunus persica (L.) Batsch] trees following late-season foliar application. *The Journal of Horticultural Science and Biotechnology*, *81*(5), pp.839-844.

Swietlik, D., 2002. Zinc nutrition of fruit crops. *HortTechnology*, *12*(1), pp.45-50.

Walworth, J.L., White, S.A., Comeau, M.J. and Heerema, R.J., 2017. Soil-applied ZnEDTA: vegetative growth, nut production, and nutrient acquisition of immature pecan trees grown in an alkaline, calcareous soil. *HortScience*, *52*(2), pp.301-305.

Walworth, J. and Heerema, R., 2020. Zinc management in arid region pecan orchards. *Univ. Arizona Ext. Bul. az1789*, *30*.

Zhang, Q. and Brown, P.H., 1999. The mechanism of foliar zinc absorption in pistachio and walnut. *Journal of the American Society for Horticultural Science*, *124*(3), pp.312-317.

Mohammad Yaghmour, Area Orchard Systems Advisor
661-868-6211 or mayaghmour@ucdavis.edu