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In a Nutshell
Tulare County

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How does walnut bud break and shoot elongation differ from pistachio and almond?

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Growers intending to diversify farming operations to more than one nut crop are challenged with learning vastly different botanical systems. Almonds, pistachios, and walnuts differ in both their reproductive strategies and their vegetative growth characteristics. Flowers may be borne on either the current year's shoot, such as in walnuts, or on the prior year's growth, like pistachio and almond. Additionally, the bud types vary between walnut, almond, and pistachio (Table 1). Walnuts are unique in that they do not have discreet vegetative buds or flower buds, but rather a compound bud and masses of non-showy male flowers assembled in catkins (Figure 1).

Table 1. The differences in vegetative and reproductive strategies between walnut, almond, and pistachio are evident in the buds formed on each crop.

Crop	Vegetative buds	Female flower buds	Male flower buds	Compound buds	Perfect Flowers
Walnut			X	X	
Almond	X				X
Pistachio	X	X	X		

Location of female walnut flowers. Walnuts lack female flower buds. The walnut's female flower primordia are encased in the vegetative shoot, making for a compound bud (Figure 1). The compound bud in walnut contains a preformed shoot, preformed leaves, and a female flower at the preformed shoot terminus. As a result, walnuts are borne on the current season's shoot. Almonds and pistachios differ from walnut in that both bear nuts on the prior year's growth.

Preformed growth. Until budbreak (Figure 2A), the preformed shoot is enclosed in the compound bud. As the shoot elongates from the bud, a series of preformed leaves emerge. On young trees, the number of preformed leaves may vary considerably between buds, with each compound bud containing generally 5-11 preformed leaves. The compound buds on mature trees exhibit less variability in the number of preformed leaves and tend to have fewer preformed leaves per bud. Because the female flower marks the terminus of the preformed shoots, shoot growth beyond the nut(s) is all in-season or 'neoformed' growth. Trees exhibiting rapid in-season growth may appear vigorous, however, this in-season growth may support malformed leaves (Fig 2C), incomplete buds in the leaf axils, and branching that lacks structural integrity.

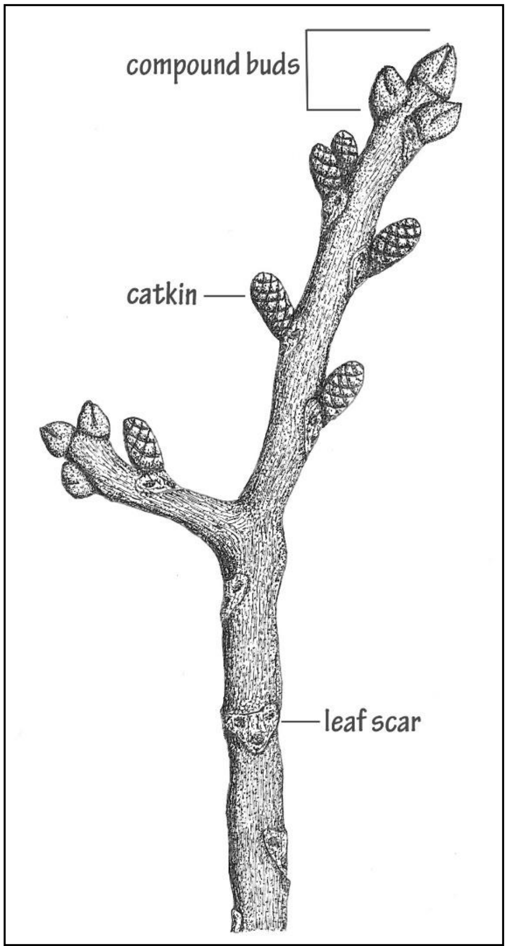

Figure 1. Catkins and compound buds are borne on the prior year's shoot. (Illustration: H. Hartzog)

