Orchard-system configurations increase efficiency, improve profits in peaches and nectarines

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Simply put, a fruit tree can be viewed as a solar collector that converts sunlight into fruit. The more efficiently this is done, the greater the potential yield and profit. Consequently, growers face an important question when planting an orchard — what planting system to use? While varieties can be changed rather easily through grafting, the spacing, rootstock and conformation aspects of an orchard are typically permanent until that orchard is removed entirely, usually only after 15 to 20 years. These aspects can have profound effects on orchard productivity. Research conducted at the UC Kearney Research and Extension Center on orchard systems — including higher-density plantings and pruning techniques that enhance light interception — has allowed growers to make better-informed decisions when planting new orchards.

Photos: Jack Kelly Clark

Tree form and height are two key factors in determining how efficiently stone fruit orchards produce fruit and grower profitability. Kevin Day, UC Cooperative Extension tree fruit farm advisor in Tulare County, *above*, is one of the principal UC scientists involved in studying different tree systems. The Quad-V orchard shown is a popular high-density system. *Right*, the traditional "open vase" peach tree is less uniform and thus more costly to maintain.

The productivity of an orchard depends in part on how well it collects sunlight. As such, "light interception" is a function of the density, height and shape of the trees, which in turn incorporates the number, angle and orientation of their branches. These characteristics are the primary components of what is called a "planting system." The ideal orchard planting system can vary based on numerous factors, including geographic location, variety and species, soil type, rootstock, and local cultural and economic concerns. However, each system has inherent qualities that, if understood, can be used to help growers meet their goals for the orchard. UC pomologists have been studying and elucidating these planting-system characteristics at the UC Kearney Research and Extension Center (KREC) for more than 30 years, in order to help growers develop profitable and sustainable orchards.

Production in orchard systems

Since the inception of the fresh-shipping tree fruit industry shortly after the California Gold Rush (during the 1860s and 1870s) the state's dominant orchard system has been the open vase, with trees trained into a wide "cone" tree shape at relatively ample spacings within the orchard. Originally, trees were planted on wide, 22-to-25-foot spacings (70 to 90 trees per acre) in both directions to allow for easy access by horses, mules and the primitive mechanized equipment that was then available. However, such wide-spaced systems came into production slowly because the trees must grow for many years before they reach full size. One of the basic axioms of planting-system design is that a tree should fill its allotted space as quickly as possible, and having done so, be maintained easily within that space.

Growers were able to reduce spacings somewhat in the 1950s due to the introduction of chemical herbicides, which reduced and sometimes even eliminated the need for cross-cultivation. Cross-cultivation is cultivating across the rows of the orchards instead of just down the row; it was

Photos: Jack Kelly Clark

The first high-density or "hedgerow" orchard systems were introduced into the United States from Europe in the 1960s. *Top*, densities as high as 600 trees per acre were obtained with trees trained to take up less space — a single upright leader (right) or a parallel-V. Increased yield in the early life of these high-density orchards was confirmed by the first UC orchard-systems trial planted at Kearney in 1972.

Just because a tree is tall does not ensure that it is inherently more productive or intercepts light more efficiently than a shorter tree.

rendered unnecessary when herbicides were introduced that could control weeds between trees, thereby allowing growers to plant trees closer together down the row. Tree densities rose slightly to 100 to 120 trees per acre, and efficiencies improved because orchards reached full production more rapidly. Closer plantings mean that trees do not have to grow as large as those that are wide-spaced. Therefore, they can reach their ultimate "design size" more quickly, and consequently also reach full production more quickly. The trees are closer together but also smaller, so that each tree produces less on a per-tree basis but per-acre yields are usually the same.

In the 1960s, the first high-density orchard plantings were introduced to California. These were based on European hedgerow systems in which row width was reduced to 12 to 15 feet, and tree distance within each row was reduced to 6 to 12 feet, thereby increasing tree densities from about 240 to 605 trees per acre. In addition, smaller tree shapes were used, usually either upright central-leader/spindle forms (without the cone), or very upright palmette or parallel-V forms (with a much more narrow cone than the open vase). It was hoped that these high-density planting systems would increase yields — both early in the life of the orchard and at maturity. They were also expected to reduce labor costs since smaller trees mean that many orchard operations such as pruning, thinning and harvesting can be performed either mechanically or with mechanically assisted devices.