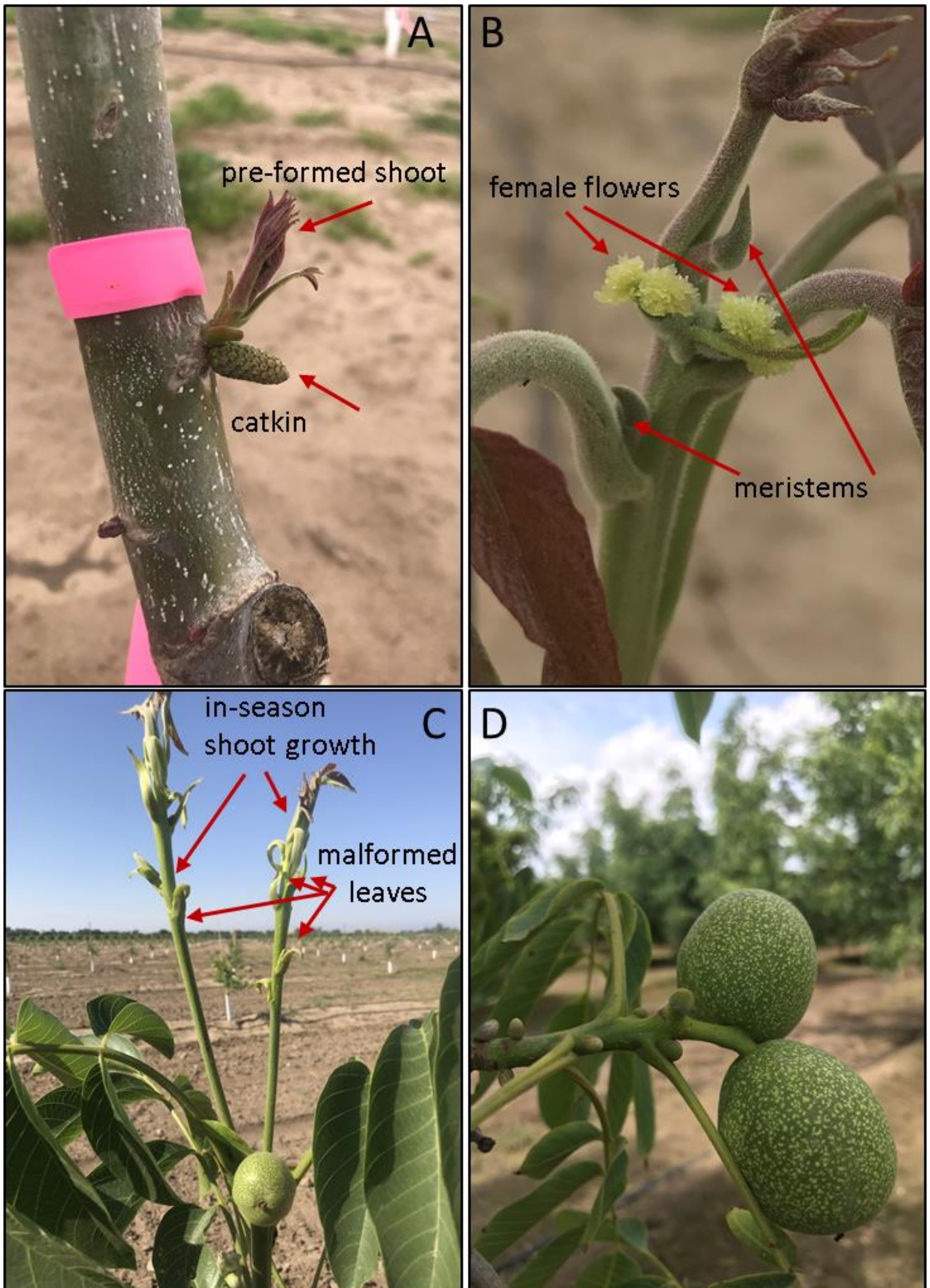

Figure 2. As the compound bud breaks, the pre-formed shoot emerges (A). In photo A, the compound bud and catkin are positioned at primary and secondary buds, respectively. The meristems giving rise to in-season growth are visible during bloom (B). Malformed leaves are borne on in-season shoots (C). On this ‘Ivanhoe’ shoot, catkins and compound buds are already visible on May 17, 2019 (D). Photos: E. Fichtner

In-season branching. In-season branching points are observed early in the growing season. As the shoot elongates, one to four meristems can form in the axils of the leaves near the nut, resulting in forking (Fig 3A). During the dormant season, the forks resulting from in-season growth are removed to maintain straight shoots (Figure 3B).

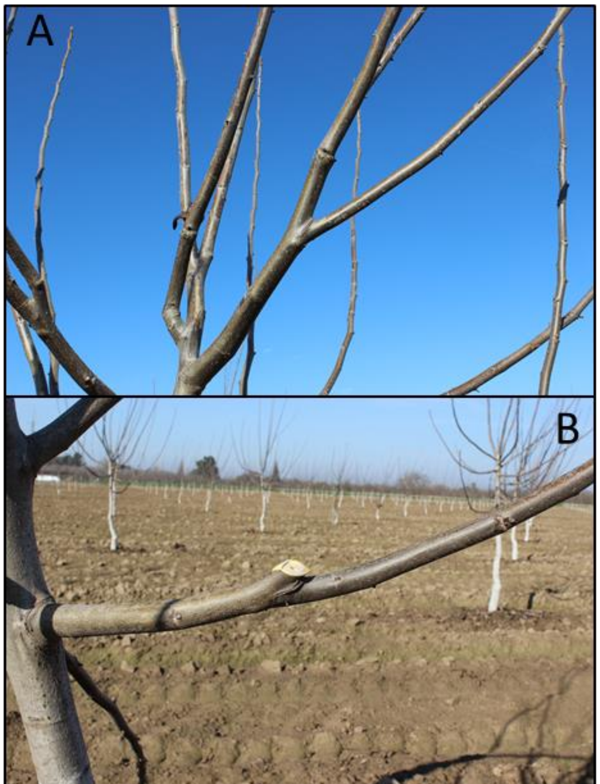

Figure 3. In-season growth may result in forking (A) that is pruned off during the dormant season (B). (Photos: E. Fichtner)

Location of male walnut flowers. Walnuts are monoecious, meaning that they bear male and female flowers on the same tree. The bearing habit of the male flowers, however, differs from that of the female flowers. Like pistachio, the male walnut flowers are arranged on catkins (Figure 2A) that are borne on the prior year's growth. Catkins are made up of numerous male (staminate) flowers. Each staminate flower bears numerous stamens, and each stamen bears numerous pollen grains. The staminate flower assembly comprising the catkin enables abundant pollen production, a useful adaptation of wind-pollinated crops.

Timing of walnut bud formation. Both catkins and compound buds on walnut are well differentiated by spring of the prior year on a mature walnut tree (Figure 2D). As a consequence, environmental stresses imposed during bud development in spring may affect the growth and bearing habits of walnut the following year. For example, environmental stresses (ie. over- or under- watering) during bud development may influence the number of preformed leaves in compound buds. The influence of these stresses may not be realized by the grower until the following spring, after bud break and shoot elongation.

The common denominator. Although the growth and reproductive habits vary considerably between walnut, almond, and pistachio, the major commonality is that buds develop the season prior to growth. Mitigating stress during bud development, regardless of crop, may have profound impacts on orchard health and productivity into the following year.

Almond bloom intensity may be affected by prior year's irrigation practices and diseases

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Factors influencing a current year's almond bloom intensity may have been initiated 9 months prior to bloom. In almond, bud development generally occurs in late spring (Figure 1). During the initial phase of bud development, vegetative and flower buds are all morphologically similar. In late summer, however, a portion of the buds will differentiate to form flower buds. Consequently, the physiological and pathological stresses exerted on almond trees the prior year may influence bloom and subsequent yield in the current year.

Figure 1. Buds (circled in red) are visible in the leaf axils on June 23, 2018. At this time, vegetative and flower buds cannot be distinguished based on morphology. Photo: E. Fichtner

Orchards that are overwatered the prior year may exhibit low bloom intensity in the current year. A review of the prior year's stem water potential records is the first step in assessing the potential influence of over-watering in suppression of subsequent bloom. Based on researcher observations, trees maintained either at or above (ie. wetter) the baseline tended to have lower bloom intensity the following year. The baseline value is the expected stem water potential of a fully-watered orchard. Baseline values vary depending on environmental conditions (temperature and relative humidity) and are specific for each crop. If stem water potential records are not available, observations of bloom distribution both within orchards and trees may elucidate the cause of current bloom irregularities.

Orchard-level observations. If bloom density at full bloom varies between rows of different varieties (forming a repeated pattern across the orchard) the prior year's water status may have influenced flower bud development.

If an orchard is comprised of multiple varieties, the bloom intensity should be evaluated for each variety at full bloom, which will likely occur on different days. If a variety characterized by smaller trees exhibits lower bloom intensity than a variety with larger trees, it is likely that the smaller trees were over-irrigated the prior season. For example, an orchard planted with Monterey and Nonpareil may have lower bloom intensity in the Monterey rows than in the Nonpareil rows (Figure 2). The Monterey trees often tend to be smaller than the neighboring Nonpareil, and therefore receive more water per unit tree canopy than the Nonpareil. As a result, Monterey may be maintained at or above the baseline in an orchard where irrigation management is based on the water status and tree water requirements of Nonpareil.