To test the hypotheses that high-density orchard plantings would increase yield and reduce labor costs, the first UC orchard-systems trial at Kearney was planted in 1972 (Gerdts et al. 1979). This trial tested four tree varieties (three peaches and one nectarine, ranging from early- to late-season in maturity) in three different training systems: the standard open vase (19-feet-by-22-feet spacing) versus two high-density systems (central leader [8-feet-by-15-feet spacing] and parallel-V [10-feet-by-15-feet spacing]). The results of this demonstration block confirmed that the high-density central-leader and parallel-V systems did indeed have greater cumulative yields than the standard open-vase system through the first 7 years of orchard life, when all the trees had matured (table 1).

Based on these encouraging results, another trial orchard was planted in 1982 (DeJong et al. 1991). This trial compared open vase to central leader and parallel-V, and also included a new type of high-density system called perpendicular-V. This new system maintained a "standard" (18 feet) row spacing but used a close (6.5 feet) spacing down the row, thereby achieving a tree density of 373 trees per acre. Equipment designed for an 18-foot row

TABLE 1. Cumulative fruit yields (1974–1978) for initial high-density planting trials at Kearney Research and Extension Center (peach and nectarine trees planted in 1972)

Variety	System*	Cumulative yield
		tons/acre
Springcrest	Central leader	42.6
	Parallel-V	44.1
	Open vase	23.7
June Lady	Central leader	54.6
	Parallel-V	46.4
	Open vase	28.0
Fantasia	Central leader	76.3
	Parallel-V	58.8
	Open vase	42.0
O'Henry	Central leader	72.3
	Parallel-V	65.5
	Open vase	38.3

* Central leader = 8'×15' spacing, 363 trees/acre; parallel-V = 1'×15' spacing, 290 trees/acre; open vase = 22'×19' spacing, 104 trees/acre.

Source: Gerdts et al. 1979.

TABLE 2. Cumulative fruit yields for four training systems, first 10 years after planting

Variety	System*	Cumulative yield
		tons/acre
Flavorcrest peach	Central leader	88.4
	Kearney-V†	110.1
	Parallel-V	96.1
	Open vase	107.4
Royal Giant nectarine	Central leader	145.9
	Kearney-V	186.4
	Parallel-V	148.9
	Open vase	169.5

* Central leader = 6.5'×18', 372 trees/acre; Kearney-V = 6.5'×18', 372 trees/acre; parallel-V = 10'×18', 242 trees/acre; open vase = 20'×18', 121 trees/acre.

† Kearney-V was originally called "perpendicular-V."

Source: DeJong et al. 1991.


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A trial orchard planted in 1982 introduced another alternative for high-density stone fruit orchards, the perpendicular V. This system maintained standard 18-feet row spacing but planted trees about 6 feet apart, affording the advantages of early high yields without the additional cost of new equipment for maneuvering in narrow row middles.

generally did not fit easily into a 12- to 14-foot row, often forcing growers converting to the close-row systems to purchase new equipment.

The results of this trial showed that like central leader and parallel-V, the new perpendicular-V system (later known as the Kearney-V or KAC-V) significantly improved the early yield (table 2). Most importantly, perpendicular-V allowed growers to adopt a high-density system without changing row spacings or buying new equipment.

Another benefit of this trial was the discovery of the importance of tree uniformity in orchard management. Open-vase orchards have a great deal of variation in tree shapes: the central trunk of each tree typically has three or four primary scaffolds (a major, permanent "branch" of a tree), and each of these then develops into as many as two or three secondary scaffolds, which in turn can branch into perhaps eight to 14 tertiary growing points by the time the tree reaches its ultimate height. In contrast, trees in the perpendicular-V system — where every tree is allowed to develop only two scaffolds and these are not allowed to branch — are more uniform.

Because an orchard can typically support only a given amount of fruit per acre, systems that use available light and labor most efficiently are generally most profitable. Just having more branches, scaffolds or growing points does not inherently make trees more productive. In the perpendicular-V orchard, every tree has exactly the same number of scaffolds and the variation between trees is reduced, thereby increasing the labor efficiencies. Uniformity also allows growers to better estimate, plan and develop the crop in an orchard; at the same time, every scaffold projects into the row middle, improving equipment usage and spray efficiency (Jack Dibble, UC Extension Entomologist [retired], personal communication).

Perpendicular-V was the first high-density system that was similar enough to open vase to be easily understood by growers, managers and workers. Perpendicular-V rapidly gained in popularity in the mid-1980s and soon became known as Kearney-V, or KAC-V. The system's primary drawback was tree cost, because three to four times more trees were initially planted. To address this, a variation of the Kearney-V called the Quad-V was soon developed and tested at Kearney (Day et al. 1993). In Quad-V, trees were planted slightly farther apart (9 to 10 feet) down the row and had four scaffolds instead of two. The Quad-V retained the uniformity aspects of the Kearney-V, but allowed for approximately a third fewer trees per acre — a significant savings. Both systems (with 'MayGlo' and 'Sparkling May' nectarines) quickly and efficiently filled their allotted spaces, had similar light interception (data not shown) and therefore similar yields (table 3). The Quad-V eventually became very popular.

TABLE 3. Yields in Kearney-V and Quad-V trial at Kearney Research and Extension Center (nectarine trees planted in 1990)

Variety	System*	1991	1992	1993	Total
		tons/acre			
Mayglo	Kearney-V	1.06b†	5.36ns‡	7.25a	13.67ns
	Quad-V	0.37a	5.65	7.53a	13.55
Sparkling May	Kearney-V	0.72ab	5.76	8.87ab	15.35
	Quad-V	0.37a	6.78	10.22b	17.38

* Kearney-V = 6'×18', 403 trees/acre; Quad-V = 9'×18', 269 trees/acre.
† Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.
‡ ns = not significant.
Source: Day et al. 1993.

During the 1980s and 1990s, fresh-market stone-fruit growers were most likely to use high-density systems because the quick (5 to 9 years) varietal turnover meant that fruit harvested early in the life of the orchard was of relatively greater value than that harvested toward the end of the variety's life. And while the developmental costs of high-density plantings were higher than those of standard plantings, this risk would likely be offset by the increased profit potential of these high-value commodities.

Profitability of systems explored

The aforementioned studies confirmed that high-density orchards have the potential to achieve full production earlier in their lives than standard open-vase orchards. These studies also showed that given equitable light-interception characteristics, high-density orchards are no more productive at full maturity than standard-density plantings.

However, these studies did not satisfactorily answer the growers' basic question of which system is most profitable. And as the California tree-fruit industry became more sophisticated in the closing decade of the 20th century, it was more important to focus on eco-

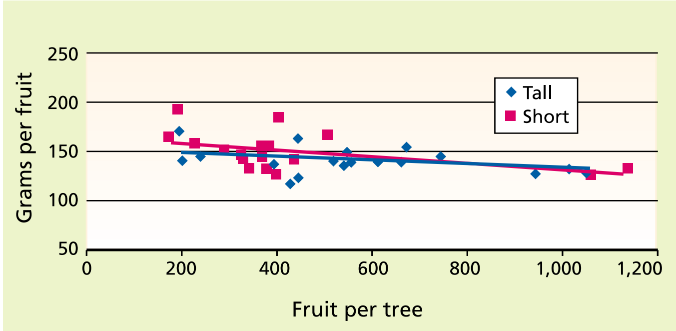

Fig. 1. Relationship between fruit size and crop load for short (limited height) and tall (standard height) 'Summer Bright' nectarine trees pruned to a Quad-V conformation.

TABLE 4. Cumulative yields and economic efficiency of four training systems of 'Ross' cling peaches after 5 years in the orchard

System*	Yield	Crop value	Costs	Profit
	tons/acre		$	
Cordon	58.05c†	12,035	6,477	5,558
KAC-V	67.78b	14,133	5,813	8,320
HiD KAC-V	77.22a	16,149	8,125	8,024
Open vase	51.46c	10,430	4,355	6,075

* Cordon = 8'×13', 419 trees/acre; KAC-V = 6.5'×18', 372 trees/acre; HiD KAC-V = 5.5'×15', 528 trees/acre; open vase = 16'×18', 151 trees/acre.

† Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

Source: DeJong et al. 1999.

nomics rather than on simply trying to maximize production.

Cling peaches trial. To explore the economics of orchard systems, in 1990 a replicated block of 'Ross' processing (cling) peaches was planted at Kearney (DeJong et al. 1999). This trial orchard compared four planting systems with different spacings: KAC-V (6.5 feet by 18 feet), high-density (HiD) KAC-V (5.5 feet by 15 feet), cordon (8 feet by 13 feet, and height limited to 7 feet) and open vase (16 feet by 18 feet). The HiD KAC-V system is even more closely planted than the KAC-V, with the goal of even more rapid full production. The cordon system consists of a single tall trunk, about 3 feet high; scaffolds are bent down off of the trunk in the first and second growing season and tied to a temporary support rope that is suspended down the row at a height of 4 to 5 feet. By tying the scaffolds down, earlier fruiting is induced and tree height is reduced, with the goal of maintaining a tree height in which all labor operations can be performed from the ground without a ladder. The orchard was 8 acres total, with four replications of each system in 0.5-acre experimental units. All associated costs and yields were recorded annually for the first 5 years after planting.