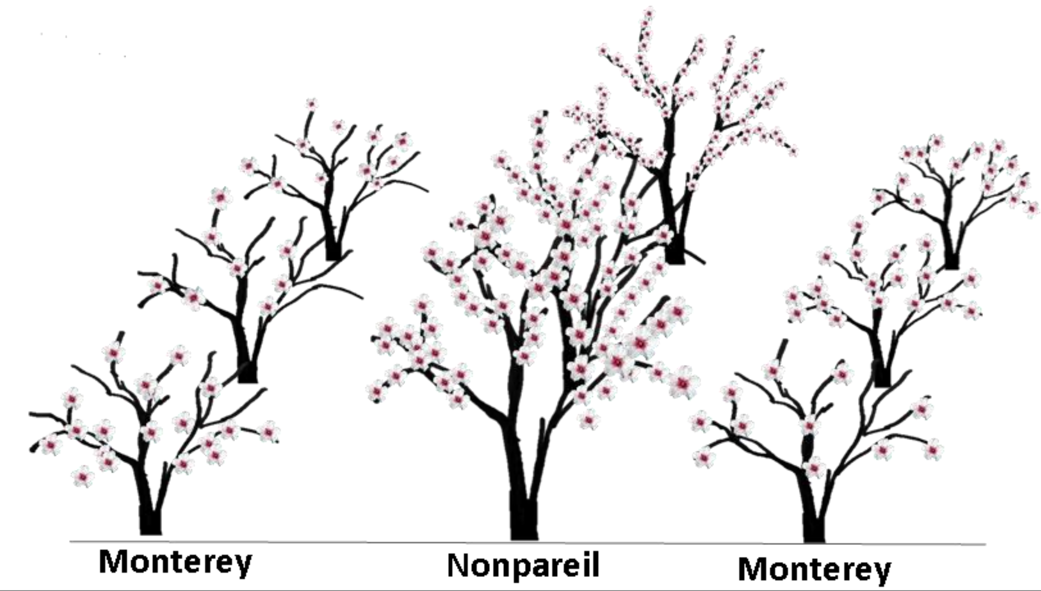

Figure 2. Look for patters of bloom intensity within orchards. If larger varieties exhibit greater bloom intensity than smaller varieties, the smaller varieties may have been overwatered the prior year in comparison to the larger varieties.

Within-tree observations. If the bloom is concentrated at the top of the canopy (Figure 3), and flowering is sparse in the lower canopy, the orchard may have been overwatered the prior season. The water potential varies throughout the tree, with the increasingly negative gradient progressing sequentially from the soil, through the roots, stems, lower canopy, and upper canopy (Figure 3). The water potential in the upper tree canopy may have been conducive to floral bud production while the water potential in the lower canopy may have been too high (ie. too wet) to promote flower bud development.

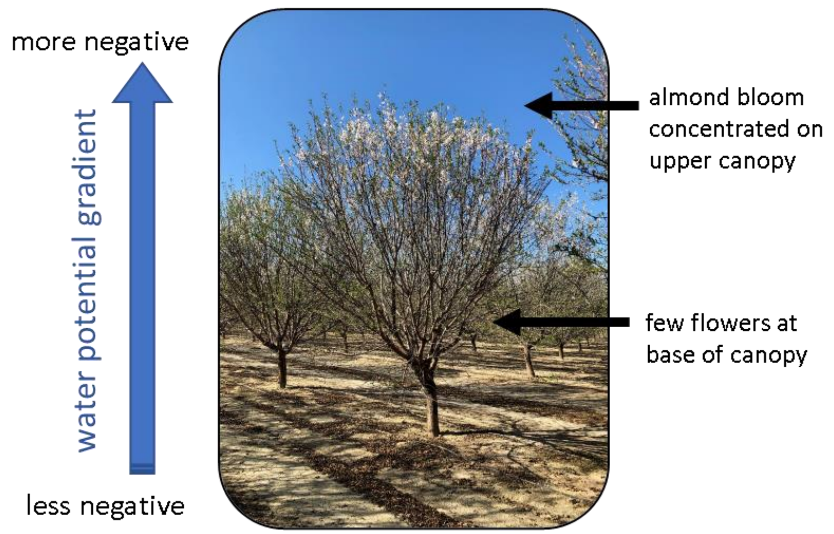

Figure 3. The higher bloom intensity in the upper canopy may be related to lower (more negative) stem water potential in this region of the canopy during bud development. In this orchard, lower positions only had vegetative buds with very few reproductive buds. Photo: B. Lampinen

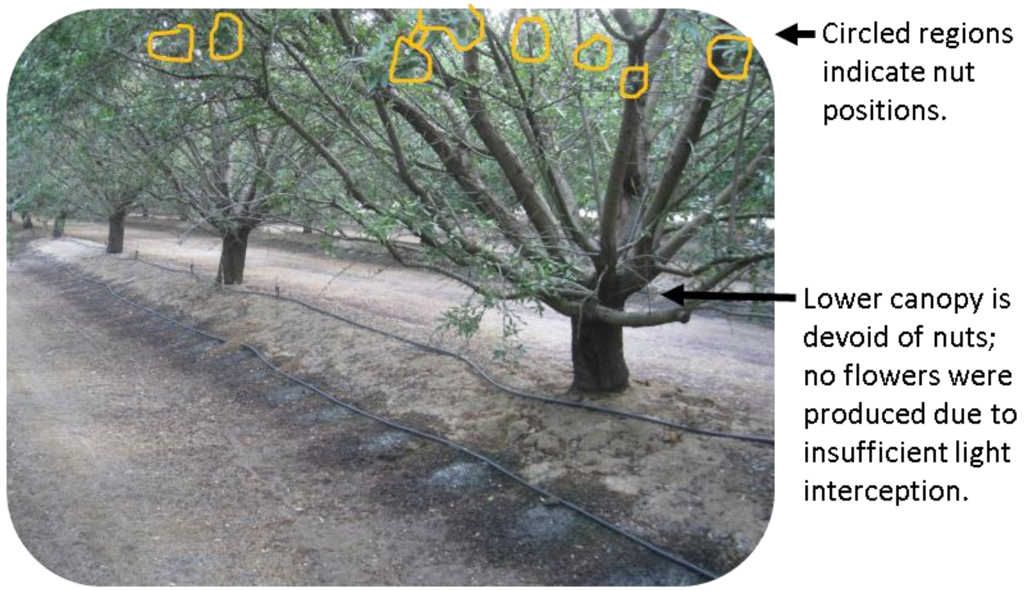

Figure 5. Shade-out is another factor that may limit floral intensity and consequent nut production to the upper canopy. Poor light interception to the lower canopy will limit photosynthesis and carbohydrate storage in spurs. As a result, spurs in the lower canopy may not support flower buds and have a higher probability of mortality than those in the upper canopy. Photo: B. Lampinen

Combination of orchard-level and tree-level observations. If bloom intensity appears to vary between rows in a pattern indicating differences between cultivars, with low bloom intensity occurring predominantly in the lower interior canopy, hull rot the prior year may be a contributing factor. Although the symptoms of hull rot are often noticed at harvest, the lasting effects of hull rot may go unnoticed until bloom and bud break the subsequent year. *Rhizopus stolonifera* is particularly responsible for producing a toxin (fumaric acid) that kills spurs and twigs (Figure 4) associated with infected nuts. Unlike slight over-irrigation the prior year, hull rot infections may result in acute spur mortality, resulting in destruction of both vegetative and floral buds. Susceptibility to the disease varies between cultivars, resulting in differential symptom development between rows. Nonpareil, Sonora, and Winters are all susceptible. Additionally, because hull rot is promoted by orchard moisture and humidity during hull split, the symptoms are more pronounced in the lower canopy (due to humidity) and the disease may have a synergistic effect with overwatering in reducing the following year's bloom.

Figure 4. Black streaking caused by *Rhizopus stolonifer*, a fungal pathogen responsible for hull rot. The pathogen kills spur and twig tissue by producing a toxin called fumaric acid. Photo: Brent Holtz

Another factor contributing to a preponderance of flower buds in the outer canopy of mature trees across orchards is shading related dieback (Figure 5). The probability of a spur setting a flower is related to previous year leaf area. For example, non-bearing spurs with a leaf area of › 50 cm^2 have over an 80% probability of supporting flowers the following year. If light infiltration to the lower canopy is not sufficient to provide adequate carbohydrate storage in spurs, flowering potential in the lower canopy will be diminished. Over 80% of the nuts produced by a given tree are borne on spurs; consequently, any factor limiting photosynthesis in spurs will affect flowering potential.

The converse scenario. A heavy bloom in the current year may be related to a propensity of non-nut bearing spurs the prior year. Several factors may have contributed to low nut set the prior year, including: i) diseases at bloom (ie. blast or brown rot), ii) weak beehives, iii) weather non-conducive to bee flight, and iv) frost during bloom. When nut set is low, spurs retain carbohydrate stores resulting in increased leaf area and an increased probability of flowering and setting a crop the following year.

Summary. If almond bloom at a given ranch appears irregular, assess potential causes by making detailed observations of the bloom patterns both within orchards and within individual trees. Also consider differences in bloom density between cultivars, being sure to make comparisons at the same time stage of bloom progression. Irrigation related records from the prior year may also provide clues for determining the potential for orchard water status to have influenced the bloom in the current year.

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