In this experiment, the two KAC-V systems were the most productive and profitable despite having the highest establishment, development and production costs (table 4). It is important to note, however, that this trial also vividly demonstrated that the development and initial production costs of these high-density systems were 50% to 100% greater than those of the traditional open-vase system. Due to the detailed record-keeping, this trial also provided tools that growers could use to estimate relative orchard profitability given particular price, cost and yield scenarios.

One surprising result of this study was that although the limited-height cordon system eliminated the use of ladders, this system still did not have lower per-acre labor costs. One of the primary beliefs in fruit production is that ladders add appreciably to the cost of labor since they are heavy and awkward to maneuver, and any time spent ascending or descending them is time lost for the primary tasks of pruning, thinning and harvesting. Since labor accounts for the majority of the orchard costs associated with fruit production — often $2,000 to $3,000 per acre annually — eliminating ladders should represent a potentially significant labor savings.

However, a physiological analysis of the cordon systems in this experiment indicated that potential economic efficiencies from lowering tree heights were not realized because training cordons to a horizontal position stimulated excessive vegetative growth (Grossman and DeJong 1998). This both increased pruning costs and decreased the trees' allocation of dry matter into fruit, reducing fruit yields. It became clear that if tree heights were to be reduced, it must be done in a manner that does not stimulate vegetative growth (vigor) at the expense of fruit growth.

Nectarine trial. To better understand the relationship between tree height and labor costs, a study with the KAC-V and Quad-V systems was begun at Kearney in 1995 (Day et al. 2003), with a replicated block of 'Summer Bright' nectarine trees growing as either two-leader (scaffold) KAC-Vs or four-leader Quad-Vs (6-feet-by-18-feet and 9-feet-by-18-feet spacing, respectively). Tree height was either allowed to develop to the common standard of 12 to 13 feet or limited to 8 to 9 feet, which meant that much of the hand labor could be performed without ladders. In order to get comparable planar bearing area between the two system heights, the limbs of the shorter trees were flattened by tying them to an angle of 50 degrees from horizontal, thereby achieving a shorter, flatter tree than is typical for California.

The results demonstrated that the labor costs for the short trees were an average of 20% to 30% less, depending on the activity, than those of tall trees. In addition, the yield potential was similar for short and tall trees (fig. 1), which was somewhat surprising and defied conventional wisdom. However, due to the flattened limb orientation, both systems had similar planar volumes and virtually identical light-interception characteristics, making it not unreasonable to assume that yields should be similar as well. Additional research will be necessary to explore the role of these factors in other locations and with different tree varieties.

As noted, one of the concerns associated with short trees is that of excess vigor. In this study, care was taken to ensure that the trees were not overwatered or overfertilized, and there was no problem with excessive vigor. However, this may not always be possible under all growing conditions and with all cultivars. The ultimate solution to the problem of excess vigor lies in developing adequate dwarfing root-

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California's tree fruit industry developed shortly after the Gold Rush of the mid-nineteenth century. For many years the state's dominant orchard system was the open vase, with trees trained into a wide "V" shape and ample spacing, allowing for 70 to 90 trees per acre. ***Above***, **long-time UC technician Jim Doyle stood next to a standard peach tree in the late 1970s.**

stocks to fit a range of orchard needs such as variety, season of ripening, soil type and pH.

Maintaining competitive orchards

To remain competitive in an increasingly global market, the California fruit industry must develop orchard systems that (1) are simple and easily understood by managers and workers, (2) are of appropriate cost relative to the potential return on investment, (3) minimize reliance on ladders, which increase labor costs and (4) ensure the production of high-quality and high-value fruit.

Regimented systems such as the KAC-V and the Quad-V are quickly becoming the norm for many growers. These systems can be successfully planted without having to alter row-spacings or purchase new equipment. There is also a trend toward somewhat reduced tree heights as growers come to understand the importance of light and its relationship to tree height and form. Just because a tree is tall does not ensure that it is inherently more productive or intercepts light more efficiently than a shorter tree. Furthermore, fresh-shipping tree fruits are somewhat unique in that there is frequently an economic reward for increased quality rather than just an emphasis on total production. The Kearney research efforts have helped shape grower understanding of the relationship between potential yield and the most profitable yield.

The stone-fruit industry needs the development of a proven dwarfing rootstock that can be relied upon to ameliorate the problem of excessive vigor in short trees. Currently, growers still question whether tree heights can be dramatically reduced in a simple, effective and sustainable manner. Research at Kearney is now focusing on developing such dwarfing rootstocks, which could potentially revolutionize production in the stone-fruit industry just as they did in the apple industry (Ferree and Carlson 1987). Next, additional research will be needed to develop sensible and successful training systems that match the growth and production characteristics of trees on these dwarfing rootstocks.

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